DATA ENVELOPMENT ANALYSIS: AN APPLICATION TO A TELEVISION PLANT FOR SUPPLIER SELECTION

Thesis submitted to the

Institute of Social Sciences

in partial fulfillment of the requirements

for the degree of

Master of Arts

in

Management

by

Metin Şatır

Fatih University

November 2003

*For all my family, especially my **wife** and **son** !*

and ***Ferhat's son !***

FATİH ÜNİVERSİTESİ
SOSYAL BİLİMLER ENSTİTÜSÜ MÜDÜRLÜĞÜ
YÜKSEK LİSANS TEZ SINAV TUTANAĞI

14/11/2003

Enstitümüz İşletme Anabilim Dalı 51020017 numaralı yüksek lisans öğrencisi Metin ŞATIR'ın hazırlayarak Enstitümüze teslim ettiği **"Data Envolepment Analysis: An Application to a Television Plant for Supplier Selection"** adlı tezi, tez jüri üyeleri huzurunda ......90..... dakika süre ile savunulmuş ve sonuçta adayın tezi hakkında, ..Oy..birliği........ (*) ile kabul.............. (**) kararı verilmiştir.

Başkan Yard. Doç. Dr. Selim ZAİM (Tez Danışmanı)

Üye Prof. Dr. Mustafa DİLBER (İlgili Anabilim Dalı Öğretim Üyesi)

Üye Prof. Dr. Necdet ŞENSOY (Anabilim Dalı Dışından/ Başka Bir Üniversite Öğretim Üyesi)

---

* **oybirliği / oyçokluğu el ile yazılacaktır.**
** **kabul / red ve düzeltme el ile yazılacaktır.**

AUTHOR DECLARATIONS

The material included in this thesis has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted.

Metin Şatır

November, 2003

ABSTRACT

METIN ŞATIR **NOVEMBER 2003**

DATA ENVELOPMENT ANALYSIS: AN APPLICATION TO A TELEVISION PLANT FOR SUPPLIER SELECTION

Data Envelopment Analysis is becoming recognized as a core decision-making units in most of companies. Organizations continuously seek to provide their needs from suppliers faster, cheaper, and better than the current competition conditions. Managers use this technique to decide correctly and safely. Rather, they must work on a cooperative basis with the best organizations in their supply chains in order to succeed. In this thesis, we studied performance management and measurements, its' definitions, models of measurements and especially data envelopment analysis. It is very important technique to measure the performance and to choose correct solution and company in business world.

In this thesis, we established the objective function about supplier selection problem of a television company. Then we solved the function with LINDO solver program and decided the best supplier for the company. The results of this model can used to decide solution which all companies should choose the best one, such as supplier selection, investment decision, strategic decisions and human resources etc.

Key words:

Productivity
Efficiency
Effectiveness
Performance
Data envelopment
Measurement
Quality

KISA ÖZET

METIN ŞATIR **AĞUSTOS 2003**

VERİ ZARFLAMA ANALİZİ: BİR TELEVİZYON FABRİKASINDA TEDARİKÇİ SEÇİMİ UYGULAMASI

Firmaların birçoğunda veri zarflama analizi karar alma üniteleri için önemli bir yöntem haline gelmiştir. Organizasyonlar sürekli olarak ihtiyaçlarını tedarikçilerden hızlı, ucuz ve günümüz rekabet piyasasının üzerinde şartlarda temin etmek peşindedirler. Bir yandan da yöneticiler doğru ve güvenli karar almak için bu tekniği kullanmaktalar. Yöneticiler kendi tedarik zincirlerinde en iyi organizasyonu kurmak ve basarıyla işlerini yönetmek istemektedirler. Bu tezde performans yönetimi ve ölçümü, tanımları, ölçüm modelleri ve özellikle veri zarflama analizini inceledik. Veri zarflama iş dünyasında performans ölçmek, doğru çözüm ve şirketleri seçmek açısından oldukça önemlidir.

Biz bu tezde, bir televizyon firmasında ortaya çıkan tedarikçi seçme probleminin amaç fonksiyonunu kurup, bu modeli LİNDO model çözme programını kullanarak çözdük. Elde edilen sonuçlar en iyi tedarikçiyi bize göstermektedir. Bununla birlikte bu sonuçlar yatırım çalışmalarında, stratejik karar birimlerinde ve insan kaynakları uygulamalarında kullanılabilir.

Anahtar Kelimeler

Verimlilik Etkinlik Etkililik
Performans Veri zarflama Ölçüm
Kalite

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DEA	Data Envelopment Analysis

ACKNOWLEDGEMENTS

First of all, I would like to express my deep gratitude to Doç.Dr. Selim ZAİM for his supervision, guidance, support and encouragement throughout this study.

I'm grateful to all the members of my family especially my mother and father for their support and friendship which will be remembered all my life. And I am deeply indebted to them who did their best to foster and educate me; my sister who has always advised me.

Last, but not least, I would like to thank Fadime AKTÜRK who is student at Fatih University, Department of English Literature and Art.

INTRODUCTION

DATA ENVELOPMENT ANALYSIS: AN APPLICATION TO A TELEVISION PLANT FOR SUPPLIER SELECTION

In the last ten years, the concept of performance increased in manufacturing, marketing, purchasing environment. All companies consider this concept during each process. Because, performance is very important to get maximum profit and to produce minimum cost. All companies want to be productive, efficient and effective. These indicate the performance values. To get high performance score from all process, there are some methods of analysis and solution. Data envelopment analysis is one of them. If managers want to measure the performance, to make the right decision or to choose the right supplier, they can use this method. Managers need a lot of right decisions about company to develop and increase the market ratio.

In view of the high percentage of the material cost in total cost, the key objective of the purchasing department should be purchasing the right quality of a product in the right quantity from the right source at the right time. The right source can provide the right quality of material on time at a reasonable price (Zaim S., Şevkli M., Tarim M., (2003), "Fuzzy Analytic Hierarchy Based Approach for Supplier", 1.page).

Traditionally, vendors were selected from among many suppliers on their ability to meet the quality requirements, delivery schedule, and price offered. In this approach, suppliers aggressively compete with each other. The relationship between buyer and seller is usually adversarial. This traditional purchasing approach places special emphasis on the commercial transaction between supplier and customer. The main purchasing objective in this approach is to obtain the lowest possible price by creating strong competition between suppliers, and negotiating with them. However, in the modern business world, many firms prefer a strategy of few suppliers. Few supplier strategies imply that a buyer wants to have a long-term relationship and the cooperation of a few dedicated suppliers (Zaim S., Şevkli M., Tarim M., (2003), "Fuzzy Analytic Hierarchy Based Approach for Supplier ", p.1).

Outline of the Thesis

The purpose of the thesis is to develop a general model about supplier selection problem. Model will present solution for this kind of problem. We used especially a problem from Television Company in Turkey. We tried to decide which one is the best supplier company.

In the first chapter, the definition of "Supplier Selection" is covered.

In the second chapter, "Data Envelopment Analysis", its definition, mathematic model of DEA and its strong and weak sides are explained.

In the third chapter, we gave some information about Analytic Hierarchy Process, because we used this process to calculate some information that we needed to establish the objective function. And then, "Data Envelopment Analysis Model" is covered and the analysis of the results determined. The results obtained are presented with the tables. And we decided which company is the best supplier.

CHAPTER 1

SUPPLIER SELECTION

Surely, one of the most important decisions of organizations is about supplier selection. Liability of supply function is usually described as to procure enough amount, sufficient quality, appropriate price, and properly delivery of raw materials, materials. and equipment. Recent years many innovations, progresses, and change occurred in the industry. Main reasons are the rise of customer demand, technological developments, innovations, and unsystematic market trends. Related with those changes, customer demands made progress and they wanted lower prices and higher quality together. With those new improvements in many countries, enterprises inevitably had to meet customer demand with new products and services, besides they were forced to ally with new suppliers. Supplier selection is an important problem than involves many criteria such as quality, cost, performance, and technology. Not only material costs, but also operation costs, maintenance costs, development and support costs should be taken into consideration. For that reason, in order to find an appropriate process between economical and performance related criteria of seller selection, criteria should be evaluated and arranged according to its importance. This process will shorten selection process and will increase success of decision making at the same time.

1.1 What is Supply?

This step of quality functions spiral is related with purchase of products (purchase of product or services from seller). Purchase is of two types: 1) Parts of products that are produced by buyer and 2) Equipment used for facility services, office equipment and machinery. The firm that we purchase from is generally called supplier and relations with that firm is called supplier relations.

1.1.1 Supply Quality Importance?

Importance of the quality of supplied material is increasing gradually for several reasons (Uğur Naci, "100 Soruda Kalite", 2001):

- Amount of the purchased product,
- High cost of suppliers' low quality products,
- Suppliers and buyers dependence to each other,
- Other internal factors in buyers' organization,

1.1.2 Supplier Relations: Aims and Operations

Total aim of the supplier relations is to constitute a relation that provides usage appropriateness with minimum input inspection or corrective precaution. Preceding operations necessary for that aim are those (Uğur Naci, "100 Soruda Kalite", 2001):

- Description of requirements of product and program quality
- To evaluate alternative suppliers
- Selection of suppliers
- To direct quality planning partnership
- Partnership with supplier during the application of the contract.
- To get the evidences of appropriateness to requriments.

- To certificate qualified suppliers.
- To direct quality improvement programs when its necessary.
- To form supplier quality rating and to use it.

Degree of those operations must be related with the purchased product type from basic consumption items to complex technologic parts. We can seperate suppliers into three categories for quality planning:

- Standart equipments and hardware.
- Mediocre important parts and materials.
- Important parts.

1.2 What Kind Of Policies Is Preferred In Supplier Relations?

While examining supplier relations those important difficulties make policy decisions necessary.

1.2.1 Main relationship between supplier and buyer

Relations may vary from "contrary position" to "team work". In contrary relations, supplier is evaluated with a suspicion of evading his low quality products from buyers' delivery inspections. Lower priced proposals are excessively considered important and both sides work for their short period pofits (even though those end up with the ruin of relations). Mutual suspicions prevent working together, planning together and other types of partnership. In some firms, those contrary relations may also spread to both insider and outer suppliers.

In a teamwork relationship, buyer and supplier work as divisions of the same company. This kind of relationship depends on mutual trust, shared planning activities, workind together and reciprocal visits and both sides don't have any secret to conceal. They regard supplier as a subsidiary of Buyers Company.

In 1980, some dramatic changes involving evaluation of old policies took place in supplier relations. The most important of those changes is to pass from contrary relations to teamwork relations. This change was important to assure progress in quality of suppliers' products. In order to improve their own quality, a company mostly using outsourced parts in their products need to improve suppliers products quality. It's evident that assurance of suppliers' quality improvement will be easier in a teamwork understeanding. To constitute such teamwork environment, suppliers had to make those policy changes that they desired for a long time (Uğur Naci, "100 Soruda Kalite", 2001):

- To make long period supply contracts instead of yearly or party based contracts. Long period contracts (generally a few years) encourage suppliers to invest for development. In fact there is an important movement to make long contracts.

- Few numbers of supplier and increasing others' market share. Between the time period 1980 to 1985 large-scale buyers decreased the number of suppliers to one third.

- In respnonse large-scale buyers established strict and new criteria for supplier convenience.

- "Whole service" means expectation of suppliers' positive contributions in product design, process design, cost reduction and such subjects.

- Positive programs for quality progress.

- Education of quality methodology.

Teamwork relation completely respects buyers' and suppliers' interdependency in a modern supply. This interdependency takes shape on three ways: technological, economic and managerial. An important item is strong communication lines are constituted instead of restricted communication channels between technical specialists. From high level to mediocre level of product complexity, teamwork policy is a must to reach usage convenience in all sorts of supply operations. Teamworks' importance in supply of standart materials is at a minimum level.

1.2.2 Relative importance of quality in supply decisions

Supplier selection should have assured usage convenience, in-time delivery and low cost. Middle and top managers of the firm determine gradual importance of these criteria. Some of the firms traditionally make contract with the supplier that offers low priced proposal. But in other firms point of view quality comes first. Quality point of view in supplier selection doesn't provide explicit information about this disctinction among the suppliers. But still, in such situations it is clear why buyer selected supplier generally. Low price or price-oriented understanding has taken root in many firms and this situation won't change without a clear policy directive.

1.2.3 One resource (supplier) versus multi suppliers

Multi-supplier resources have many advantages. Competition may result as better quality, low price and better service. Risk of supply stoppage because of strike or other events may be the least. One resource (supplier) may also have advantages: amount of the conrtact will be higher in respect to multi suppliers and one supplier will consider more importance and attention. On the other side, if there isn't an alternative supply resource, this monopoly of one supplier will have a negative affect. In the most general examples of one supplier, both of the firms belonged to same group of firms. Policy decisions must designate the issue of using multi suppliers. For example in 1970, Toyota had only about 200 suppliers in respect to Amerikan automotive firms using thousands of suppliers. For the products that require a teamwork relationship, few numbers of suppliers mean more time for mutual visits and provide many technological cooperation possibilities. There are many advantages of existing inner resources: a better employee relationship, using existing capacity, cost advantages and so on. Merely some administrators report that inner supply is the biggest source of quality problems. If such problems are difficult to solve, superiority of the quality of outer suppliers may be the distinguishing factor while making decision about outer or inner purchasing.

1.2.4 Long or Short Term Relations

In a teamwork relation required type of supply, suppliers' being under the guarantee of long term contracts is important. On the other side, supplier will have little initiative to participate in teamwork. In some firms such long-term relations represent policy change more than applicating annual repeating proposal admissions.

1.2.5 Technical Support to Suppliers

Technical support may take many shapes: assurance of education material, to arrange education courses together, reliability engineering support, quality engineering support (for example process sufficiency researches), technological consulting support (ex. Measure support). To provide or not to provide this sort of materials to supplier or driving supplier to research other type of resources are policy decisions.

1.2.6 Printed (Written) Quality Policy

Many examples about verbal quality policies of suppliers exist in ongoing long term industry practices. Some elements of written quality policies are present in firms "supplier relations handbooks' " pages. As soon as firms' mutual dependence increases, their need to written policies will increase too. Generally, written policies, information about them and information about importance of using supplier are gathered in a "supplier relations handbook".

As a wide scale document, we can mention about American Ministry of Defence's MIL-Q-9858 Standart which was prepared for managing quality relations with contractors. The aforementioned standart involves some issues on quality policies.

"Ten Principle about Supplier and Buyer Relations", are especially about policy decisions for supplier relations' and improved by Japanese Engineers and Scientists Foundations research commission, resumely involves those issues (Uğur Naci, "100 Soruda Kalite", 2001):

- Mutual benevolence and cooperation
- An understanding formerly based on contract.
- Agreement on development methods.
- Consent plans for ending up disputes
- Change on basic information
- Adequate performance in related functions, ex. Inventory controls.
- Supplier's responsibility for transferred good quality products and support data.
- Priority of consumer benefit.

1.3 How is Organization of Supplier Relations?

In most firms, there is a problem: Who is responsible from supplier quality? Even though disputes are ample, this issue is unnecessary. Instead of that, it's better to determine all spesific precautions and decisions, which constitute supplier relations. After separate discussions on each of these specific precautions and decisions, generally an easy agreement can be set on many of them. A few disputable issues really need a solution. A typical list of responsibilities can be seen from the table below (Uğur Naci, "100 Soruda Kalite", 2001):

Table 1.1. Supplier relations' responsibility matrix

Activity	Shared Departments		
	Product developing	Purchasing	Quality Control
1. Determining a supplier quality policy	X	X	XX
2. Using a large number of suppliers for important supplies		XX	
3. Evaluating quality sufficiency of potential suppliers	X	X	XX
4. Determining conditions for suppliers	XX		X
5. Driving quality planning partnership	X		XX
6. Driving supplier research		X	XX
7. Evaluating sent products	X		XX
8. Development programs	X	X	XX
9. Using supplier quality classifying for selecting supplier		XX	X

XX=Primary responsibility, X= secondary responsibility

For another point of view purchasing department has the main responsibility and performs some detailed activities. With respect to that purchasing department personnel need more information about quality: especially about supplier sufficiency and effects of low supplier quality.

1.4 How Can We Evaluate Supplier Sufficiency?

There are two aspects of supplier evaluation:

1. Evaluation of product samples and description of supplier designs.
2. Description of supplier sufficiency about production parties' quality assurance.

1.4.1 Description of Supplier Design

In some supply activities, buyer presents a description of desired product and expects supplier to design and produce as it is described. This supplier description after the first step is the evaluation of the design in aspect of performance and other imperatives. Supplier prepares samples of the suggested product. Samples are either tested by buyer or first tested by supplier and results are sent to buyer. Various performance tests: heat, vibration, humidity, and other terms. Reliability, easy maintenance, and other functional parameters are simultaneously evaluated. But, because of the limited numbers of samples and time evaluation is also limited. For those last parameters buyer may request researches such as Reliability Envision and Fault Manner and Effect Analysis.

The most important variables that affect design descriptions are agents of future production. For a new design, samples are produced in engineering and development workshops. In such situations, results of a design description test will bring a little information about supplier's competence of conforming to design. But description test results show whether supplier has comprehended the performance provisions and meet the design conditions or not.

1.4.2 Description of Supplier Production Process

For evaluating suppliers' production systems comformity to design, they must take different steps. Such an evaluation of production quality may take various shapes: before product performance, process sufficiency analysis and evaluation of suppliers quality system.

Former product performance. The best way of estimating future quality is to examine former quality of suppliers existing similar products or the same products.

Process Sufficiency Analysis. Process potential research firstly provides an initial evaluation. These researches are short term and are'nt sufficient to measure long-term process sufficiency. Typically, at least 30 pieces are taken during production of 300 pieces. On a control diagram sample, means and differences of the highest and lowest samples are marked (Statistical Methods for Quality Development book examines the subject comprehensively). If the results are statistically in control, namely if the process is stable data can be used for calculating process sufficiency. Tolerance must have passed in for standart deviation to be admitted.

1.4.3 Evaluation of Supply System with a Quality Research

A Supplier Research is a facility visit which evaluates suppliers' competence to conform to quality provisions in production parties. For an investigation normal steps are like those (Gökdere Halis,"Bilgi sistemlerinde tedarikçi seçimi", KalDer Forum Nisan-Mayıs-Haziran 2001) :

- To collect existing information about suppliers' former experiences. By the way, important issues to pay attention during the investigation are determined before.
- To send a question form to supplier. Therefore, supplier will be able to help for collecting existing information and planning the visit, so they can save time

during the visit. This kind of former preparations makes it possible to pay attention to probable difficulties during the contract.

- To organize investigation team. Specialists from purchasing, production, engineering, and quality department may be involved.

- Managing the investigation. Generally investigation lasts a few days in the suppliers' facility. It begins with an opening speech that explains the aim of the visit; visit program and the desired information, and the general issues to pay attention to during the investigation.

a) *Sufficiency of Management:* Primarily related with those subjects:

Policies: Is the supplier willing to "be a team": mutual visits, interdependency, cooperative planning and having no secret?

Organization: Are activities for gaining the quality described and determined? Are different departments assigned to activities in a logical relationship?

Personnel: Are managers, specialists, and employee educated and encouraged to join well-constructed courses and to take description certificates? Is is possible to see evidences of high motivation for quality issues related with other parameters (cost, delivery etc.).

b) Techonological Sufficiency: Here in, these issues are considered: Equipments and conveniences in suppliers' facility, their orderliness, regularity and conditions; sufficiency of process for meeting production specifications, degree of comprehending process variables and product outcomes, and reliability of measurement equipments.

c) Quality Discipline Sufficiency: Here, typically quality oriented systems and procedures are important. These involve systems for process control, product inspection and test, data records and summaries, documentation, and maintenance of equipments. Additionally, this part of investigation looks for existence and perfection of quality handbooks, and preparations for investigations of systems and procedures sufficiency. Nevertheless, systems must be applied to spesific products. For example, in order to assure that planned process control is done, a qualified supplier is to prepare process work flow charts that shows process control points and proposed inspections.

Detailed information can be gathered form the preceding question form, and the inspection lists used during the visit. Those can be added (Uğur Naci, "100 Soruda Kalite", 2001):

- Management: Psycology, quality policies, organization structure, doctrin, participation to Quality

- Design: Organization, the system used capacityo of specifications, orientation to modern techniques, and attention to reliability, engineering change control, and development labrotaries.

- Production: Physical convenience, maintenance, special processes, process sufficiency, production capacity, planning capacity, party descriptions and observations.

- Purchase: Specifications, supplier relations, procedures.

- Quality Assurance: Investigation of conformity to organization structure, quality control, reliability control, existence of reliability engineering, quality planning (material, process, finish works, storage, package, shipping procedure, service works)

- Investigation and test: Labrotaries, special tests, instruments, measurement control

- Quality coordination: Organization for coordination, directive analysis, control on supplementary industries, quality cost analysis, corrective action recycle, discarding inappropriate products.

- Data systems: Convenience, procedures, effective usage, reports.

- Personnel: Doctrine, education, motivation

- Quality Results: Gained performance, simple usage of product, customer prestige, supplementary industry prestige.

Third party Evaluations: This term means supplier evaluation is done by buyer or some one other than supplier. In fact, powers behind these evaluations are:

- Beyond the quality carried out by supplier, large scale buyers that demand quality assurance.

- Independent insurance firms that demand quality certification as an estimator.

- Government foundations bound to safety, health, and environment oriented administrative arrangements

Recently, for quality-oriented information, a developing and an additional independent demand is about consumer economics. For example, as a response to the fee that consumer foundation can denote presenting rival products, helping them with information they need. These tendencies in quality area all together are similar to tendencies in independent inspections in financial area. BSI created the service for evaluating an organizations quality program. Investigation BS5759 issue makes a comparison. Quality Systems 1979 issue involves fundemantal elements of a quality system. BSI provides an evaluation of contract-based supplier.

1.4.4 Approved Supplier Lists

A supplier can be defined "qualified" in two aspects:

- Business subjects, honesty, financial sufficiency.

- Product quality (design and production sufficiency).

Description process requires two different evaluations. Results are usually formulated in approved supplier lists (one usually in business subjects and other, for quality of specific products). Business related qualification of a supplier does'nt mean a products automatically qualification.

1.5 What's Supplier Selection?

Supplier selection begins with decision of purchase. That decision requires anaylysis of required talents and easiness, facility capacity, sufficiency to delivery programs, "doing" or "purchasing"s expected costs and othe subjects. Proposal accepting process sometimes shows excessiveness in design provisions. An electronic firm decided to buy a part that they can produce themselves. Unexpected high priced proposals of many suppliers confused their mind. Supplier claimed that price was normal to meet all these provisions. Same provisions were also used in their own firm but costs were simply divided to a lot of product. After evaluation of provisions, it's denoted that some of these provisions were unnecessary.

At the beginning, if there is no former experience about supplier, selection should be used with those (Gökdere Halis,"Bilgi sistemlerinde tedarikçi seçimi", KalDer Forum Nisan-Mayıs-Haziran 2001) :

- Reputation of supplier

- Information collected from similar products experienced buyers about supplier.

- Suppliers' design and description tests.

- Investigation of suppliers production convenience

- Information from databanks

These inputs as a group may lead to some hesitation about the real performance of the supplier. Many buyers relegate the supplier into a contingency category until these doubts are eliminated. After that point suppliers settle on approved suppliers. To be included in this group provides many advantages to the firms compared to those who are excluded. These advantages are usually extra shares and longer contracts. Supplier selection is not only based on quality, but also based on price, delivery according to schedules and opinios on other parameters.

1.5.1 Total Cost of a Supply

Total costs of a supplied product involve price, scrap, re-processing, delays, outer failure and other costs originating from low supplier quality. These additional costs are at times more than favourable proposal price and supply economy. In this situation, purchase manager is easily accused of only taking the cheapest price into consideration.

Purchase managers admit that purchase decision musn't be based only on supply prices, but on all expenditures. Besides, they state their lack of information and inability to appraise all these costs. Instead, such appraisals should be made by, for example, quality or accounting departments. Theoretically, it's better to appraise these additional costs with an improved accounting system that defines and appraises all supplier originated quality costs. Practically, it appears that those costs follow "a few important, many useful" Pareto principles. It's useful to appraise a few important costs. To follow data required for many useful costs is formality and it's difficult to make a judgement because of that. Solution of that dilemma is to deal individually with "a few important" events and deal wholly or sample based evaluations with "many usefull" events. Some organizations improved quality cost indexes for "a few important" . This index is defined as division of the sum of supplier quality cost and supply cost by supply price. Supplier quality cost is sum of quality problems of supplied materials. To follow this cost entirely, a wide record protection system is necessary. What can be done to define main categories of that cost and to collect real cost data from these categories? For example, a firm defined categories as shown below (Uğur Naci, "100 Soruda Kalite", 2001):

- Costs because of refused parties: It's estimated as stationery, transport and other cost occurred for each refused party.

- Research of complaint costs: These are the correction costs because of quality issues occurring on supplier parts.

- Acceptance Inspection: This is the cost of the acceptance investigation. Acceptance investigations mostly depend on suppliers' reputation.

- Inappropriate product costs after acceptance investigation: These costs are inappropriate products' costs that are percepted during assembly or after delivery to customer.

Supplier quality cost index is defined as multiplication of supplier proposal price and index of similar product, and used for estimating total purchasing costs in the future. If these data reach the purchase manager, he can easily choose the lowest cost proposal instead of lowest priced proposal.

1.6 Suppliers Circumstance

Some of the purchased material may be produced in the same firm. That has many reasons; producer of the part may be in the same group of companies, one customer determined the supplier; there may be only one supplier or required amounts may be too small. If one supplier provides low quality and doesn't take preventive measures, serious problems occur. Here, main problem is to determine the steps to take preventive measures. It's important that the problem must be presented with its effects to supplier. While there's one supplier, determining sales affects of the problem doesn't form a strong effect on acceleration of preventive actions. But denoting how to calculate costs of low quality may be helpful for accelerating the preventive actions.

Additionally, there are other alternative options (Dağdeviren Metin, Eren Tamer,"Tedarikçi seçiminde analitik hiyerarşi prosesi kullanılması", Gazi Ünv. Müh. Mim. Fak. Dergisi, Cilt 16, No 2, 41-52, 2001)

- To show functions of the product. In this way, even if they don't obey the specifications, they can respond to user convenience.

- To classify quality characteristics according to their seriousness. Such a study will cause suppliers' effort to intensify in few numbers of critical characteristics and important quality issues.

- Technical support to supplier, for example partnership in quality development teams.

- Economic support, for example to purchase an important counter or instrument. Other than those options beneficial to suppliers, there are other solutions that will bypass the supplier or will find a real solution for suppliers' problems.

- To acquire test equipments that can distinguish good products from the bad ones.
- To carry out an operation to make supplier's products convenient.
- Not to purchase.
- Make an agreement with a rival supplier that can solve the problem.
- To make a new design which will make suppliers' product redundant.
- To get brother firms support those who do business with supplier.
- To get customers' support (buyers) who are also customers of our suppliers.
- Investigate supplier firm's top management's suitability and willingness for a long term relationship and team work.

CHAPTER 2

DATA ENVELOPMENT ANALYSIS

2.1 What is the Data Envelopment Analysis?

Just as performance has several definitions because it is a multi-dimensional concept, performance measurement methods vary in the same way as well. These measurement methods can be separated into three three different groups in the structural respect. These are; proportion analysis, methods without parameters, and methods with parameters.

Proportion analysis includes mono-dimensional analysis in respect of scope and aim. These are independent analysis that is developed to measure the own performances of each sub-system and require making comments between single input and output. Similarly, methods with parameters (regression analysis), are focused on average behaviors. Although, they can associate many inputs with single output, they are still limited for total measurements like the detailed measurements of inefficiency. Also, they absolutely animate the existence of an analytic form. However, methods without parameters use mathematical programming as a solution technique and have an appropriate structure for environments of production with many inputs and outputs.

The most important characteristic of these, especially the data envelopment analysis (DEA) is their ability in defining the amount of inefficiency in each decision-making unity and their sources. They enable the necessary decisions to be taken for activating the units that are not active, as the units' reference heap. In this way, it can guide the managers in the fact that how much input should be decreased and/or output should be increased in the units that are not active. In the last twenty years, DEA is put into practice primarily in institutions without profit motive, in the service sector (hospital, university, the military, etc.), in the evaluations of research and development projects, in the measurements of relative performances of multi-national or multi-branched business enterprises. An important innovation of the method is the fact that it is possible to carry out measurements in the environment where many outputs are got by using many inputs, without having the need to envisage the existence of a pre-determined function of analytic productions, just as in the parametric methods (Ülengin Füsun, Besen Buket, Performans Yönetim Sistemi ve Veri Zarflama Analizi, İstanbul Teknik Üniversitesi, 1995).

DEA is a criterion of efficiency without parameters, which was developed by Charnes Cooper and Rhodes (CCR) for the first time, in order to measure the relative efficiencies of economic decision units that are similar to each other in respect of the good or service they produced. This method, which aimed at measuring the comparative efficiencies of institutions that do not have profit motive, began to be used widely in the measurement of relative efficiency between institutions in the sectors of production with profit motive and service, later on. To sum up, DEA has developed the concept of relative efficiency of Farrel (1957) and made it possible to conduct measurements of efficiency easily in the environment of production with many outputs rather than the environment of production with single output (Yolalan O. R., "İşletmeler Arası Göreli Etkinlik Ölçümü", Milli Prodüktivite Merkezi Yayınları, No: 483, 1993).

2.2 The Concept of Data Envelopment Analysis

Although, the studies of DEA started in 1978, Thanassoulis made the first definition of the method in 1987. "Data envelopment Analysis is a method based on linear programming that is used to compare the efficiencies of decision-making units that do not have profit motive". However, Boussofione changed this definition in 1991 after the practice of the method in private sector as well, in this way;

"Data envelopment analysis is a linear programming based method that is used in measuring the relative performance of organizational units in the situations when many inputs and outputs make comparison difficult (Yolalan O. R., "İşletmeler Arası Göreli Etkinlik Ölçümü", Milli Prodüktivite Merkezi Yayınları, No: 483, 1993).

DEA is the approach of comparing the efficiencies of organizational units that are composed of homogenous units such as school, hospital, bank and public units.

2.3. Mathematical Modeling of Data Envelopment Analysis

DEA is a method in which linear programming is used to find the optimal composition of inputs and outputs according to existing performances. In its base lies the evaluation of the production activities of similar decision units; DEA is used to measure the relative performances of organizational units where too many outputs and inputs, rather difficult to compare, are presented. Measuring relative efficiency is conducted in two phases. First of all, the best observations decision units that form efficiency limit which produce the most output composition by using the least input composition within any observation heaps. At the second phase, the mentioned limit is accepted as reference and the distance of inefficient decision units to this limit or their level of efficiency is measured as radial. Models of DEA can make the comparative measurement of decision units that have same inputs and outputs. A model is solved for each decision unit. At the end of linear programming, the decision units the aim function of which are equal to 1 are determined as efficient and the decision units the aim function of which are not equal to 1 are tried to be similar to one of the appropriate efficient decision units. In this way, it is made possible for each inefficient unit to be made efficient.

When organizations have output is more than input, the definition of efficiency should be made in this way;
EFFİCIENCY = Σ Weighted Outputs / Σ Weighted Inputs
(Shang and Sueyoshi, A bibliography of Data envelopment analysis 1987, p. 45).

In this definition, we meet the problem of determining the weights of inputs and output. This problem becomes greater for especially the organizational units that do not have close relationship between them. This problem can be overcome by a system in which the input and output systems form there own weights on their own.

DEA models are separated into two groups:

- Directed towards input
- Directed towards output

Three different kinds of program are defined in each group:

- Fractional
- Weight
- Envelopment

DEA models directed towards input and output, in fact, are very similar to each other. In the model directed towards input it is tried to maximize the ratio of weighted output to weighted input, whereas, in the model directed towards output, an objective function is formed to minimize the ratio of weighted input to weighted output. In other words, while in the model directed towards input, how should the most appropriate input composition should be in order to produce a certain output composition in the most efficient way is searched, in the model directed towards output, the answer to the question that how much output composition can be obtained at most by a certain input composition is looked for. The formulas given below include DEA models directed towards input.

The objective function lying in the basis of DEA can be expressed in this way:

$$E_k = \max \frac{\sum_{r}^{t} U_r Y_{rk}}{\sum_{i}^{m} V_i X_{ik}}$$

Limits:

$$\frac{\sum U_r Y_{rk}}{\sum V_i X_{ik}} =< 1$$

$U_r, V_i >= \varepsilon$

k = 1, ...,n

r = 1, ...,t

i = 1, ...,m

Here;

E_k = the efficiency of "k" decision unit

U_r = the weight given to " r" th output by "k" decision unit

V_i = the weight given to "I" th input by "k" decision unit

Y_{rk} = the "r" th output produced by "k" decision unit

X_{ik} = the "I" th input used by "k" decision unit

ε = A small enough positive number

n = the number of decision unit

t = the number of output

m = the number of input

The objective function and limits above are the fractional model that forms the basic skeleton of DEA. According to this, each decision-making unit in the observation heap is compared to other observations and their levels of efficiency are determined. Relative efficiency criterion (E_k) is defined as the ratio of weighted outputs to weighted inputs for "k" decision unit.

In the fractional DEA model explained above, each decision-making unit in the observation heap is taken into consideration and their comparative level of efficiency with other observation is measured. Although, the ratio in the objective function of this model reflects the ratio of weighted output to weighted input or the concept of productivity, as this is not a linear program, some problems in respect of solution technique occur (Işcan Firuzan, Karsak Ertuğrul, "Ağırlık kısıtlamaları, çapraz etkinlik ve pencere analizi yöntemleri kullanılarak veri zarflama analizi ile performans yönetimi", Galatasaray Üniversitesi, Haziran 1999).

For this reason, with the help of variation transformation proposed by Charnes and Cooper (1962), the weight linear program below has been attained from the fractional program above.

The weight DEA model is formulated as below:

$$E_k = \max \left(\sum_r U_r Y_{rk} \right)$$

Limits:

r

$\Sigma V_i X_{ik} = 1$

i

$\Sigma U_r Y_{rj} - \Sigma V_i X_{ij} <= 0$

r

$U_r, V_i >= \varepsilon$

j = 1, ...,n

r = 1, ...,t

i = 1, ...,m

According to this model, the weighted output for a decision-unit in the objective function is tried to be maximized. If k decision unit is efficient, the value of objective function equals to 1 and the limit for this decision unit becomes equal to 0. If the decision unit the relative efficiency of which measured is not efficient, the value of objective function will be less than 1 in this situation. In order to make these decision units efficient, which reference heaps will be used is determined. And for this, the values of weight given to outputs and inputs created in the solution of inefficient decision unit are placed in all limits, and the decision unit equaled to zero, enters in its own reference heap. The inefficient decision unit is made efficient by being similar to the "theoretical unit" which is formed by the values of decision units that form their own reference heaps. In this model, forming the reference heaps takes time. In the envelopment method, however, this operation can be done much more easily. The envelopment method is composed of the dual of weight DEA model. In this way, it becomes possible to calculate the inert input and / or output vectors, which are possible to be decreased or increased, though not measured radically. Envelopment DEA model is like below (Ülengin Füsun, Besen Buket, Performans Yönetim Sistemi ve Veri Zarflama Analizi, İstanbul Teknik Üniversitesi, 1995);

$Ek = \min\theta - (\varepsilon \Sigma S_i^-) - (\varepsilon \Sigma S_r^+)$

$\Sigma X_{ij}\lambda_j + S_i^- - aX_{ik} = 0$

$\Sigma Y_{ij}\lambda_j + S_r^+ - Y_{ik} = 0$

$\lambda j >= 0$
$S_i^-, \ S_r^+ >= 0$
θ = special value

2.4 What are the steps of Data Envelopment Analysis?

- 1. Step: Choosing observation group
- 2. Step: Choosing input and output groups
- 3. Step: Relative efficiency measurement with DEA
- 4. Step: Detail analyze for each decision unit
- 5. Step: Evaluation of general results for observation group

(Yolalan O. R., "İşletmeler Arası Göreli Etkinlik Ölçümü", Milli Prodüktivite Merkezi Yayınları, No: 483, 1993).

2.4.1 Choosing Observation Group

First step includes the evaluations of decision units that will measure the efficiency. The observation heap should be homogeneous about meaningful of results. The meaning of homogeneous heap is that the decision units have same inputs and outputs. Because of structure of DEA, number of input should be "m", number of output "p", and decision unit should at least be " m+p+1" (Ülengin Füsun, Besen Buket, Performans Yönetim Sistemi ve Veri Zarflama Analizi, İstanbul Teknik Üniversitesi, 1995.).

Homogeneous group, which is formed by decision units, should carry this characteristic:

- Units' own similar aims and duties.
- All units have some marketing condition.
- All input and output factors which characterize the performance of units in the group are same.

Definition of units, which will be evaluated by the analyzing of output enveloping, is affected by two limits. First one is the organizational, physical and regional limit. The other is the periods during which activities of measurement are applied.

It should not be forgotten in output enveloping that efficiency is measured according to decision units and factors chosen (Golany and Roll, Some models for estimating technical and scale inefficiencies in data envelopment analysis, v.30, n.9, 1989, p.68).

2.4.2. Choosing Input and Output Groups

As it is a datum-based technique, for the measurement made with DEA to be accurate, inputs and outputs regarded should be meaningful, too. This aim is for the selection of input and output, which can best express the production technology.

For this reason, first a list of all candidate inputs and outputs, which are related to production, should be made. Then, the idea of the expert who will make the measurement of efficiency and varieties between which there is high correlation with the help of some analysis of previous statistics and which does not have a direct effect on production should be eliminated. To get rid of mistakes in datum is a very important fact. Doubtlessly, results of activities, which will get a model result, which symbolizes the system, best, may be misleading (Yolalan O. R., "İşletmeler Arası Göreli Etkinlik Ölçümü", Milli Prodüktivite Merkezi Yayınları, No: 483, 1993).

- Is the factor related to one or a few of the aims of activity?
- Does the factor include the information that others do not?
- Are the data of the factor reliable and easily got?

Another relationship for the analysis of data enveloping is "isotonicity" relation. This can be explained, as "an increase in any input should not cause a decrease in any output". Finally, some values of factor should be turned into a situation, which will be suitable for this law before analyzing them.

Sources, which are used, or conditions, which affect the activities, are a typical input. Advantage, which can be measured, forms outputs. But, at the same time, some factors can be regarded as both input and output. In such a situation regression analyze of factors should be made. If the relation is weak with inputs and strong with outputs, factor should be classified as input. If it is contrary it should be regarded as output. If it has a weak relation with all factors, factor may be neglected. However, if it has a strong relation with all factors, it is also possible to neglect the factor. Because, this shows that information of the factor is also present in other factors (Ülengin Füsun, Besen Buket, Performans Yönetim Sistemi ve Veri Zarflama Analizi, İstanbul Teknik Üniversitesi, 1995).

2.4.3. Relative Efficiency Measurement with DEA

After choosing input / output groups and observation group which is formed by decision units whose comparative analysis will be made, analyst who will make efficiency measurement chooses the most suitable DEA model for present production environment. By solving the related linear program for each decision unit one can reach the relative efficiency results (Yolalan O. R., "İşletmeler Arası Göreli Etkinlik Ölçümü", Milli Prodüktivite Merkezi Yayınları, No: 483, 1993).

There may be some differences between the advanced analysis of relative values of efficiency calculated by main CCR model and the results got in the other applications of other models of DEA. As explained before, there are two approaches in the formulation of CCR model.

These are for increasing output and decreasing input. While deciding which to apply, present conditions should be taken into consideration. For example, if input is less flexible, formulation of output can be less. On the other hand, output can be strongly related to management rank and environmental factors. In these situations, formulation of input is more suitable (Golany and Roll, "Some models for estimating technical and scale inefficiencies in data envelopment analysis", Supply Chain Management, Vol.30, No.9, 1995).

2.4.4. Detail Analysis for Each Decision Unit

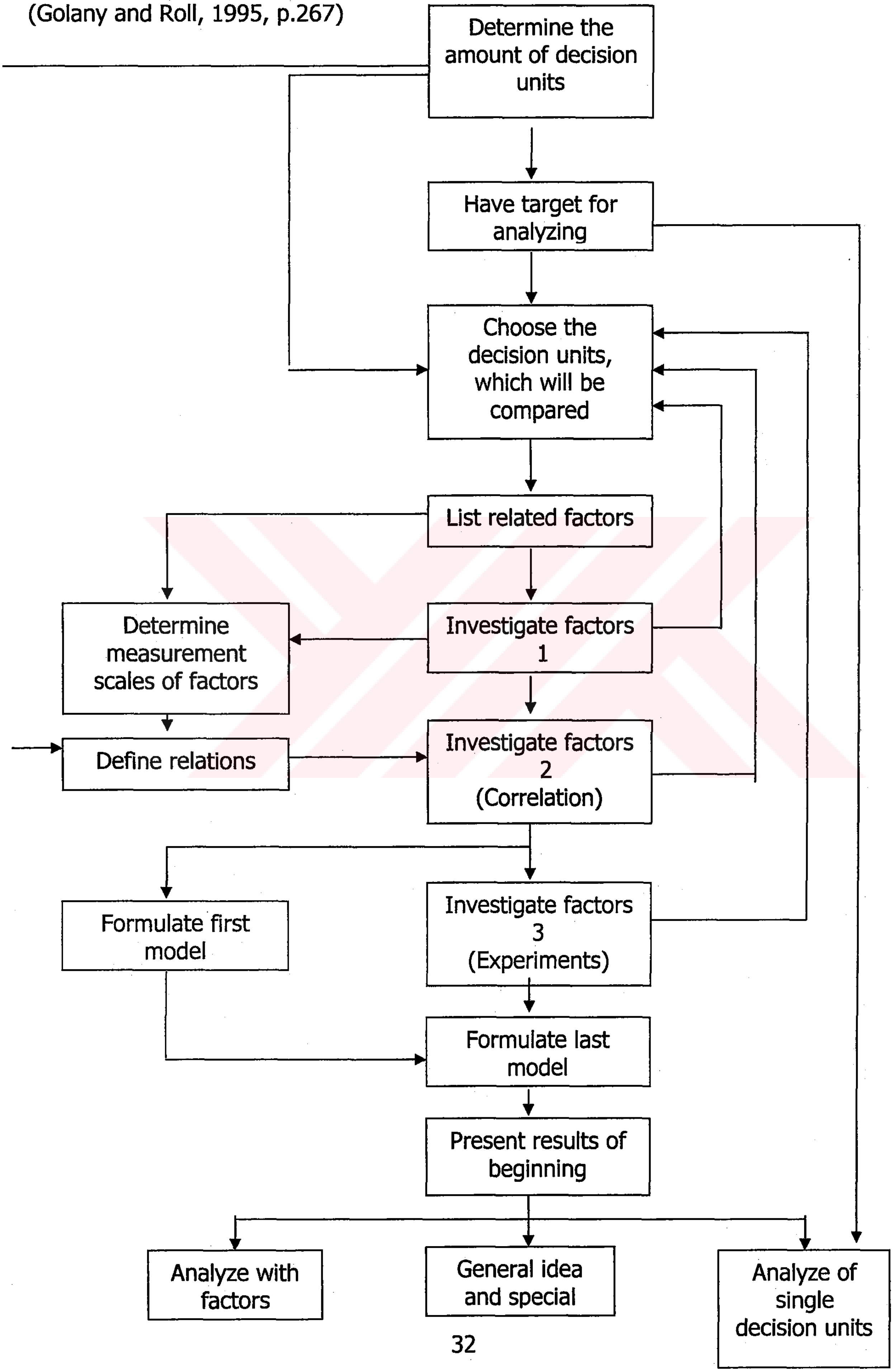
In the light of the result groups got from linear programming, information about precautions that should be taken is given to the manager of each decision unit which is not active in order for him to turn his management into an active situation (Yolalan O. R., "İşletmeler Arası Göreli Etkinlik Ölçümü", Milli Prodüktivite Merkezi Yayınları, No: 483, 1993).

2.4.5. Evaluation of General Results for Observation Group

Common discoveries are searched for decision units of observation group, which are active, and not in the last level of DEA. Moreover, evaluations about the general situation of industry branch to which decision units that form observation group can be made. Application steps, which are explained above, are given in figure 4.1.

Figure 2.1 Application of DEA

(Golany and Roll, 1995, p.267)



2.5. DEA and Performance Management

Main result of data envelopment analyze is the relative activity of decision units. Here relative activity point of one unit represents the maximum point of input which that unit has to use for counting the present output level. On the other hand, opposite of efficiency point is the minimum factor which can be multiplied by the present output level to activate the unit while input level of any unit is stable in its present level. In this way, analysis of data envelopment not only shows the active and inactive units but also defines the indications for balancing the sources and increasing outputs.

Relative activities of units are the first and most clear information, which is obtained in the result of envelopment analysis. Moreover, it leads to evaluate the performance of units singly and make inactive units active. Some advanced applications of data envelopment analysis are as follows (Işcan Firuzan, Karsak Ertuğrul, Haziran 1999);

- Defining effective operational activities,
- Defining aims,
- Defining efficient strategies,
- Observing activities which change in time,
- Delivering sources.

2.6. Strong and Weak sides of DEA

It is possible to list strong sides of DEA as follows:

- It provides a condition to decrease the various dimensions of management to only one efficiency measurement without having a unifying problem in the production situations where there are many inputs and outputs.

- It is independent from input and output measurement units. It provides various dimensions of management to be measured at the same time. It is possible to evaluate factors except economic values.

- It does not require a hypothesis about the analytic structure of production function in advance.

- While counting efficiency for each decision unit, it determines the maximum objective function and the most suitable solution group for each decision unit group.

- It divides decision units into two as efficient and inefficient, and it leads the management by creating information about the precautions that should be taken to make in efficient ones efficient.

- It gives opportunity to evaluate not only decision units but also performance of time. In literature of data envelopment analysis, this characteristic is named as window analysis.

- It provides very important information for source management and strategy planning.

Besides these advantages, weak sides of DEA are as follows:

- It is very sensitive to mistakes of data as it is a data based method.

- When chosen input and output do not reflect system well, measurement will be unsuccessful.

- Especially, when there is no natural opportunity to envelop, institutional decision unit cannot be meaningful enough. In these situations when marginal substitute and productivity do not have much meaning, results of DEA are not enough.

- Very small or large values of input and output of observation group creates problems in the measurement of efficiency.

- When it is used in the analysis of a system which is formed by many inputs and outputs, many decision changes occur for each decision units and this creates problems in commenting decision changes.

CHAPTER 3

DEA MODEL FOR SUPPLIER SELECTION

3.1. The Definition of Model

The goal of this study is to set up a general model, which will assist to get solution about the supplier selection problems of TV set manufacturing in Turkey. Particularly, the study was carried out to solve the supplier selection problem for tube purchasing at a major Turkish TV manufacturing company[1]. There are only a few big companies in this sector and they have almost 85 percent of market share. In order to maintain the confidentiality of the firm utilized in the case illustration, the TV manufacturing company is referred to as Company A. In the study three suppliers of company A will be evaluated and named as supplier A, supplier B, and supplier C. The model presented in this study utilizes the analytic hierarchy process (AHP) and data envelopment analysis (DEA) approach. In this model qualitative data were used in DEA to determine the best supplier for the buyer company. The important point of this model is on the impreciseness of judgment that is attributed to the human perception of events. The main steps of the model are;

1. What are the criteria for supplier selection structure?
2. How did we calculate the weights of the suppliers?
3. How did we compute the overall score of each supplier?
4. How did we solve the model with DEA approach?

In the previous chapters, AHP and DEA are briefly described and the definition of AHP as an appropriate tool for the supplier selection process is explained.

[1] The name of the company had to be kept confidential upon the request of its management.

3.2. What are the criteria for supplier selection structure?

Figure 1 shows the structuring of the supplier selection problem hierarchy of three levels. The top level of the hierarchy represents the target of the problem. At the second level, these criteria are decomposed into various attributes that may affect the supplier's choice. The last one is the bottom level of the hierarchy that shows the alternative suppliers. These factors were determined from reviewing literature and using a brainstorming tool among the members of the supplier chain department (Zaim S., Şevkli M., Tarim M., (2003), "Fuzzy Analytic Hierarchy Based Approach for Supplier ", p.5).

Each factor in the structure is briefly described below:

Shipping procedure: Does shipping organization of the company provide that what our procedure is? Shiping procedure is very important for the company. Because, all materials are sensitive and fragile. They need good and safety package, sensitive carrier staff and special attention.

Delivery: Delivery refers to the dealer's ability to get delivery schedules. It covers compliance with quantity and packaging standards, delivery to request date, and order fill lead-time.

Cost Analysis: A product's costs can be grouped into two categories, which are initial and operating costs.

Number of Employees: Number of employees refers to the total number of the employees in the supplier company. The total number of the employees also indicates the size of the supplier.

Organizational Structure: Organizational structure means to the organizational structure of the company and the obvious of employee job definitions within this structure, management, goals and objectives, etc.

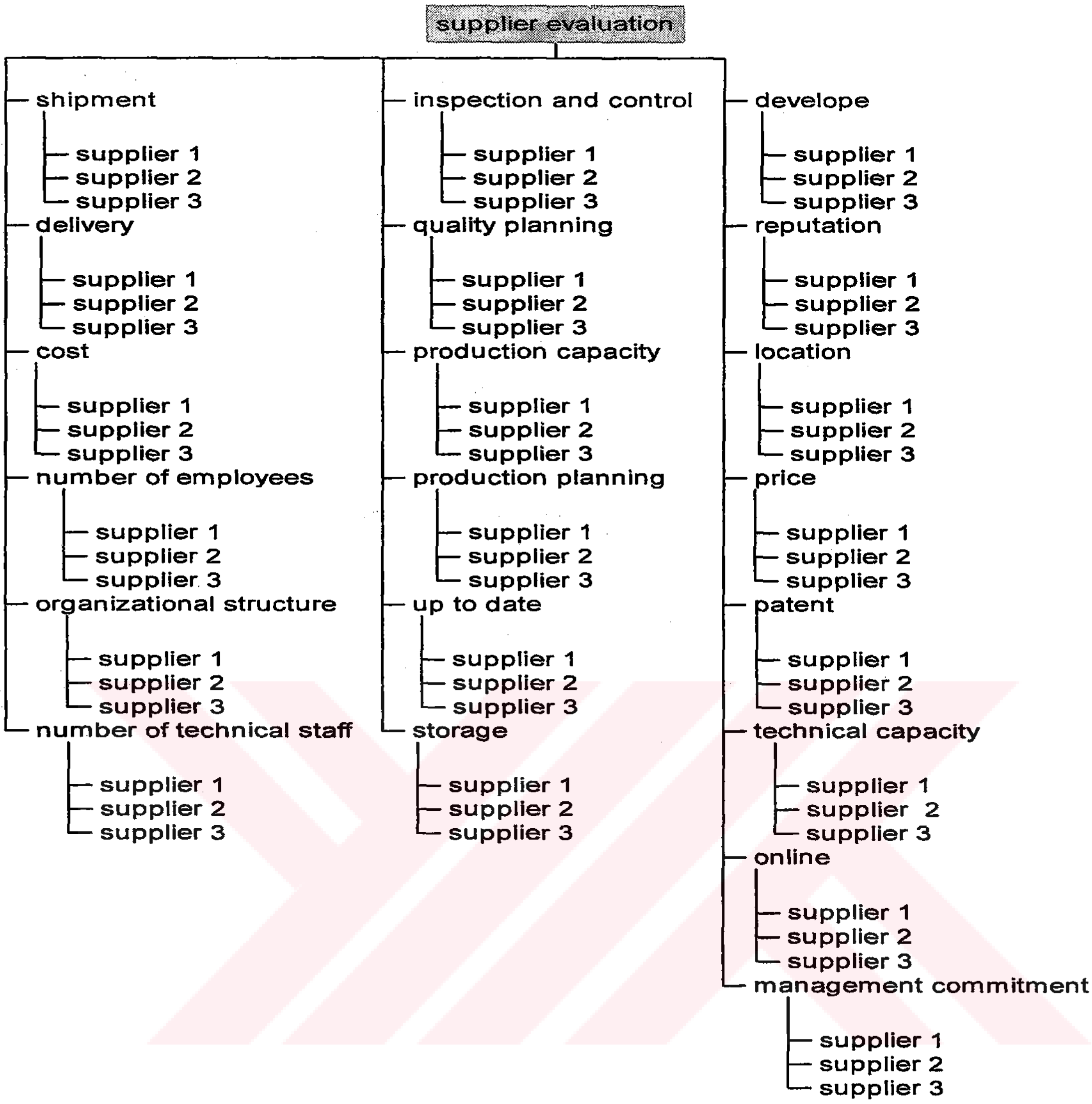
Management Commitment: It means to the preparation of the organization system regarding the quality assurance system, which support the participation of work force, emphasizing the importance of the role of the quality function in the company, the implementation of quality improvement programs, appropriate environmental policy and regular management reviews.

Inspection and control: The aim of inspection is to assure the buyer that the supplier has delivered an item, which replies to the description furnished. Its procedure can involve measurement, testing, touching, weighing. Its objective is to find out the bad process immediately. Inspection and control can be applied to the work in process, for last control of the product or for calibration activities.

Quality Planning: Quality planning includes compliance with control specifications, prototype control, traceability, quality cost, etc.

Production Capacity: Production capacity involves the design capacity and effective capacity. Design capacity is expressed as the number of units produced in a specific time period such as per week, per month or per year. Effective capacity is the capacity a firm expects to achieve given the current operating constraints. Effective capacity is often lower than design capacity.

Figure 3.1 The Structuring Of the Supplier Selection Problem



Production planning: Lead-time includes inventory management, inventory level of raw materials, work in process and finished goods, production planning, scheduling, and just in time.

Storage and Packaging: It includes the effectiveness of the transportation, storage, and packaging function.

Up to Date Techniques and Equipment: It involves the technological compatibility, manufacturing infrastructure resources, etc.

Product Development: Product development includes market research, product and market testing, new product development, business analysis, etc.

Reputation: It refers to the reputation brand of the supplier.

Location: It refers to the location of the supplier's firm.

Price: The price of the product.

Patent: The patent right of the product, which is supplied by the supplier.

Technical Capability: It includes Project management skill and value management concepts.

Electronic Data Interchange and internet: It refers to the capability of direct electronic transmission of data and standard business forms between a buying firm and its suppliers. It includes internet, extranet, and intranet functions of the suppliers (Zaim S., Şevkli M., Tarim M., (2003), "Fuzzy Analytic Hierarchy Based Approach for Supplier ",7. page).

3.3. How did we calculate the weights of the suppliers?

We used the AHP (Analytic Hierarchy Process) system to calculate the score of the each factor. Each company or supplier is compared according to AHP system methodology. We need table that will include all scores of companies or suppliers. To prepare this table we should calculate and brief the results of comparisons. First of all we explained AHP methodology. Then, all the scores is presented in the tables below.

3.3.1. Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) provides the objective mathematics to process the inescapably subjective and personal preferences of an individual or a group in making a decision. With the AHP, the Analytic Network Process (ANP), one constructs hierarchies or feedback networks, then makes judgments or performs measurements on pairs of elements with respect to a controlling element to select the best alternative.

In fact, the AHP works by developing priorities for alternatives and the criteria used to judge the alternatives. Usually the criteria, whose choice is at the mercy of the understanding of the decision-maker (irrelevant criteria are those that are not included in the hierarchy), are measured on different scales, such as weight and length, or are even intangible for which no scales yet exist. Measurements on different scales, of course, cannot be directly combined. First, priorities are derived for the criteria in terms of their importance to achieve the goal, and then priorities are derived for the performance of the alternatives on each criterion. These priorities are derived based on pair wise assessments using judgment or ratios of measurements from a scale if one exists. The process of prioritization solves the problem of having to deal with different types of scales, by interpreting their significance to the values of the user or users.

Finally, a weighting and adding process is used to obtain overall priorities for the alternatives as to how they realize to the goal. This weighting and adding parallels what one would have done arithmetically prior to the AHP to combine alternatives measured under several criteria having the *same* scale (a scale that is often common to several criteria is money) to obtain an overall result. With the AHP a multidimensional scaling problem is thus transformed to a one-dimensional scaling problem.

AHP has the seven pillars. Those are very important to understand AHP methodology. We explained pillars of AHP in the below (Thomas L. Saaty, "The Seven Pillars of the Analytic Hierarchy Process", Mervis Hall University of Pittsburgh):

1) **Ratio scales, proportionality, and normalized ratio scales** are central to the generation and synthesis of priorities, whether in the AHP or in any multi-criteria method that needs to integrate existing ratio scale measurements with its own derived scales.

2) **Reciprocal paired comparisons** are used to express judgments semantically automatically linking them to a numerical fundamental scale of absolute numbers (derived from stimulus- response relations) from which the principal eigenvector of priorities is then derived, the eigenvector shows the dominance of each element with respect to the other elements, an element that does not have a particular property is automatically assigned the value zero in the eigenvector without including it in the comparisons.

3) **Sensitivity of the principal right eigenvector** to perturbation in judgments limits the number of elements in each set of comparisons to a few and requires that they be homogeneous, the left eigenvector is only meaningful as reciprocal; due to the choice of a unit as one of the two elements in each paired comparison to determine the relative dominance of the second element, it is not possible to derive the principal left eigenvector directly from paired comparisons as the dominant element cannot be decomposed a priori , as a result, to ask for how much less one element is than another we must take the reciprocal of what we get by asking how much more the larger element is.

4) **Homogeneity and clustering** are used to extend the fundamental scale gradually from cluster to adjacent cluster, eventually enlarging the scale from 1-9 to 1-_.

5) **Synthesis that can be extended to dependence and feedback** is applied to the derived ratio scales to create a one-dimensional ratio scale for representing the overall outcome. Synthesis of the scales derived in the decision structure can only be made to yield correct outcomes on known scales by additive weighting.

6) **Rank preservation and reversal** can be shown to occur without adding or deleting criteria, such as by simply introducing enough copies of an alternative or for numerous other reasons, this leaves no doubt that rank reversal is as intrinsic to decision making as rank preservation also is. It follows that any decision theory must have at least two modes of synthesis, in the AHP they are called the distributive and ideal modes, with guidelines for which mode to use, rank can always be preserved by using the ideal mode in both absolute measurement and relative measurement.

7) **Group judgments** must be integrated one at a time carefully and mathematically, taking into consideration when desired the experience, knowledge, and power of each person involved in the decision, without the need to force consensus, or to use majority or other ordinal ways of voting, the theorem regarding the impossibility of constructing a social utility function from individual utilities that satisfies four reasonable conditions which found their validity with ordinal preferences is *no longer true* when cardinal ratio scale preferences are used as in the AHP. Instead, one has the possibility of constructing such a function. To deal with a large group requires the use of questionnaires and statistical procedures for large samples.

3.3.2. The Calculation of the Suppliers' Scores

We used AHP to calculate the suppliers' scores. All calculation system is presented in below. We explained that how we found the suppliers' scores for each factor.

We created a table to compare suppliers' ability according to AHP. First, we put the names of suppliers horizontal and vertical position, after that, compared each other at the same factor. And then we added each column values. We obtained a row that there are values of each supplier. The next step is 1/ column sum. And then, we created a new table that there are three values for each supplier. The last one is to calculate average of the three values. After this calculation, we obtained a new column that there are the last scores of the suppliers in there.

The calculation system is presented after the calculations as a formulation.

Table 3.1 Shipping Procedure calculation for suppliers

Shipping Procedure

Supplier	A	B	C
A	1	3	5
B	1/3	1	3
C	1/5	1/3	1
Column sm:	**1.533**	**4.333**	**9.000**

Supplier	A	B	C	*Row Averages*
A	0.6522	0.6923	0.5556	0.6333
B	0.2174	0.2308	0.3333	0.2605
C	0.1304	0.0769	0.1111	0.1062
				1.0000

For shipping procedure factor, the best supplier is A. Because, it has the highest value.

Table 3.2 Delivery calculation for suppliers

Delivery

Supplier	A	B	C
A	1	1/5	1/6
B	5	1	1/2
C	6	2	1
Column sum:	**12.000**	**3.2000**	**1.6667**

Supplier	A	B	C	*Row Averages*
A	0.0833	0.0625	0.1000	0.0819
B	0.4167	0.3125	0.3000	0.3431
C	0.5000	0.6250	0.6000	0.5750
				1.0000

For delivery factor, the best supplier is C. Because, it has the highest value.

Table 3.3 Cost calculation for suppliers

Cost

Supplier	A	B	C
A	1	1/3	1/6
B	3	1	1/2
C	6	2	1
Column sum:	**10.000**	**3.3333**	**1.6667**

Supplier	A	B	C	*Row Averages*
A	0.1000	0.1000	0.1000	0.1000
B	0.3000	0.3000	0.3000	0.3000
C	0.6000	0.6000	0.6000	0.6000
				1.0000

For cost factor, the best supplier is C. Because, it has the highest value.

Table 3.4 Number of Emplyees calculation for suppliers

Number of Emplyees

Supplier	A	B	C
A	1	1/3	1/5
B	3	1	1/2
C	5	2	1
Column sum:	**9.0000**	**3.3333**	**1.7000**

Supplier	A	B	C	*Row Averages*
A	0.1111	0.1000	0.1176	0.1096
B	0.3333	0.3000	0.2941	0.3092
C	0.5556	0.6000	0.5882	0.5813
				1.0000

For number of emplyees factor, the best supplier is C. Because, it has the highest value.

Table 3.5 Organizational Structure calculation for suppliers

Organizational Structure

Supplier	A	B	C
A	1	4	6
B	1/4	1	3
C	1/6	1/3	1
Column sum:	1.4167	5.3333	10.000

Supplier	A	B	C	*Row Averages*
A	0.7059	0.7500	0.6000	0.6853
B	0.1765	0.1875	0.3000	0.2213
C	0.1176	0.0625	0.1000	0.0934
				1.0000

For organizational structure factor, the best supplier is A. Because, it has the highest value.

Table 3.6 Number of technical staff calculation for suppliers

Number of technical staff

Supplier	A	B	C
A	1	1/3	2
B	3	1	5
C	1/2	1/5	1
Column sum:	4.5000	1.5333	8.0000

Supplier	A	B	C	*Row Averages*
A	0.2222	0.2174	0.2500	0.2299
B	0.6667	0.6522	0.6250	0.6479
C	0.1111	0.1304	0.1250	0.1222
				1.0000

For number of technical staff factor, the best supplier is B. Because, it has the highest value.

Table 3.7 Management Commitment calculation for suppliers

Mang. Commitment

Supplier	A	B	C
A	1	4	5
B	1/4	1	3
C	1/5	1/3	1
Column sum:	**1.4500**	**5.3333**	**9.0000**

Supplier	A	B	C	*Row Averages*
A	0.6897	0.7500	0.5556	0.6651
B	0.1724	0.1875	0.3333	0.2311
C	0.1379	0.0625	0.1111	0.1038
				1.0000

For management commitment factor, the best supplier is A. Because, it has the highest value.

Table 3.8 Inspection and Control calculation for suppliers

Inspection and Control

Supplier	A	B	C
A	1	5	7
B	1/5	1	3
C	1/7	1/3	1
Column sum:	**1.3429**	**6.3333**	**11.000**

Supplier	A	B	C	*Row Averages*
A	0.7447	0.7895	0.6364	0.7235
B	0.1489	0.1579	0.2727	0.1932
C	0.1064	0.0526	0.0909	0.0833
				1.0000

For inspection and control factor, the best supplier is C. Because, it has the highest value.

Table 3.9 Quality Planning calculation for suppliers

Quality Planning

Supplier	A	B	C
A	1	7	9
B	1/7	1	2
C	1/9	1/2	1
Column sum:	1.2540	8.5000	12.000

Supplier	A	B	C	*Row Averages*
A	0.7975	0.8235	0.7500	0.7903
B	0.1139	0.1176	0.1667	0.1327
C	0.0886	0.0588	0.0833	0.0769
				1.0000

For quality planning factor, the best supplier is A. Because, it has the highest value.

Table 3.10 Production Capacity calculation for suppliers

Production Capacity

Supplier	A	B	C
A	1	1/5	1/4
B	5	1	3
C	4	1/3	1
Column sum:	10.000	1.5333	4.2500

Supplier	A	B	C	*Row Averages*
A	0.1000	0.1304	0.0588	0.0964
B	0.5000	0.6522	0.7059	0.6194
C	0.4000	0.2174	0.2353	0.2842
				1.0000

For production capacity factor, the best supplier is B. Because, it has the highest value.

Table 3.11 Production Planning calculation for suppliers

Production planning

Supplier	**A**	**B**	**C**
A	1	2	1/4
B	1/2	1	1/5
C	4	5	1
Column sum:	**5.5000**	**8.0000**	**1.4500**

Supplier	**A**	**B**	**C**	***Row Averages***
A	0.1818	0.2500	0.1724	0.2014
B	0.0909	0.1250	0.1379	0.1179
C	0.7273	0.6250	0.6897	0.6806
				1.0000

For production planning factor, the best supplier is C. Because, it has the highest value.

Table 3.12 Up to Date calculation for suppliers

Up to date

Supplier	**A**	**B**	**C**
A	1	1	4
B	1	1	4
C	1/4	1/4	1
Column sum:	**2.2500**	**2.2500**	**9.0000**

Supplier	**A**	**B**	**C**	***Row Averages***
A	0.4444	0.4444	0.4444	0.4444
B	0.4444	0.4444	0.4444	0.4444
C	0.1111	0.1111	0.1111	0.1111
				1.0000

For up to date factor, the best suppliers are A and B . Because, they have the highest value.

Table 3.13 Storage calculation for suppliers

Storage

Supplier	A	B	C
A	1	3	1/3
B	1/3	1	1/4
C	3	4	1
Column sum:	**4.3333**	**8.0000**	**1.5833**

Supplier	A	B	C	*Row Averages*
A	0.2308	0.3750	0.2105	0.2721
B	0.0769	0.1250	0.1579	0.1199
C	0.6923	0.5000	0.6316	0.6080
				1.0000

For storage factor, the best supplier is C. Because, it has the highest value.

Table 3.14 Development calculation for suppliers

Development

Supplier	A	B	C
A	1	1/3	6
B	3	1	8
C	1/6	1/8	1
Column sum:	**4.1667**	**1.4583**	**15.0000**

Supplier	A	B	C	*Row Averages*
A	0.2400	0.2286	0.4000	0.2895
B	0.7200	0.6857	0.5333	0.6463
C	0.0400	0.0857	0.0667	0.0641
				1.0000

For development factor, the best supplier is B. Because, it has the highest value.

Table 3.15 Reputation calculation for suppliers

Reputation

Supplier	A	B	C
A	1	3	8
B	1/3	1	6
C	1/8	1/6	1
Column sum:	**1.4583**	**4.1667**	**15.000**

Supplier	A	B	C	*Row Averages*
A	0.6857	0.7200	0.5333	0.6463
B	0.2286	0.2400	0.4000	0.2895
C	0.0857	0.0400	0.0667	0.0641
				1.0000

For reputation factor, the best supplier is A. Because, it has the highest value.

Table 3.16 Location calculation for suppliers

Location

Supplier	A	B	C
A	1	4	5
B	1/4	1	3
C	1/5	1/3	1
Column sum:	**1.4500**	**5.3333**	**9.0000**

Supplier	A	B	C	*Row Averages*
A	0.6897	0.7500	0.5556	0.6651
B	0.1724	0.1875	0.3333	0.2311
C	0.1379	0.0625	0.1111	0.1038
				1.0000

For location factor, the best supplier is A. Because, it has the highest value.

Table 3.17 Price calculation for suppliers

Price

Supplier	A	B	C
A	1	1/3	1/4
B	3	1	1/3
C	4	3	1
Column sum:	**8.0000**	**4.3333**	**1.5833**

Supplier	A	B	C	*Row Averages*
A	0.1250	0.0769	0.1579	0.1199
B	0.3750	0.2308	0.2105	0.2721
C	0.5000	0.6923	0.6316	0.6080
				1.0000

For price factor, the best supplier is C. Because, it has the highest value.

Table 3.18 Patent calculation for suppliers

Patent

Supplier	A	B	C
A	1	1	1
B	1	1	1
C	1	1	1
Column sum:	**3.0000**	**3.0000**	**3.0000**

Supplier	A	B	C	*Row Averages*
A	0.3333	0.3333	0.3333	0.3333
B	0.3333	0.3333	0.3333	0.3333
C	0.3333	0.3333	0.3333	0.3333
				1.0000

For patent factor, all the suppliers are same. Because, all of them have same value.

Table 3.19 Techinical Capacity calculation for suppliers

Technical Capacity

Supplier	A	B	C
A	1	1/4	5
B	4	1	9
C	1/5	1/9	1
Column sum:	**5.2000**	**1.3611**	**15.000**

Supplier	A	B	C	*Row Averages*
A	0.1923	0.1837	0.3333	0.2364
B	0.7692	0.7347	0.6000	0.7013
C	0.0385	0.0816	0.0667	0.0623
				1.0000

For technical capacity factor, the best supplier is B. Because, it has the highest value.

Table 3.20 Online calculation for suppliers

Online

Supplier	A	B	C
A	1	1	3
B	1	1	3
C	1/3	1/3	1
Column sum:	**2.3333**	**2.3333**	**7.0000**

Supplier	A	B	C	*Row Averages*
A	0.4286	0.4286	0.4286	0.4286
B	0.4286	0.4286	0.4286	0.4286
C	0.1429	0.1429	0.1429	0.1429
				1.0000

For online factor, the best suppliers are A and B. Because, They have the highest value.

3.4. How did we compute the overall score of each supplier?

We compared all suppliers for the buyer about factors. How much more preferred is which supplier than the other supplier in determining the best supplier? Afterthat, we calculated last scores in the tables. In the gray boxes, we wrote the row averages. The formülation is :

Last score (row averages) = [(A value / column sum.)+(B value / column sum.)+(C value / column sum.)] / 3

We brief all the last scores in the same table below:

Table 3.21 The weighted of all suppliers according to factors

	Shipping Procedure	Delivery	Cost	Number of Employees	Org. Structure
A	0.6333	0.0819	0.1000	0.1096	0.6853
B	0.2605	0.3431	0.3000	0.3092	0.2213
C	0.1062	0.5750	0.6000	0.5813	0.0934
	Production Cap.	Number of Tech. Staff	Manag. Com	Inspection and Control	Quality Planning
A	0.0964	0.2299	0.6651	0.7235	0.7903
B	0.6194	0.6479	0.2311	0.1932	0.1327
C	0.2842	0.1222	0.1038	0.0833	0.0769
	Patent	Tech Cap.	Online	Production Planning	Up to Date
A	0.3333	0.2364	0.4286	0.2014	0.4444
B	0.3333	0.7013	0.4286	0.1179	0.4444
C	0.3333	0.0623	0.1429	0.6806	0.1111
	Storage	Development	Reputation	Location	Price
A	0.2721	0.2895	0.6463	0.6651	0.1199
B	0.1199	0.6463	0.2895	0.2311	0.2721
C	0.6080	0.0641	0.0641	0.1038	0.6080

We needed last scores of the suppliers' factors to decide what the best supplier is. To obtain this table, we used the AHP system methodology. And now, we will use DEA system to choose the best supplier for Buyer Company.

3.5. How did we solve the model with DEA approach?

First of all, we used outputs and inputs to build the model with DEA about this problem. It is rule of DEA. We decided outputs and inputs of the problem. When we decide outputs, we consider some acceptances. Those are:

- We observed a stable relationship between capacity and usage of capacity. In fact, we don't have data about capacity directly. But, we have data about production planning, number of employees, technologic capacity, storage, number of technical staff. When we accept that capacity is one of the outputs, all data is considered. As a result, all data show informations of capacity of the company. Therefore, we decided that capacity is one of the outputs.

- We considered that quality planning provides to achieve quality aims. In fact, we don't have data about quality directly. But, we have data about organizational structure, technologic capacity, up to date, development, inspection and control, management commitment. When we accept that quality is one of the outputs, all data is considered. As a result, all data show informations of quality of the company. Therefore, we accepted that quality is one of the outputs.

We measured the supplier companies according to inputs and outputs. Outputs and inputs are;

Inputs of the problem;

- Shipping procedure
- Organizational structure
- Cost
- Number of Employees

- Price
- Patent
- Technologic Capacity
- Online
- Production Planning
- Up to Date
- Storage
- Development
- Location
- Number of Technical Staff
- Inspection and Control
- Management Commitment

Outputs of the problem;

- Reputation
- Production Capacity
- Quality

We obtained the all scores of the supplier according to each factor. Then, we built the model with all the scores, and then we solved this model with LINDO solver program to know which company's cost is minimum. Each input was used to build the model, and we considered all suppliers' score. We presented all objective functions and solutions in the below.

When we built the objective function for solution, we used some variables. All variables' meaning is like below:

T: Objective function (Minimum Cost)
Y1: Output-1
Y2: Output-2
Y3: Output-3

Production Capacity
For supplier A

Objective function;

```
MIN     T
 SUBJECT TO
      1)  0.0964 Y1 + 0.6194 Y2 + 0.2842 Y3 >= 0.0964
      2)  0.6333 T - 0.6333 Y1 - 0.2605 Y2 - 0.1062 Y3 >=0
      3)  0.0819 T - 0.0819 Y1 - 0.3431 Y2 - 0.5750 Y3 >=0
      4)  0.1000 T - 0.1000 Y1 - 0.3000 Y2 - 0.6000 Y3 >=0
      5)  0.1096 T - 0.1096 Y1 - 0.3092 Y2 - 0.5813 Y3 >=0
      6)  0.6853 T - 0.6853 Y1 - 0.2213 Y2 - 0.0934 Y3 >=0
      7)  0.2299 T - 0.2299 Y1 - 0.6479 Y2 - 0.1222 Y3 >=0
      8)  0.6651 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
      9)  0.7235 T - 0.7235 Y1 - 0.1932 Y2 - 0.0833 Y3 >=0
     10)  0.3333 T - 0.3333 Y1 - 0.3333 Y2 - 0.3333 Y3 >=0
     11)  0.2364 T - 0.2364 Y1 - 0.7013 Y2 - 0.0623 Y3 >=0
     12)  0.4286 T - 0.4286 Y1 - 0.4286 Y2 - 0.1429 Y3 >=0
     13)  0.2014 T - 0.2014 Y1 - 0.1179 Y2 - 0.6806 Y3 >=0
     14)  0.4444 T - 0.4444 Y1 - 0.4444 Y2 - 0.1111 Y3 >=0
     15)  0.2721 T - 0.2721 Y1 - 0.1199 Y2 - 0.6080 Y3 >=0
     16)  0.2895 T - 0.2895 Y1 - 0.6463 Y2 - 0.0641 Y3 >=0
     17)  0.6651 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
     18)  0.1199 T - 0.1199 Y1 - 0.2721 Y2 - 0.6080 Y3 >=0
     19)  Y1 >= 0.0001
     20)  Y2 >= 0.0001
     21)  Y3 >= 0.0001
     22)   T >= 0.0001
 END
```

Solution:
OBJECTIVE FUNCTION VALUE = 0.6525372

VARIABLE	VALUE
T	0.652537
Y1	0.000100
Y2	0.155573
Y3	0.000100

Production Capacity
For supplier B

Objective function;

```
MIN     T
 SUBJECT TO
       1)  0.0964 Y1 + 0.6194 Y2 + 0.2842 Y3 >= 0.6194
       2)  0.2605 T - 0.6333 Y1 - 0.2605 Y2 - 0.1062 Y3 >=0
       3)  0.3431 T - 0.0819 Y1 - 0.3431 Y2 - 0.5750 Y3 >=0
       4)  0.3000 T - 0.1000 Y1 - 0.3000 Y2 - 0.6000 Y3 >=0
       5)  0.3092 T - 0.1096 Y1 - 0.3092 Y2 - 0.5813 Y3 >=0
       6)  0.2213 T - 0.6853 Y1 - 0.2213 Y2 - 0.0934 Y3 >=0
       7)  0.6479 T - 0.2299 Y1 - 0.6479 Y2 - 0.1222 Y3 >=0
       8)  0.2311 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
       9)  0.1932 T - 0.7235 Y1 - 0.1932 Y2 - 0.0833 Y3 >=0
      10)  0.3333 T - 0.3333 Y1 - 0.3333 Y2 - 0.3333 Y3 >=0
      11)  0.7013 T - 0.2364 Y1 - 0.7013 Y2 - 0.0623 Y3 >=0
      12)  0.4286 T - 0.4286 Y1 - 0.4286 Y2 - 0.1429 Y3 >=0
      13)  0.1179 T - 0.2014 Y1 - 0.1179 Y2 - 0.6806 Y3 >=0
      14)  0.4444 T - 0.4444 Y1 - 0.4444 Y2 - 0.1111 Y3 >=0
      15)  0.1199 T - 0.2721 Y1 - 0.1199 Y2 - 0.6080 Y3 >=0
      16)  0.6463 T - 0.2895 Y1 - 0.6463 Y2 - 0.0641 Y3 >=0
      17)  0.2311 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
      18)  0.2721 T - 0.1199 Y1 - 0.2721 Y2 - 0.6080 Y3 >=0
      19)  Y1 >= 0.0001
      20)  Y2 >= 0.0001
      21)  Y3 >= 0.0001
      22)  T >= 0.0001
 END
```

Solution:
OBJECTIVE FUNCTION VALUE = 1.000687

VARIABLE	VALUE
T	1.000687
Y1	0.000100
Y2	0.999939
Y3	0.000100

Production Capacity
For supplier C

Objective function;

MIN T
SUBJECT TO
1) 0.0964 Y1 + 0.6194 Y2 + 0.2842 Y3 >= 0.2842
2) 0.1062 T - 0.6333 Y1 - 0.2605 Y2 - 0.1062 Y3 >=0
3) 0.5750 T - 0.0819 Y1 - 0.3431 Y2 - 0.5750 Y3 >=0
4) 0.6000 T - 0.1000 Y1 - 0.3000 Y2 - 0.6000 Y3 >=0
5) 0.5813 T - 0.1096 Y1 - 0.3092 Y2 - 0.5813 Y3 >=0
6) 0.0934 T - 0.6853 Y1 - 0.2213 Y2 - 0.0934 Y3 >=0
7) 0.1222 T - 0.2299 Y1 - 0.6479 Y2 - 0.1222 Y3 >=0
8) 0.1038 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
9) 0.0833 T - 0.7235 Y1 - 0.1932 Y2 - 0.0833 Y3 >=0
10) 0.3333 T - 0.3333 Y1 - 0.3333 Y2 - 0.3333 Y3 >=0
11) 0.0623 T - 0.2364 Y1 - 0.7013 Y2 - 0.0623 Y3 >=0
12) 0.1429 T - 0.4286 Y1 - 0.4286 Y2 - 0.1429 Y3 >=0
13) 0.6806 T - 0.2014 Y1 - 0.1179 Y2 - 0.6806 Y3 >=0
14) 0.1111 T - 0.4444 Y1 - 0.4444 Y2 - 0.1111 Y3 >=0
15) 0.6080 T - 0.2721 Y1 - 0.1199 Y2 - 0.6080 Y3 >=0
16) 0.0641 T - 0.2895 Y1 - 0.6463 Y2 - 0.0641 Y3 >=0
17) 0.1038 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
18) 0.6080 T - 0.1199 Y1 - 0.2721 Y2 - 0.6080 Y3 >=0
19) Y1 >= 0.0001
20) Y2 >= 0.0001
21) Y3 >= 0.0001
22) T >= 0.0001

END

Solution:
OBJECTIVE FUNCTION VALUE = 1.001253

VARIABLE	VALUE
T	1.001253
Y1	0.000100
Y2	0.000100
Y3	0.999748

Quality
For supplier A

Objective function;

MIN T
SUBJECT TO
1) 0.7903 Y1 + 0.1327 Y2 + 0.0769 Y3 >= 0.7903
2) 0.6333 T - 0.6333 Y1 - 0.2605 Y2 - 0.1062 Y3 >=0
3) 0.0819 T - 0.0819 Y1 - 0.3431 Y2 - 0.5750 Y3 >=0
4) 0.1000 T - 0.1000 Y1 - 0.3000 Y2 - 0.6000 Y3 >=0
5) 0.1096 T - 0.1096 Y1 - 0.3092 Y2 - 0.5813 Y3 >=0
6) 0.6853 T - 0.6853 Y1 - 0.2213 Y2 - 0.0934 Y3 >=0
7) 0.2299 T - 0.2299 Y1 - 0.6479 Y2 - 0.1222 Y3 >=0
8) 0.6651 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
9) 0.7235 T - 0.7235 Y1 - 0.1932 Y2 - 0.0833 Y3 >=0
10) 0.3333 T - 0.3333 Y1 - 0.3333 Y2 - 0.3333 Y3 >=0
11) 0.2364 T - 0.2364 Y1 - 0.7013 Y2 - 0.0623 Y3 >=0
12) 0.4286 T - 0.4286 Y1 - 0.4286 Y2 - 0.1429 Y3 >=0
13) 0.2014 T - 0.2014 Y1 - 0.1179 Y2 - 0.6806 Y3 >=0
14) 0.4444 T - 0.4444 Y1 - 0.4444 Y2 - 0.1111 Y3 >=0
15) 0.2721 T - 0.2721 Y1 - 0.1199 Y2 - 0.6080 Y3 >=0
16) 0.2895 T - 0.2895 Y1 - 0.6463 Y2 - 0.0641 Y3 >=0
17) 0.6651 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
18) 0.1199 T - 0.1199 Y1 - 0.2721 Y2 - 0.6080 Y3 >=0
19) Y1 >= 0.0001
20) Y2 >= 0.0001
21) Y3 >= 0.0001
22) T >= 0.0001

END

Solution:
OBJECTIVE FUNCTION VALUE = 1.001094

VARIABLE	VALUE
T	1.001094
Y1	0.999973
Y2	0.000100
Y3	0.000100

Quality
For supplier B

Objective function;

```
MIN     T
 SUBJECT TO
      1)  0.7903 Y1 + 0.1327 Y2 + 0.0769 Y3 >= 0.1327
      2)  0.2605 T - 0.6333 Y1 - 0.2605 Y2 - 0.1062 Y3 >=0
      3)  0.3431 T - 0.0819 Y1 - 0.3431 Y2 - 0.5750 Y3 >=0
      4)  0.3000 T - 0.1000 Y1 - 0.3000 Y2 - 0.6000 Y3 >=0
      5)  0.3092 T - 0.1096 Y1 - 0.3092 Y2 - 0.5813 Y3 >=0
      6)  0.2213 T - 0.6853 Y1 - 0.2213 Y2 - 0.0934 Y3 >=0
      7)  0.6479 T - 0.2299 Y1 - 0.6479 Y2 - 0.1222 Y3 >=0
      8)  0.2311 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
      9)  0.1932 T - 0.7235 Y1 - 0.1932 Y2 - 0.0833 Y3 >=0
     10)  0.3333 T - 0.3333 Y1 - 0.3333 Y2 - 0.3333 Y3 >=0
     11)  0.7013 T - 0.2364 Y1 - 0.7013 Y2 - 0.0623 Y3 >=0
     12)  0.4286 T - 0.4286 Y1 - 0.4286 Y2 - 0.1429 Y3 >=0
     13)  0.1179 T - 0.2014 Y1 - 0.1179 Y2 - 0.6806 Y3 >=0
     14)  0.4444 T - 0.4444 Y1 - 0.4444 Y2 - 0.1111 Y3 >=0
     15)  0.1199 T - 0.2721 Y1 - 0.1199 Y2 - 0.6080 Y3 >=0
     16)  0.6463 T - 0.2895 Y1 - 0.6463 Y2 - 0.0641 Y3 >=0
     17)  0.2311 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
     18)  0.2721 T - 0.1199 Y1 - 0.2721 Y2 - 0.6080 Y3 >=0
     19)  Y1 >= 0.0001
     20)  Y2 >= 0.0001
     21)  Y3 >= 0.0001
     22)   T >= 0.0001

 END
```

Solution: OBJECTIVE FUNCTION VALUE = 0.6288406

VARIABLE	VALUE
T	0.628841
Y1	0.167884
Y2	0.000100
Y3	0.000100

Quality
For supplier C

Objective function;

MIN T
SUBJECT TO
1) 0.7903 Y1 + 0.1327 Y2 + 0.0769 Y3 >= 0.0769
2) 0.1062 T - 0.6333 Y1 - 0.2605 Y2 - 0.1062 Y3 >=0
3) 0.5750 T - 0.0819 Y1 - 0.3431 Y2 - 0.5750 Y3 >=0
4) 0.6000 T - 0.1000 Y1 - 0.3000 Y2 - 0.6000 Y3 >=0
5) 0.5813 T - 0.1096 Y1 - 0.3092 Y2 - 0.5813 Y3 >=0
6) 0.0934 T - 0.6853 Y1 - 0.2213 Y2 - 0.0934 Y3 >=0
7) 0.1222 T - 0.2299 Y1 - 0.6479 Y2 - 0.1222 Y3 >=0
8) 0.1038 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
9) 0.0833 T - 0.7235 Y1 - 0.1932 Y2 - 0.0833 Y3 >=0
10) 0.3333 T - 0.3333 Y1 - 0.3333 Y2 - 0.3333 Y3 >=0
11) 0.0623 T - 0.2364 Y1 - 0.7013 Y2 - 0.0623 Y3 >=0
12) 0.1429 T - 0.4286 Y1 - 0.4286 Y2 - 0.1429 Y3 >=0
13) 0.6806 T - 0.2014 Y1 - 0.1179 Y2 - 0.6806 Y3 >=0
14) 0.1111 T - 0.4444 Y1 - 0.4444 Y2 - 0.1111 Y3 >=0
15) 0.6080 T - 0.2721 Y1 - 0.1199 Y2 - 0.6080 Y3 >=0
16) 0.0641 T - 0.2895 Y1 - 0.6463 Y2 - 0.0641 Y3 >=0
17) 0.1038 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
18) 0.6080 T - 0.1199 Y1 - 0.2721 Y2 - 0.6080 Y3 >=0
19) Y1 >= 0.0001
20) Y2 >= 0.0001
21) Y3 >= 0.0001
22) T >= 0.0001

END

Solution: OBJECTIVE FUNCTION VALUE = 0.8452401

VARIABLE	VALUE
T	0.845240
Y1	0.097278
Y2	0.000100
Y3	0.000100

Reputation
For supplier A

Objective function;

MIN T
SUBJECT TO
1) 0.6463 Y1 + 0.2895 Y2 + 0.0641 Y3 >= 0.6463
2) 0.6333 T - 0.6333 Y1 - 0.2605 Y2 - 0.1062 Y3 >=0
3) 0.0819 T - 0.0819 Y1 - 0.3431 Y2 - 0.5750 Y3 >=0
4) 0.1000 T - 0.1000 Y1 - 0.3000 Y2 - 0.6000 Y3 >=0
5) 0.1096 T - 0.1096 Y1 - 0.3092 Y2 - 0.5813 Y3 >=0
6) 0.6853 T - 0.6853 Y1 - 0.2213 Y2 - 0.0934 Y3 >=0
7) 0.2299 T - 0.2299 Y1 - 0.6479 Y2 - 0.1222 Y3 >=0
8) 0.6651 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
9) 0.7235 T - 0.7235 Y1 - 0.1932 Y2 - 0.0833 Y3 >=0
10) 0.3333 T - 0.3333 Y1 - 0.3333 Y2 - 0.3333 Y3 >=0
11) 0.2364 T - 0.2364 Y1 - 0.7013 Y2 - 0.0623 Y3 >=0
12) 0.4286 T - 0.4286 Y1 - 0.4286 Y2 - 0.1429 Y3 >=0
13) 0.2014 T - 0.2014 Y1 - 0.1179 Y2 - 0.6806 Y3 >=0
14) 0.4444 T - 0.4444 Y1 - 0.4444 Y2 - 0.1111 Y3 >=0
15) 0.2721 T - 0.2721 Y1 - 0.1199 Y2 - 0.6080 Y3 >=0
16) 0.2895 T - 0.2895 Y1 - 0.6463 Y2 - 0.0641 Y3 >=0
17) 0.6651 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
18) 0.1199 T - 0.1199 Y1 - 0.2721 Y2 - 0.6080 Y3 >=0
19) Y1 >= 0.0001
20) Y2 >= 0.0001
21) Y3 >= 0.0001
22) T >= 0.0001

END

Solution: OBJECTIVE FUNCTION VALUE = 1.001066

VARIABLE	VALUE
T	1.001066
Y1	0.999945
Y2	0.000100
Y3	0.000100

Reputation
For supplier B

Objective function;

MIN T
SUBJECT TO
1) 0.6463 Y1 + 0.2895 Y2 + 0.0641 Y3 >= 0.2895
2) 0.2605 T - 0.6333 Y1 - 0.2605 Y2 - 0.1062 Y3 >=0
3) 0.3431 T - 0.0819 Y1 - 0.3431 Y2 - 0.5750 Y3 >=0
4) 0.3000 T - 0.1000 Y1 - 0.3000 Y2 - 0.6000 Y3 >=0
5) 0.3092 T - 0.1096 Y1 - 0.3092 Y2 - 0.5813 Y3 >=0
6) 0.2213 T - 0.6853 Y1 - 0.2213 Y2 - 0.0934 Y3 >=0
7) 0.6479 T - 0.2299 Y1 - 0.6479 Y2 - 0.1222 Y3 >=0
8) 0.2311 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
9) 0.1932 T - 0.7235 Y1 - 0.1932 Y2 - 0.0833 Y3 >=0
10) 0.3333 T - 0.3333 Y1 - 0.3333 Y2 - 0.3333 Y3 >=0
11) 0.7013 T - 0.2364 Y1 - 0.7013 Y2 - 0.0623 Y3 >=0
12) 0.4286 T - 0.4286 Y1 - 0.4286 Y2 - 0.1429 Y3 >=0
13) 0.1179 T - 0.2014 Y1 - 0.1179 Y2 - 0.6806 Y3 >=0
14) 0.4444 T - 0.4444 Y1 - 0.4444 Y2 - 0.1111 Y3 >=0
15) 0.1199 T - 0.2721 Y1 - 0.1199 Y2 - 0.6080 Y3 >=0
16) 0.6463 T - 0.2895 Y1 - 0.6463 Y2 - 0.0641 Y3 >=0
17) 0.2311 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
18) 0.2721 T - 0.1199 Y1 - 0.2721 Y2 - 0.6080 Y3 >=0
19) Y1 >= 0.0001
20) Y2 >= 0.0001
21) Y3 >= 0.0001
22) T >= 0.0001

END

Solution: OBJECTIVE FUNCTION VALUE = 1.000418

VARIABLE	VALUE
T	1.000418
Y1	0.000262
Y2	0.999392
Y3	0.000100

Reputation
For supplier C

Objective function;

MIN T
SUBJECT TO
1) 0.6463 Y1 + 0.2895 Y2 + 0.0641 Y3 >= 0.0641
2) 0.1062 T - 0.6333 Y1 - 0.2605 Y2 - 0.1062 Y3 >=0
3) 0.5750 T - 0.0819 Y1 - 0.3431 Y2 - 0.5750 Y3 >=0
4) 0.6000 T - 0.1000 Y1 - 0.3000 Y2 - 0.6000 Y3 >=0
5) 0.5813 T - 0.1096 Y1 - 0.3092 Y2 - 0.5813 Y3 >=0
6) 0.0934 T - 0.6853 Y1 - 0.2213 Y2 - 0.0934 Y3 >=0
7) 0.1222 T - 0.2299 Y1 - 0.6479 Y2 - 0.1222 Y3 >=0
8) 0.1038 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
9) 0.0833 T - 0.7235 Y1 - 0.1932 Y2 - 0.0833 Y3 >=0
10) 0.3333 T - 0.3333 Y1 - 0.3333 Y2 - 0.3333 Y3 >=0
11) 0.0623 T - 0.2364 Y1 - 0.7013 Y2 - 0.0623 Y3 >=0
12) 0.1429 T - 0.4286 Y1 - 0.4286 Y2 - 0.1429 Y3 >=0
13) 0.6806 T - 0.2014 Y1 - 0.1179 Y2 - 0.6806 Y3 >=0
14) 0.1111 T - 0.4444 Y1 - 0.4444 Y2 - 0.1111 Y3 >=0
15) 0.6080 T - 0.2721 Y1 - 0.1199 Y2 - 0.6080 Y3 >=0
16) 0.0641 T - 0.2895 Y1 - 0.6463 Y2 - 0.0641 Y3 >=0
17) 0.1038 T - 0.6651 Y1 - 0.2311 Y2 - 0.1038 Y3 >=0
18) 0.6080 T - 0.1199 Y1 - 0.2721 Y2 - 0.6080 Y3 >=0
19) Y1 >= 0.0001
20) Y2 >= 0.0001
21) Y3 >= 0.0001
22) T >= 0.0001

END

Solution: OBJECTIVE FUNCTION VALUE = 0.7939878

VARIABLE	VALUE
T	0.793988
Y1	0.079940
Y2	0.042930
Y3	0.000100

Now, we summarized all results of functions according to each output in the table below:

Table 3.22 The Results of Production Capacity Output

Variable	Supplier A	Supplier B	Supplier C
T	0.652537	1.000687	1.001253
Y1	---	---	---
Y2	0.155573	0.999939	---
Y3	---	---	0.999748

Table 3.23 The Results of Quality Output

Variable	Supplier A	Supplier B	Supplier C
T	1.001094	0.628841	0.845240
Y1	0.999973	0.167884	0.097278
Y2	---	---	---
Y3	---	---	---

Table 3.24 The Results of Reputation Output

Variable	Supplier A	Supplier B	Supplier C
T	1.001066	1.000418	0.793988
Y1	0.999945	---	0.079940
Y2	---	0.999392	0.042930
Y3	---	---	---

We choose the best supplier company for last tables. As we see, the best supplier company is ***Supplier A***. Because, the score of supplier A is the highest score for solution.

CONCLUSION

This thesis presented the methodology of performance management system, control, models and especially applying data envelopment analysis and demonstrated this application for a manufacturing company. And then, we applied the model in a supplier selection problem. As a result of model solving, we decided the best supplier company that is ***supplier A***. all companies can use this model when they need to help for solution and decision. It is very useful method.

The objective of this data envelopment analysis application is to apply a systematic analysis to help decision making for considerations such as the number of suppliers and to provide improvement targets for suppliers (Jian Liu, Fong-yuen Ding and Vinod Lall, Using data envelopment analysis to compare suppliers for supplier selection and performance improvement, v.5, n.3, 2000, p. 149).

Today's global market managers are realizing that their suppliers have a major influence on customers' satisfaction level. Therefore, they should not make their decision only regarding price. A company must get the product to its customer when, where, and how they want it, and they must provide the required amount of product at the minimal cost at the desired quality level and at the right time to its customer (Zaim S., Şevkli M., Tarım M., Fuzzy Analytic Hierarchy Based Approach for Supplier Selection, 2003, p.19).

In this study, we used some properties as inputs and outputs. They are very important points for the companies. They show us what the companies' ability and quality are. Quality and ability mean on time delivery and service, good price, management system of company, production capacity, human resources capacity etc.

Finally, as in all quantities models, the DEA model contains a set of assumptions which govern its usefulness in any situation. The DEA model assumes that suppliers are able to move in this direction in order to achieve complete DEA efficiency. To the extent that suppliers are not able to move in this direction or are able to achieve efficiency by moving in some other direction, the value of the model diminishes (Weber Charles A., Data envelopment analysis approach to measuring vendor performance, p.37).

The results of the DEA model presented in this thesis will stimulate companies in the use of DEA for supplier selection.

BIBLIOGRAPHY

Braglia Marcello, Petroni Alberto, "A quality assurance-oriented methodology for handling trade-offs in supplier selection", v.30, n.2, 2000.

Braglia Marcello, Petroni Alberto, "A quality assurance-oriented methodology for handling trade-offs in supplier selection" , International Journal of Physical Distribution & Logistics Management, Vol. 30, No.2, pp. 96-111, 2000.

Carr S. Amelia, Pearson N. John, "The impact of purchasing and supplier involvement on strategic purchasing and its impact on firm's performance", International Journal of Operations & Production Management, Vol.22, No.9, pp. 1032-1053, 2002.

Dağdeviren Metin, Eren Tamer,"Tedarikçi seçiminde analitik hiyerarşi prosesi kullanılması", Gazi Ünv. Müh. Mim. Fak. Dergisi, Cilt 16, No 2, 41-52, 2001.

Degraeve Zeger, Labro Eva, Roodhooft Filip, "An evaluation of vendor selection models from a total cost of ownership perspective", European Journal of Operational Research 125, pp. 34-58, 2000.

Ghodsypour S. H., O'Brien C., "A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming", International Journal of Production Economics 56, pp. 199-212, 1998.

Ghodsypour S. H., O'Brien C., "The total cost of logistics in supplier selection, under conditions of multiple sourcing, multiple criteria and capacity constraint", International Journal of Production Economics 73, pp. 15-27, 2001.

Golany and Roll, "Some models for estimating technical and scale inefficiencies in data envelopment analysis", Supply Chain Management, Vol.30, No.9, 1995.

Gökdere Halis,"Bilgi sistemlerinde tedarikçi seçimi", KalDer Forum Nisan-Mayıs-Haziran 2001.

Handfield Robert, Walton V. Steven, Sroufe Robert, Melnyk A. Steven, "Applying environmental criteria to supplier assessment: A study in the application of the analytical hierarchy process", European Journal of Operational Research 141, pp. 70-87, 2002.

Işcan Firuzan, Karsak Ertuğrul, "Ağırlık kısıtlamaları, çapraz etkinlik ve pencere analizi yöntemleri kullanılarak veri zarflama analizi ile performans yönetimi", Galatasaray Üniversitesi, Haziran 1999.

Jayaraman Vaidyanathan, Srivastava Rajesh, Benton W.C., "Supplier selection and order quantity allocation: A comprehensive model", The Journal of Supply Chain Management, Spring 1999.

Jian Liu, Fong-yuen Ding and Vinod Lall, "Using data envelopment analysis to compare suppliers for supplier selection and performance improvement", v.5, n.3, 2000.

Kannan R. Vijay, Tan Keah Choon, " Supplier selection and assessment: Their impact on business performance", The Journal of Supply Chain Management, Fall 2002.

Liu Jian, Ding Fong-Yuen, Lall Vinod, " Using data envelopment analysis to compare suppliers for supplier selection and performance improvement", Supply Chain Management: An International Journal Vol.5, No.3, pp. 143-150, 2000.

Nydick R.L., Hill R.P., "Using the Analytic Hierarchy Process to Structure the

Supplier Selection Procedure", Journal of Purchasing and Management, Vol.25, No: 2, pp. 31-36, 1992.

Sarkis Joseph, Tailuri Srinivas, "A model for strategic supplier selection", The Journal of Supply Chain Management, Winter 2002.

Shang and Sueyoshi, "A bibliography of Data envelopment analysis", the University of Massachusetts Department of Industrial Engineering, 1987.

Sinuany-Stern Zilla, Mehrez Abraham, Hadad Yossi, "An AHP/DEA methodology for ranking decision making units", International Transactions in Operational research 7, pp.109-124, 2000.

Thomas L. Saaty, "The Seven Pillars of the Analytic Hierarchy Process", Mervis Hall University of Pittsburgh.

Uğur Naci, "100 Soruda Kalite", 2001.

Ülengin Füsun, Besen Buket, Performans Yönetim Sistemi ve Veri Zarflama Analizi, İstanbul Teknik Üniversitesi, 1995.

Weber A. Charles, "A data envelopment analysis approach to measuring vendor performance", Supply Chain Management, Vol.1, No.1, pp.28-39, 1996.

Yolalan O. R., "İşletmeler Arası Göreli Etkinlik Ölçümü", Milli Prodüktivite Merkezi Yayınları, No: 483, 1993.

Zaim S., Şevkli M., Tarım M., "Fuzzy Analytic Hierarchy Based Approach for Supplier Selection", 2003.