Performance Efficiency of a Chemical Company Using DEA

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ABSTRACT

The chemical companies that produce unsaturated polyester resins generally suffer from the high cost in production. Most of them focus on quality control in order to avoid the cost of rework and increase performance assurance. Data Envelopment Analysis (DEA) models are used recently as one of the most powerful non-parametric methods to computing the efficiency of the multiple inputs and outputs of decision-making units (DMU's). However, these models are sensitive about inputs and outputs selection, and a number of them against the number of DMUs.

This paper uses Data Envelopment Analysis (DEA) models to find the efficiency performance of a chemical company in a certain period of time in a manner that maintenance, production and management cost are minimized taking into consideration environmental hazard and maximizing profit. Constant Return to Scale (CRS) models are used to verify the most significant factors that affect efficiency values in the company and forecasting the desired cost reduction in a future period of time. The results determined the efficient DMUs and contained the values needed for inefficient DMUs to reach optimum targets.

Keywords: Unsaturated Polyester Resin (UPR), Constant return to scale, Input-oriented model, Efficiency evaluation, Data Envelopment Analysis (DEA).

ÖZ

Doymamış polyester reçineleri üreten kimya şirketleri genellikle yüksek üretim maliyetinden muzdariptir. Çoğu, yeniden işleme maliyetinden kaçınmak ve performans güvencesini artırmak için kalite kontrolüne odaklanır. Veri Zarflama analizi (VZA) modelleri son zamanlarda karar verme birimlerinin (KVB'lar) çoklu giriş ve çıkışlarının verimliliğini hesaplamak için en güçlü parametrik olmayan yöntemlerden biri olarak kullanılmaktadır, ancak bu modeller girdi çıkh seçimi ve girdi çıkh sayısına karşı KVB sayısı konularında hossastır.

Bu makale, bir kimyasal şirketin belirli bir dönemde verimlilik performansını çevre tehlikesi göz önünde bulundurularak ve karı en üst düzeye çıkararak bakım, üretim ve yönetim maliyetlerini en aza indirecek şekilde bulmak için Veri Zarflama Analizi (VZA) modellerini kullanmaktadır Sürekli Ölçeğe Dönüş (ÖSG) modelleri, şirketteki verimlilik değerlerini etkileyen en önemli faktörleri doğrulamak ve gelecek dönemde istenen maliyet düşüşünü tahmin etmek için kullanılır. Sonuçlar verimli KVB'ları belirledi ve verimsiz KVB'ların optimum hedeflere ulaşması için gereken değerleri içeriyordu.

Anahtar Kelimeler: Doymamış Polyester Reçine (DPR), Ölçeğe sabit geri dönüş, Girdi odaklı model, Verimlilik değerlendirmesi, Veri Zarflama Analizi (VZA).

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

AHP	Analytic Hierarchy Process
ANN	Artificial Neural Network
ARAS	Additive Ratio Assessment
BBC	Banker, Charnes and Cooper
BMCs	Bulk Molding Compounds
C$^{\circ}$	Degree Celsius
CCR	Charnes, Cooper and Rhodes Model
CEM	Customer Relationship Management
cP	Centipoise
CPM	Critical Path Method
CRS	Constant Return to Scale
DCPD	Dicyclopentadiene Capped Resin
DEA	Data Envelopment Analysis
DEACM	Data Envelopment Analysis Cross-model
DM	Decision Makers
DMU	Decision-Making Units
ERM	Enhanced Russell Measure
ERP	Enterprise Resource Planning
FDEACM	Fuzzy DEA Cross-model
FIS	Fuzzy Inference System
FMEA	Linguistic Failure Modes and Effects Analysis
FRPs	Fiber Reinforced Plastics
FSDEA	Frontier-shift Data Envelopment Analysis

GP	General-Purpose Resin
HDT	Heat Deflection Temperature
HSE	Health, Safety, and Environment Management
IEPMI	Electronic Products Manufacturing Industries
IERE	Industrial Environmental Regulation Efficiency
ISO	International Organization for Standardization
ISO	Isophthalic Resin
JIT	Just In Time Method
Kpsi	Kilo-Pound per Square Inch
mmol/g	Millimoles per Gram
M_n	Average Molecular Weight
MRP	Material Requirement Planning
OHSAS	Occupational Health and Safety Assessment Series
PCA	Principle Component Analysis
PCE	Prospect Cross-Efficiency Model
PERT	Program Evaluation and Review Technique
PPS	Production Possibility Set
Psi	Pounds per Square Inch
PSM	Purchasing and Supply Management
PVC	Polyvinyl Chloride
R&D	Research and Development
RPN	Risk Priority Number
RTS	Return to Scale
SAW	Simple Additive Weighting
SMCs	Sheet Molding Compounds

TQM	Total Quality Management
UPR	Unsaturated Polyester Resin
VRS	Variable Returns to Scale Model

Chapter 1

INTRODUCTION

Unsaturated polyester resin is considered one of the most used raw materials in a wide verity of products, many global and local companies competing to reach customer satisfaction and profit which means a high performance with low cost. This chapter provides information about the industry and present one of the many companies that is involved with this market and a small introduction about the proposed method with thesis structure.

1.1 Unsaturated Polyester Resin

Polymers are derived from two words, “poly” and “meres”, which are Greek words for many parts. These two words are referring to this material because polymers have a high molecular weight which ranges between ten thousand to one million grams per mole. These molecules take the form of several structural units that are in some cases, bond together by covalent bonds.

Polymers nowadays are used in different products such as clothing, plastic bags, paints and many others as the polymers industry have increased in development replacing other industries like copper, steel, aluminum and more (Namazi, 2017).

1.1.1 Unsaturated Polyester Resin Production

The productions of unsaturated polyester resin consist of two main raw materials; polyester and thinners. The most common thinner that is used in producing resins is styrene monomer; other monomers can be used such as methyl styrene and alkyl methacrylate monomers. Thinners play an essential role by lowering the viscosity of the unsaturated polyester resin and connecting with the polyester by a double bond connection.

There are two main keys in order to prepare for polyester production:

a) The formulation, which is the percentage of raw materials are added in order to have good irritability and density for the chains that connect the polyester and thinners.
b) The layout of the molecules that will give the best resolvable in styrene and give good mechanical characteristic for the cured materials.

The product is made using a chemical process called esterification, where one or more organic chemical compounds reacted with maleic anhydride with or without adding a dicarboxylic acid-like aromatic and aliphatic dicarboxylic. This process happens in a high temperature in order to vibrate the water that is produced during the process. In this process, the carboxylic acid will give the energy for the reaction to occur, so there is no need for stimulant materials.

The organic compound known as fumarates is created during the esterification through a step called isomerization of the melic anhydride double bond structure at elevated temperature. The isomerization is done successfully at a range above 80 percent, but the final product must be done with isomerization that ranges above 90 percent, and that is possible if the selection of the glycols and dicarboxylic are correct and avoid the overheating in order not to cause gelation (becoming gel).

The process of producing an unsaturated polyester resin can divide into two ways: single-stage process and a two-stage process.

The single process is done by adding all the raw materials in one reactor where it is mixed and heated by heating pipes containing hot oil until it reaches almost 200˚C and keep react for at most 20 hours where the product will have three specific properties:

a) The carboxylic acid is nearly gone from the product where the leftover is between 0.1-0.5 mmol/g.
b) The molecular weight of the product should be around 700-3000.
c) The viscosity that is required either by the customer or standard specification is achieved, which is in most time calculated by the styrene solution, normally a final product with 40 percent of styrene have 300-500 cP.

After these specifications are obtained the product transfer to a blender which contain cold styrene solution, in order to extend the life of the product, inhibitors such as hydroquinone and t-butyl hydroquinone are added to the styrene since the styrene are very reactive.

The two-stage process is done when having slowly dissolvable and re-actable acid like isophthalic acid where the melic anhydride and glycol are most likely to react with themselves alone in a huge percentage which decreases the wanted physical properties. In the first stage the acid is added to the glycol at a rate of (1:2) respectively and mix them, until it produces diol ester with low molecular weight and then adding the melic anhydride.

When the unsaturated polyester resin is made in the laboratory for small amounts, they are made in a glass resin reactor which must be fully equipped with good agitation, nitrogen bubbling device, collector for water that comes from the chemical reaction and reflux condenser with low-pressure steam for heat. Usually, the malic anhydride is heated to 60˚C in order to transform to liquid and mix with glycol, once it mixed the reaction start to generate heat by itself where it reaches between 100˚C and 150˚C and then continue heating until it reaches 200˚C and takes samples until the specific mentioned properties are met.

The commercial production can reach tons in a single line of production, however, it must have equipment's similar to the laboratory with a very complicated control system and a blinder.

1.1.2 Resin Production Types

The basic resin that can be produced contains maleic anhydride and propylene glycol mixed with styrene; the final product will have no flexibility to elongate because the melic anhydride makes 50 percent of the total product, which means that the product will have high tensile strength but minimal elongation (brittle).

In order for the product to suits the most general application, the mechanical properties must be changed where the resin must be more resilience.

Three changes can be done to the product to change its specification:

a) Replacing the glycol and/or acid with a different kind of glycol and acids.

b) Replacing the polymer.

c) Increase or decrease the molecular weight.

These three changes can lead to unlimited options in which each option can give a different product characteristic, even if two companies produce the same product, it is highly unlikely they have the same combination and formulation. With that, there is no way to classify the unsaturated polyester resin by its chemical structure. The attempt to do that can only give some guidelines as the person enter this type of industry.

Nowadays, three basic resins are produced:

a) The general-purpose resin, which consists of phthalic anhydride or maleic anhydride, and glycol resins (GP)
b) The isophthalic resin, which consists of isophthalic acid, maleic anhydride and glycol resin (ISO)
c) The Dicyclopentadiene capped resin, which made from Dicyclopentadiene along with the standard glycol and anhydride (DCPD).

There is the fourth type which is vinyl ester. This type is ester-capped polyethers and does not considered polyester.

As mentioned before, the maleic anhydride and glycol provide a brittle product with low elongation (less than 1%). In order to provide more flexibility, the maleic is replaced with phthalic anhydride, this will increase elongation of the solid product, making it less brittle. Also, some type of acids can be added to provide strength, this action (replacing the maleic with phthalic) resulted in producing the first unsaturated polyester resin that can be used in many applications as general-purpose resin, without adding any extra cost as the phthalic has almost the same cost as maleic.

The differences in the properties of the three product types of basic resins are introduced in the table below:

Table 1: Properties of the Three Basic Resin Products

Resin type	properties						
	Styrene content (%)	Viscosity	Tensile strength (psi)	Elongation (%)	Flexural strength (psi)	Flexural modulus (kpsi)	HDT[a] (˚C)
GP	40	Medium	8000	1.5	16000	500	80
ISO	45	High	10000	2.5	18000	500	100
DCPD	40	Low	7000	1	15000	600	70

The general-purpose resin considers undesirable in the environment that contains humidity because it is resistant to water is weak. The product will fail in any application where water is involved and especially in high temperature as a result of the ester, where it gains high strain energy due to the unfavorability of the ester to transform, so it contains high energy and releases it on another ester which is next to it in the benzene ring.

A solution by a group called Amoco chemical has been presented to address this problem, the new, improved resin known as high-performance resins were developed before the foundation of the isophthalic resins.

Isophthalic; which is the oxidation of m-xylene, came after the existence of high-performance resin. It contains two properties that consider very important to the industry. Firstly, it can dissolve in any organic compounds. Secondly, the melting point for the acid is high. These two properties make it hard to combine with maleic anhydride and glycol with the desired percentage. This is the reason that the two-stage process exists.

The Isophthalic resin which is done using the two-stage process, especially if propylene or neopentyl glycol are involved as a raw material. Because it does not have any strain energy in the esters, the final product is good to use in an environment that includes water. Most of these products can work as a gel coat to protect the surfaces from corrosion such as boat parts that are in the water, and these properties make it worth even though the price is high from general-purpose resin.

The Dicyclopentadiene is the best type of products regarding the desired properties. Dicyclopentadiene is one of the materials that are used due to its ability to make large groups at the end of the chain of polymers where the number of average molecular weight M_n is between 1500 and 3000.

The Dicyclopentadiene is made from the two Cyclopentadiene reacted with Diene. The Dicyclopentadiene is stable thermodynamically at room temperature. It can be found as a side product from the alkene cracking process where it can be contained by distillation, the most common country that contains DCPD is North America.

The low cost of DCPD results in the desire and hard work to include it in the unsaturated polyester resin production as a raw material for a long time. The process to include the DCPD in the production is called “water process”, where DCPD are mixed with maleic and water that are less than DCPD in the amount in an elevated temperature little below the temperature in which DCPD is dissolving. This will result in creating ester. Then the mixture will be mixed with glycol and more of maleic anhydride. The final result is polyester with a molecular weight less than 1000, containing between 30 to 40 percent of DCPD in its structure.

The inclusion of DCPD in the unsaturated polyester resin production as a raw material gives two advantages to the industry of polyester resin than other types. Firstly, the cost of DCPD is lower than phthalic anhydride, which is used for the general-purpose resin, so the cost of UPR using DCPD will be affected in the right way. Secondly, because of the large group in which DCPD is made, the shrinkage due to curing is decreased since DCPD macromolecule prevents it from getting close to each other. According to these two factors, the best consume for this type of product will be as a raw material for making boats and bath tubes.

The low molecular weight of DCPD resin cause in small elongation before it breaks, even though there is rare demanding desire inflexible product, there is the possibility to blend a second raw material with more prolongation with the mixed solution and co-cure the formulation.

The mixing of a second raw material with DCPD resin has become essential. Most common materials that are mixed as a secondary raw material with the DCPD are isophthalic, orthophthalic, and vinyl ester resins. These materials that have high molecular weight can increase the backbone of the pure DCPD resin. Other properties can be gained like protection from chemical reactions and water corrupting when mixed with vinyl ester and isophthalic.

1.1.3 The Characteristics of UPR

The industry of the unsaturated polyester depends on the desires of the customer; this led to the growth of the polymers in variety. In order to meet the customer specifications, the selection of the chemical elements, among other things such as additives, fillers, and reinforcements are crucial to gain these specifications. Common specifications can be summarized to cost, durability, shrinkage, surface reaction, weight, tensile, flexural, elongation, fatigue, impact absorption, electrical properties and physical properties. In order to contain the desired specification, there must be a harmonization between chemical elements, additives, fillers and reinforcements that are used in the creation of the product.

1.1.3.1 Chemical Elements

The desired characteristics for the product wanted by the costumers are usually known, and several chemical elements can be used to reach the goal. However, many companies compete locally and globally, so the cost is playing a significant rule to satisfy the costumers.; This limit the selection of chemical elements that can be used to get the desired specifications. Even though there are only three types of polyester resins, there are hundreds of methods and combinations in using chemical elements for each family to get the wanted properties of the product. The tables below show some common chemical elements and their advantage that can be shown in the end product.

Table 2: Anhydrides/Acids Advantages for End Product

Chemical elements	**End product advantage**
Phthalic anhydride	Reduce cost, Styrene unity
Malice anhydride	Chemical resistance, Hardness
Adipic acid	Resilience, Strong backbone
Isophthalic acid	Strong backbone, Chemical resistance
Terephthalic acid	Increase thermal resistance

Table 3: Glycols Advantages for End Product

Chemical elements	End product advantage
Propylene glycol	Styrene unity
Ethylene glycol	Hardness, Low cost
Dipropylene glycol	Resilience, Strong backbone
Diethylene glycol	Resilience, Strong backbone
Methylpropane diol	Strong backbone, chemical resistance
Neopentyl glycol	Ultraviolet and chemical resistance

There is also Dicyclopentadiene (DCPD) among chemical elements that has low cost, enhance the outer layer of the subject that are coated and have low chemical resistance.

1.1.3.2 Additives

Additives can be added to increase the quality of the end-use products in terms of properties such as reduce bubbles, cure percentage, stiffen, lowering density, preventing the product from reacting with the mold, moisten and scattering of fillers, thixotropy, shrinkage and static decrease.

One of the most known types of additives is low-profile additives. Thermosetting polymers get smaller when they are cured, which reflects badly on a coated surface, the low-profile additives can prevent the polymer resin from squeezing on itself. Which give the ability for the polymer resin to enter the vehicle market as body parts coat, where the surface of a vehicle should be "class A" to be accepted in the market, and this can be provided by the low-profile additives.

The low-profile additives can be divided into poly (vinyl acetate), polystyrene, polyethylene and polycarbonate. It can prevent the shrinkage of the polyester by splitting to a second phase and enlarge while the polyester is curing. These low-profile additives help to provide a variety of application for the polymers resin. By preventing shrinkage, for example, the vehicle market where the surface quality is priority has been available.

1.1.3.3 Fillers

Other than additives, polymers resin characteristics, and cost can be improved using fillers, the table below contains general fillers and their affect in polymers.

Table 4: General Fillers and Their Affect

General fillers	End product advantage
Calcium carbonate	Low cost
Clay	Enhanced surface
Alumina trihydrate	Fire resistant
Talc	Increase temperature resistance
Mica	Enhance disintegrate

1.1.3.4 Reinforcements

Polymer resin can be used in construction. However, in order to do such a thing, there must be an improvement in physical properties. Reinforcement can improve the physical properties, especially tensile strength, impact strength and stiffness, which are the most necessary properties in structural implementation. Reinforcements can be divided into two groups; regular particles such as glass and irregular particles like fibers.

Fiberglass is considered to be one of the most known reinforcements used for polymer resin production. The mixture of unsaturated polyester resin and fiberglass has the names of composites, laminates and fiber-reinforced plastics (FRPs). These composites are always in demand. The fiberglass is cut by using liquid resin stream, it can be cut to “chopped roving mat, woven cloth or needle-punched ‘knitted fabric’”. Fiberglass with a variety of weights and mixing positions exist to achieve the desired strength for the interlaced and knits. It can be used by adding more than one layer of fiberglass to increase properties such as hardness, impact resistance and modulus of rupture; many products can have mixed of many fiberglass layers and knits or interlaced, then a last layer of fiberglass is added like the hull of a normal boat. This mixture can be known as 'laminate schedule'. It is also known if the hardness increases the elasticity and impact resistance are also increases. The laminate schedule usually includes 35 to 40 per cent of reinforcement fiberglass. In the other hand, the cost for the fiberglass is higher than unsaturated polyester resin which something needs to be considered when making a laminate schedule in order to achieve balance.

One of the rarest fibers that are included are carbon fiber and aramid fibers; they usually used for more demanding end product like the military or aerospace sectors. That is referring to its high cost for the high geared reinforcements.

The relation between the hardness and the thickness in laminate are cubic, so the more the thickness there is, the more the hardness, many methods exist in order to increase the thickness other than having many layers of fiberglass and resin. Materials that have a lightweight core like end-grained balsa wood, high-density polyurethane foam, PVC foam and honeycombed can be used in improving the thickness. Materials can be squeezed between the rows of unsaturated polyester resin to enhance the laminate hardness; this objective can be achieved using a technique called 'sandwich construction.

1.1.4 Unsaturated Polyester Resin Implementation

Many industries use polyester resin as a raw material in a different production. The most industries that use UPR are navy, construction and vehicles. Also, many sizes can be included from the small ones like clothes buttons to big ones like an overpass. The table below shows the most important productions that involve UPR.

Table 5: Applications using Unsaturated Polyester Resin

Market	Navy	Construction	Vehicles	General use
Applications	Powerboats, sailboats, canoes, kayaks, personal watercraft	Bathtubs, shower stalls, hot tubs, spas, cultured marble, building panels, swimming pools, etc...	Body panels, 'under the hood' components, truck cabs, tractor components, structural elements	Buttons, sports equipment, medical equipment housings, computer housings, ladders, utility poles

Even though there are many types of resins because of the different chemical components that are included as raw materials for UPR. Some industries require specific characteristics, and these specific characteristics can be used to divide the chemical components to categorize. Nonetheless, the requirement specifications can lead to the use of some of these materials out of its category. So, the category can only be used as a general reference. These categories and the chemical components that are most used in these categories are summarized to:

a) Navy:

a. General-purpose: propylene glycol and phthalic anhydride

b. Hull and docks: DCPD, propylene glycol and phthalic anhydride resin blends.

c. Tooling/molds: isophthalic.

b) Gel coats:

a. General use: propylene glycol and phthalic anhydride.

b. General purpose: isophthalic and propylene glycol.

c. UV performance: neopentyl glycol and isophthalic.

c) Vehicles:

a. Bulk molding compound: propylene glycol, Dipropylene glycol and isophthalic.

b. Body panels: propylene glycol and phthalic anhydride.

c. Truck body: propylene glycol and phthalic anhydride.

d) Construction:

a. Tubs and showers: DCPD, propylene glycol and phthalic anhydride blends

b. Panels: diethylene glycol and phthalic anhydride.

c. Faux marble: diethylene glycol and isophthalic.

d. Tanks and pipes: propylene glycol and isophthalic.

Gelcoat consider one of the special categories of polyester resin. Gelcoats can provide both smooth shine surface for parts made from unsaturated polyester resin and protection from a chemical reaction with water and light. Gelcoat consists of resin, fillers and pigments, where the percentage of fillers and pigments combined does not exceed 40 percent. Usually, the process of making Gelcoat requires more amount of styrene monomer as a solvent than the resin need.

The Gelcoat can be made from three types of resin, example on each type are orthophthalic, isophthalic and neopentyl-glycol-based gel. The isophthalic and orthophthalic are considered to be the most used in general, where it covers 66%, and the rest are divided between other Gelcoats of their own type. In contrast, the neopentyl-glycol-based gel coats are basically used for navy applications, where the Gelcoat used for the navy requires great function regarding dissolving and withering. Other famous uses for Gelcoat are bathtubs and the vehicle market.

1.1.4.1 Navy

The naval applications consider one of the biggest markets for polyester resin. The first time the unsaturated polyester used in sailing was the second half of 20^{th} century, since then the sailing business has grown dramatically and produces boats in huge quantities for the market due to the cheap manufacturing cost of unsaturated polyester resin.

Most of the parts in the boats that are made from unsaturated polyester resin are body, decks and many small parts like hatches and engine covers. The body and the decks of a boat is usually made from unsaturated polyester resin with layers of fiberglass and cloth knits and cutup fibers. However, in the navy industry the application is concentrated on the Gelcoat to give nice surfaces and protection from a chemical reaction with the environment.

Different types of resins can be used to make the body and decks according to the demand. Boats such as high performance, high speed and blue water boats can be made from the strongest resins of vinyl ester or a mixture of vinyl ester and DCPD resins. While commonly used boats are produced from the low cost of orthophthalic mixed with DCPD. DCPD is used with boat bodies to give the surface a beautiful look, and because the shrinkage of the DCPD is lower than orthophthalic resin. Even though DCPD and orthophthalic resins are low on cost, the DCPD is tough and not stable with the presence of high humidity and temperature. This can cause degeneration of polymer that lies directly under the Gelcoat. Many of polymer degeneration can cause what is known as hull blisters, which effect the industry of navy. To increase the stability of DCPD in environments with high humidity and temperature and lower the toughness, the DCPD is usually mixed with another resin like orthophthalic, vinyl ester or isophthalic, which is a common method nowadays. The boats that are usually staying in the sea can be protected using 'skin coat' where a sheet of vinyl ester and chopped fiberglass are added directly beneath gel coat to prevent chemical reaction with humidity and temperature and stop blistering.

The boats are usually made by open mold spray-up process. However, this process can environmentally hazard because of releasing high amount of styrene monomer during the process. For that reason, the closed molded process is being tested commercially in hoping that one day it will take the place of open mold process.

1.1.4.2 Constriction

The construction market for UPR can be dividing into four major sections:

a) Bathroom parts and attachments.
b) Tubes, tanks and installation parts
c) Panels.
d) Other things such as pultruded window frame

There are many demands in the construction market regarding permanence and design flexibility that the polyester resin has achieved in a low cost compared to other common materials that are used in construction like steel, cast iron, wood and ceramics.

Most of the construction market that uses UPR is focused in bathtubs, showers and sinks. Where 90% of the unsaturated polyester is used in the construction industry to make fiberglass-reinforced bathtubs and shower stalls. Unsaturated polyester resin has replaced cast-iron in bathtubs. In comparison, the highly filled cast replaced ceramics and steel in bathroom sinks and kitchen tables, respectively because of the resin low cost.

The main reason for the make of tubes, tanks and their installation parts from the unsaturated polyester resin was the laws regarding environment, lower cost in labor during work in construction and preventing chemical reactions.

Environmental laws regarding breathable air and water that exist underground assist the construction market to make a chain for tanks under and above the ground for sewers and other toxic material for the environment. These laws emphasis sewerage faculties must contain components such as storage and tubes which prevent any leak that can happen; they also make particular instructions to install and force hard punishments for anyone who breaks it. Usually, the storage which is made from polyester and reinforced with fiberglass has low-cost manufacture in comparison with steel and provides resistance to a chemical reaction. The same thing goes for the metal pipeline which is being replaced these days with unsaturated polyester resin pipe.

Normally, the use of UPR in the panels industry concludes in semitransparent roof panels like greenhouse panels that are used in roof and bathroom panels that are used in the wall. The panel market in common is low in cost market, which is sheared between unsaturated polyester resin and thermoplastic.

There are nearly hundreds of products in the construction market that use unsaturated polyester resin such as window frames, doors, cabinet enclosures, electrical boxes and many other things. Moreover, with the advanced technology, the UPR spread more in the construction market like concrete rebar, bridge construction and common infrastructure repair.

1.1.4.3 Vehicles

Unsaturated polyester resin is used in different kinds of vehicles industry such as body components regardless they are hidden or they generally seen, the internal structure of the car and many different uses that can include trucks, buses and rail cars. The UPR is desired because it can reduce weight, have chemical resistance with the environment and making the body parts fit together perfectly. In the other hand, the contest between UPR and thermoplastic resins in the automotive market is strong.

The metal parts that were used in the car industry has been replaced with the unsaturated polyester resin because it has a small amount of weight and resistance to any reaction with their surroundings and can be made in different and weird shapes using a molding process which makes combining the car parts much easier. Finally, it can endure the high temperature from the oven for the automotive painting without any deformation.

There are two known mixtures of UPR, fillers and fiberglass that are used in the vehicle production; Sheet molding compounds (SMCs) and bulk molding compounds (BMCs).

These two combinations have very good specifications such as high hardness, unaffected by the high temperature and low thermal expansion. Their low resistance to creep makes them more desirable over thermoplastic resins, and their low shrinkage and their ability to make the surface shine give them the ability to produce a class A surface, these characteristics make them more desirable for making many different parts from body panels to the unseen parts (Scheirs & Long, 2003).

1.2 Company Background

1.2.1 General View

Boytek Company is considered one of the most leading producers in high-quality unsaturated polyester, resin, vinyl ester resins, Gelcoats and pigment pastes.

The company started working in 1978, when the company started to produce alkyd and unsaturated polyester resins. However, during 1982 the company stopped producing alkyd. It started focusing in polyester resin production, few years after the company started to include Gelcoats, pigments pastes and vinyl ester resins to their production offer, nowadays the company has massive production of different products that satisfy the composite industry.

In order to cover the increasing demand lead by the product's versatility, the company built and operated a second plant in Çerkezköy/Istanbul in 1999, in 2009 a third plant was working in Tuzla/Istanbul which double the production capacity.

Because the new existent of residents and building Atatürk airport the first plant in Yenibosna has been shut down and the company seize the opportunity to invest in the tourism sector where they opened Gorrion hotel and create GORRION brand in 2014, this hotel has 252 luxury rooms 2000 m^2 meeting facilities, SPA center, among other things to serve local and international guests.

By 2010 Boytek company started production of SMC-BMC in association with Menzolit.

Today Boytek has a big reputation exporting to different parts of the world including Europe, Asia, Middle East and Africa, competing with renowned companies around the globe. As a result, Boytek has been the exclusive distributor for OCV Reinforcements products, Ashland Derakane resins and other global companies.

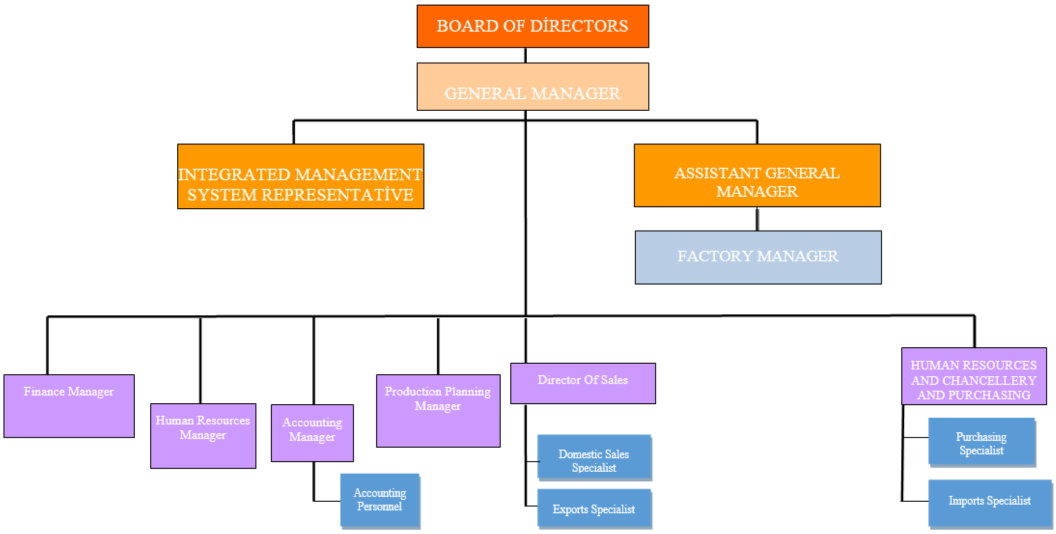

Figure 1: Main Management Flowchart.

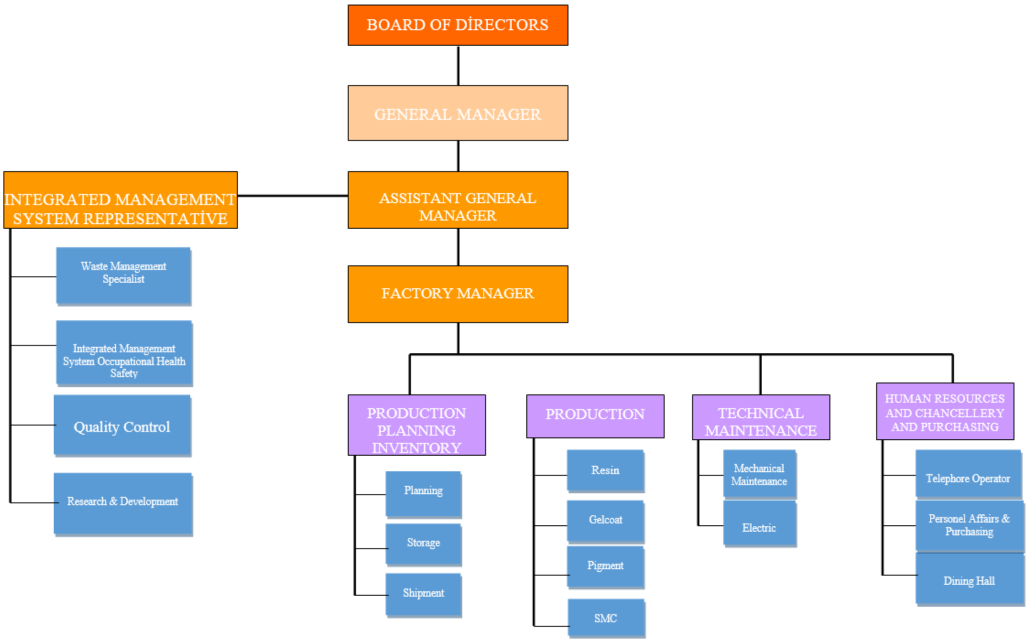

Figure 2: Main Factory Flowchart.

1.2.2 Vision

a) Be among the most environmentally friendly chemical companies of Turkey.

b) Become a world-famous brand.

c) Contribute to the development of Turkish and global composites industry.

d) Launch and develop new product solutions that will improve the quality of life.

1.2.3 Mission

a) Produce innovation and top-quality products for the composites industry.

b) Be always ready for competition in the globalizing world: by taking human health as a priority, using knowledge accumulation, experience and top-notch technology.

c) Respond to the needs of local and global markets.

1.2.4 Values

a) Integrity.

b) Respect for people.

c) Respect for the environment.

d) Provide the customer with the best products on time with the best terms.

1.2.5 Corporate Strategy

a) Enhance the company key business operations and to invest in performance businesses.

b) Invest in science and technology in order to strengthen their production business and increase company efficiency.

c) Reach the highest level of corporate performance by developing high added value products.

1.2.6 Products

a) BRE Range.

b) BVE Range.

c) Gelcoat.

d) Pigment Paste.

e) SMC-BMC.

1.3 Problem Definition

Remaining competitive with other global companies requires a high performance and top-quality products, which is the essence of the unsaturated polyester companies. Also, the cost of products is a key factor to stay in competition with other companies. These two things which are the high-quality specifications for products and the cost reduction rarely meet in the same line.

The company provides job shops which mean that the customer asks for specific properties and the company provide them for a reasonable price.

Moreover, due to increasing awareness of the environmental problems and dealing with lethal chemical components, the company should take steps to reduce the environmental hazards while keep producing high-quality products.

These situations, along with outer factors such as political and economic, could affect the performance and the profit of the company.

The company faced these statements by multiple actions that can be summarized to:

a) Environmentally:

Boytek resins have many achievements in improving, not just the performance but also the environmental protection along with it, and these achievements can be summarized into:

i. Efficient use of energy and natural resources
ii. Waste minimization by supporting the re-using and recycling efforts.
iii. Keeping as a priority, the activities that reduce the use of dangers materials at the design and production stages and develop products that have less impact in the environment.
iv. Supporting all employees and working in cooperation with universities that have the expertise to accomplish these activities.
v. Reducing the impact on the environment with source re-education, by burning liquid waste generated from the production with the company incinerator in cooperation with Istanbul Technical University and rewarded for this achievement by the president of Turkey Mr. Süleyman Demirel.

b) Health and Safety:

In order to decrease risk and other factors that affect the employees' health, the company take many actions that include:

i. Protecting the individual health of the employees and creating a safe and healthy working environment.
ii. Identifying the causes of possible workplace accidents and occupational diseases, evaluating the risks, developing roles and methods to endorse appropriate control measures, and eliminating the hazards.

c) Management system policy:

Boytek Company has considered each of customer satisfaction, product quality greatly, continues technology development, education, team spirit, environmental awareness, and continues improvement by taking the following steps:

i. Follow the latest technology to improve the factors which affects the quality of the products and integrate this technology in the company system. This enhance the production ability, which increase the capacity and variety of products.
ii. Encouragement for education as the basis of level and continuation of product quality
iii. Set business goals on a yearly basis that complies with the company standers and ensure continuity to reach these goals
iv. Technical follow up and support for clients all over the world.

In order to achieve top quality and high standards Boytek is committed to complying with ISO 9001, ISO 14001 and OHSAS 18001 standards and legal requirements with the participation of staff from all levels, based on the idea of continues improvement and development with the use of modern technology and the scientific methods.

d) Research and Development:

R&D is considered one of the most important investment in order to add value to the customer and the company industry while the R&D can use the latest technology and keep up to date. The R&D which is located in Çerkezköy is working on developing new products and technologies.

The work in the R&D laboratory can be summarized to:

a) Development of new products.

b) Optimization and modification of existing products

c) Customization of products according to new demands and applications.

d) All kinds of tests on finished products

1.4 Suggested Method

There are many tools that can be used to optimize the performance and productivity of the companies such as; Production planning and control, Inventory control, Job evaluation, facilitates planning and material handling, Linear programming, Network analysis (PERT, CPM), Queuing models, Sequencing and transportation models, Statistical techniques, Quality control, Decision-making theory, Replacement models, Assembly line balancing, MRP-JIT-ISO-TQM, and last but not least the method that is suggested which is DEA.

DEA was first introduced in 1978 to measure the performance of multiple inputs and outputs. Since then DEA is considered one of the most effective methods to measure the productivity and efficiency of various comparable units known as decision-making units DMU.

DEA has been used in different applications such as banking, health care, educational services and last but not least industrial application (Emrouznejad & Podinovski, 2004).

The efficiency of each DMU can be measured by dividing the total output by the total input. These summations are calculated by using weighted sum for each input and output; the most efficiency DMU can be defined as the DMU that uses the least input to produce bigger output (Ning, Marc, Cynthia, & Thomas, 2019).

The first known DEA model was Charnes, Cooper, Rhodes model (CCR) which calculate the efficiency by maximizing the efficiency of each DMU's separately subject to that none of the efficient DMU's are more than one, because of the simplest of the CCR the model can determine the efficient and the non- efficient only, other methods have improved the ability to distinguish between the DMU's and rank them such as; Super efficiency, Cross efficiency, weight evaluation, interval efficiency, weight restrictions, involving AHP and multivariate statistics in DEA and much more (Wenli, Ying-Ming, & Shulong, 2017).

In this study the goal is to measure the performance of the company according to multiple inputs and outputs in three consecutive years, where the study can show the performance and determine the most effective inputs in that year, this study also shows the most efficient DMU's which will lead to the most efficient month and calculate each of Lambda, Efficiency and Cross efficiency, Slack, Weights, Targets which can help in defining the most efficiency and forecasting future production planning.

The advantages of DEA can be summarized as follows:

1. One of the best linear programming that can have multiple inputs and outputs
2. Non-parametric method which means it does not need to follow any normal distribution.

On the other hand, DEA has limitations, such as:

1. DEA is sensitive when it comes to inputs and outputs. Any unclear (fuzzy) data can affect the measurement of the DMUs and give uncertain results.
2. The requirement to have numbers of DMUs at least equal to the sum of inputs and outputs (rule of thumb), if the number of DMUs were less than the summation the results will be inaccurate.

1.5 Structure of the Thesis

These studies are divided into four sections:

a) Section one will talk about the use of DEA in other chemical companies.
b) Section two will discuss the methodology that the study has follow, DEA models will be represented in detail with their general formulas and the models used in this paper, also this section will discuss the collection of data and how it was organized and divided into groups.
c) Section three will show the results of the analysis using PIM-DEA software and compare the results in order to find the best DMUs and how to improve efficiency.
d) Section four will be summarizing our conclusion about the study. Also, use the data in order to forecast the next amount of cost reduction for the months coming in order to reach the desired efficiency and give recommendation about how to improve the efficiency along with future research.

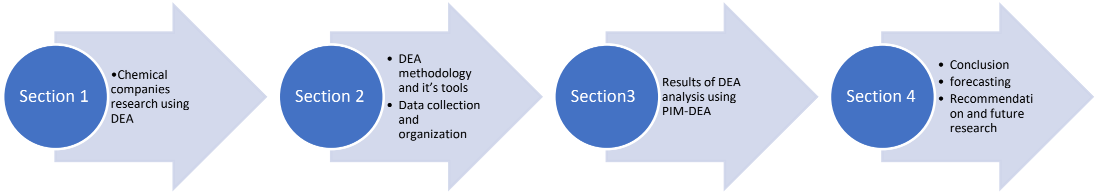

Figure 3: Thesis Flow Chart

Chapter 2

LITERATURE REVIEW

DEA models are used in different variety of applications which indicate the great advantage that Data envelopment analysis posies in increasing the performance of industry sector among other sectors. As an example in construction, (Nahangi, Chen, & McCabe, 2019) used DEA to determine efficiency in construction sites where the results show that the number of accidents happened in the construction sites are the controlling factor relating to the efficiency. Also, in financial, (Hajiagha, Mahdiraji, & Tavana, 2019) introduce a new model called bi-level DEA to determine the efficiency and target settings, which is applied in a private bank called (Peoples Bank) with 45 branches distributed in Iran. This method has been able to predict some targets of the bank for the efficient branches. This chapter will talk about the achievements of DEA in the chemical sector.

2.1 Chemical

(Ghapanchi, Jafarzadeh, & Khakbaz, 2008) introduced a multicriteria decision-making model (DEA) in order to select appropriate enterprise resource planning (ERP) systems. This can help companies' decision-makers to have a general agreement. This method can also be used in another enterprise system, like Customer Relationship Management (CEM).

(Tsolas, 2015) used two kinds of DEA metrics to evaluate the credit risk-taking consideration of efficiency and effectiveness in a group of companies for raw materials and chemicals in Greek. The conclusion was the incompetence in efficiency of both raw materials and chemical companies. However, the more significant issue is that the companies that work on raw material should give more attention to their profit-oriented policies in order to succeed in their business.

(Azadi, Jafarian, Saen, & Mirhedayatian, 2015) developed an integrated DEA enhanced Russell measure (ERM) model in fuzzy context in order to make the selection of the best sustainable supplier. This model can determine the effectiveness, efficiency and productivity while having an uncertain environment with unequal α levels. The model is used in a resin company to display the efficiency for sustainable supplier selection which results helped the managers to select the appropriate supplier.

(Han Y. , Geng, Zhu, & Qu, 2015) included a method to analyze efficiency. This method is based on fuzzy DEA cross-model (FDEACM) with fuzzy data. Which has optimum objectivity and resolving power for decision making. The results of this method led to the enhancement of the ethylene production conditions and give instructions for the efficiency of energy utilization during the ethylene production process.

(Han Y. , Geng, Gu, & Zhu, 2015) used evaluation method that can overcome the difficulties in evaluation and comparison of the different decision-making units (DMUs) and can reflect the effectiveness of DMUs and lead to improvement directions for the ineffective DMUs depending on slack variables. The results of this research show that energy consumption analysis is effective and efficient to use in order to improve energy efficiency in ethylene production systems.

(Han, Geng, & Zhu, 2016) introduced a DEA integrated artificial neural network (ANN) approach (DEA-ANN), which uses a DEA model with slack variables for sensitivity analysis to discover the effective DMUs and point out the way to optimize the ineffective DMUs. The results from optimization and prediction to reduce the energy consumption lead ethylene production and improve energy efficiency.

(Han Y. , Geng, Wang, & Mu, 2016) applied a performance analysis and optimal temperature selection method of ethylene cracking furnaces using the data envelopment analysis cross-model (DEACM) integrated analytic hierarchy process (AHP) (DEACM-AHP). This DEACM discards any none reasonable weight disruption for input-output factors which make it possible to calculate and point out the performance status and the optimal temperature for the furnace. While the AHP can identify the reasonable weight allocation of each input-output index and have the consistent fusion result of ethylene cracking furnaces with different temperatures. The results of the research prove that the method can be used to lead the ethylene production system to have less energy consumption and enhance energy efficiency.

(Gong, Shao, & Zhu, 2017) introduced a new energy efficiency evaluation method for ethylene depends on DEA integrated factor analysis with respect to operation classification. Choosing the production working conditions by k-means algorithm depends on three factors; raw material composition, cracking depth and load rate. This method provides a more effective energy efficiency evaluation in the complicated working conditions of ethylene production with the declined dimension of input indicators.

(Chen, Han, & Zhu, 2017) used a novel DEA model to predict the energy and environmental efficiency of the petrochemical industry accurately. This method applied in a number of ethylene plants according to dissimilar scales, showed the effectiveness of the model that are used and give some gaudiness to improve the energy efficiency and carbon dioxide emissions reduction of ethylene plants in the petrochemical industry.

(Geng, Dong, Han, & Zhu, 2017) applied a method depend on an improved environment DEA cross model (DEACM) to analyze energy and environment efficiency for complex chemical process. The conclusion of this research indicates that DEACM is sufficient in discrimination than basic DEA by analyzing energy and environment efficiency of the ethylene production process in complex chemical processes. Also, it can contain the potential of energy-saving and carbon emission reduction of ethylene plants, and enhance energy efficiency with making less carbon emission by enhancing the orientation of inefficient DMUs.

(Rezaee, Yousefi, Eshkevari, Valipour, & Saberi, 2020) proposed a hybrid approach build on the Linguistic Failure Modes and Effects Analysis FMEA, Fuzzy Inference System (FIS) and Fuzzy Data Envelopment Analysis (DEA) model to measure a novel score for concealing some RPN defects and deciding the importance of HSE risks. This method has been tested on a current working company in the chemical industry. The results of the score show top priority for risks, which lead to protection procedures to be shown in accordance with the research and to have more analysis of the results, the self-organizing map has been applied in this study.

(Saljooghi & Rahimi, 2019) used DEA models and Return to Scale (RTS) to test the efficiency of supply chain management of companies that produce resin. This study was done on 27 resin companies, which were deviated to two types; crisp and fuzzy data. The results showed that there are six companies that have crisp data were network efficient, while only three companies with fuzzy data were network efficient.

Chapter 3

METHODOLOGY

This paper used data envelopment analysis to determine the efficiency of the company. This chapter will provide basic information about the DEA and give a comparison between CRS and VRS. Also, the method in which the data has been collected is discussed, and the arrange of the data while adding some of them together to a number of groups are explained.

Some important parameters that are shown in the equations below are presented as follows:

n= number of DMUs.

m= number of inputs used by DMUs.

s= number of outputs used by DMUs.

y_{rj}= amount of output r from DMU_j; {j=1,…, n}, {r=1,…, s}

y_{rj0}= amount of output r from DMU_{j0}; {j=1,…, n}, {r=1,…, s}

u_r, U_r= the weight given to output r; {r=1,…, s}

x_{ij}= amount of input i from DMU_j; {j=1,…, n}, {i=1,…, m}

x_{ij0}= amount of input i from DMU_{j0}; {j=1,…, n}, {i=1,…, m}

v_i, V_i= the weight given to input I; {i=1,…, m}

λ_j= weight assigned to DMU_j; {j=1,…, n}

S_i^+, S_r^-= the amount of slacks for input i or output r; {i=1,…, m}, {r=1,…, s}

h, ϕ= efficiency value for DMU_{j0}

h^*, ϕ^*= optimal efficiency value for DMU_{j0}

3.1 Data Envelopment Analysis

Many models can be used which are divided into CCR models and BCC models. This paper talks about the basic models of this two and mention the models which is used in the paper.

3.1.1 CCR Models

The efficiency of DMU (Decision Making unit) can be calculated using a method introduced by Charmes, Cooper and Rhodes in 1978 (CCR). This method came from extrapolating Farrell's measure to contain many inputs and outputs at the same time and apply it using mathematical programming. This is known as the DEA Constant Return to Scale (CRS), which is determined as follows:

Assumption: all firms are operating at an optimal scale.

For each DMU with m inputs, $\{x_i;\ i=1,\ldots,\ m\}$ and s outputs, $\{y_r;\ r=1,\ldots,\ s\}$ the efficiency for each DMU_j where $\{j;\ j=1,\ldots,n\}$ can be calculated as follows:

$$Eff = \frac{\sum_r u_r y_{rj}}{\sum_i v_i x_{ij}};\forall i,\forall j \tag{3. 1}$$

The weights of the input "v" and output "u" are given so that each DMU_j has the highest efficiency possible which is equal or less than one, if the DMU has an equal efficiency one then it is considered efficient otherwise it is not efficient. After a certain amount of time, a new model came out where the efficiency can be determined as the percentage of the sum of weighted output to the sum of weighted inputs. So, the calculation of DMU_{j0} can be done as follows:

$$Eff = \max_{U_r,V_i} \frac{\sum_r U_r y_{rj0}}{\sum_i V_i x_{ij0}} \tag{3. 2}$$

s.t.

$$\frac{\sum_r U_r y_{rj}}{\sum_i V_i x_{ij}} \leq 1\ ;\forall j \tag{3. 3}$$

$U_r , V_i \geq 0 ; \forall r, \forall i.$ (3. 4)

This model can be modified to LP model with an orientation towards output or input, the model with input orientation tends to minimize the percentage of input used while having the same amount of output produced for each DMU. However, the model with output orientation tends to maximize the output production while having the same amount of input for each DMU. The input-oriented model is shown below:

$$Eff = \min_{u_r, v_i} \sum_i v_i x_{ij0} \quad (3.\ 5)$$

s.t.

$$\sum_r u_r y_{rj} - \sum_i v_i x_{ij} \leq 0 ; \forall j \quad (3.\ 6)$$

$$\sum_r u_r y_{rj0} = 1 \quad (3.\ 7)$$

$$u_r , v_i \geq 0 ; \forall r, \forall i. \quad (3.\ 8)$$

While for output-oriented model:

$$Eff = \max_{u_r, v_i} \sum_r u_r y_{rj0} \quad (3.\ 9)$$

s.t.

$$\sum_r u_r y_{rj} - \sum_i v_i x_{ij} \leq 0 ; \forall j \quad (3.\ 10)$$

$$\sum_i v_i x_{ij0} = 1 \quad (3.\ 11)$$

$$u_r , v_i \geq 0 ; \forall r , \forall i. \quad (3.\ 12)$$

These two models have pairs, and this led to the calculation of the efficiency while taking consider of production possibility set (PPS). An unquestionable and independent improvement of these models can be presented in Banker, Charnes and Cooper (1984) (BCC). Assume that DMUs {(xj, yj) j=1,…, n} is explained the same way as mentioned before. BCC propose that production possibility set have five assumptions:

assumption 1: Non-empty. (xj, yj)∈**P** (∀ j=1,...,n) then **P** is non empty.

assumption 2: Constant Returns to Scale (CRS). If (xj, yj) ∈**P** then for any non-negative scalar $\alpha \geq 0$ ($\propto$xj, $\propto$yj) ∈**P.**

assumption 3: Strong Disposability.

a) If (*x*j, *y*j) ∈**P** and *x*j1 ≥ *x*j then (*x*j1, *y*j) ∈**P** (Input Disposability).

b) If (*x*j, *y*j) ∈**P** and *y*j1 ≤ *y*j then (*x*j, *y*j1) ∈**P** (Output Disposability).

Assumption 4: Convexity. P is a closed and convex set.

Assumption 5: Minimum extrapolation. P is the smallest intersection of all production sets satisfying postulates 1 to 4 and which contains all the observed DMUs.

If all assumptions are true regarding **P** then **P** can be identified as:

P= {(x_{j0}, y_{j0}) s.t. $\sum_j \lambda_j x_j \leq x_{j0}$ *and* $\sum_j \lambda_j y_j \geq y_{j0}$, $\lambda_j \geq 0$; *j=1, ..., n*}. (3. 13-3. 14)

The vector $\lambda = (\lambda 1, \lambda 2, \ldots, \lambda n) \in R^{+n}$ give the ability to minimize or maximize solo distinguished DMU in order to make an undistinguished but practical DMU.

Using production possibility set, Farrell's technical efficiency Shephard's distance formula. A new LP model can be made to measure the efficiency of $DMU_{j0,}$ which is known as (Output oriented - CRS envelopment) model:

$$\max_{\lambda, h, s_i^-, s_r^+} h \tag{3. 15}$$

s.t.

$$\sum \lambda_j x_{ij} + S_i^- = x_{ij0} \quad \forall i \tag{3. 16}$$

$$\sum \lambda_j y_{rj} - S_r^+ = h y_{rj0} \quad \forall r \tag{3. 17}$$

$$S_i^+, S_r^- \geq 0 \qquad \forall i, \forall r \tag{3. 18}$$

$$\lambda_j \geq 0 \ \forall j. \tag{3. 19}$$

The model above is the other pair for the output-oriented model that is mentioned before.

The DMU_{j0} is Pareto efficient if two conditions are fellfield; first, the optimal value of h (h^*) is equal one and S_i^- & S_r^+ equal zero for all i and r. this indicates that DMU_{j0} is the best unit in producing output with minimum input or inputs in comparison with the other DMUs or mixed units of DMUs.

S_i, S_r represents slack. In other words, if S_i^{-*} are not zero, then there is an inefficiency in using input i, where if S_r^{+*} are not zero then there is an inefficiency in producing output r.

The model mentioned can increase the output of DMU_{j0} by taking consider of CRS-PPS. In order to have n number of optimal sets of values (h^*, λ^*) the single DMU that is being evaluated must be calculated n times from the model.

The efficiency expressed as $1/h_{j0}^*$ for the DMU_{j0}. if h_{j0}^* is larger than one then radial expansion can be done while if h_{j0}^* equal one, there is no radial expansion.

If λ is bigger than zero, this value is considered as the set that is dominating in DMUs which is on the constructed production frontier where DMU_{j0} is measured. The DMUs that have positive values are matched to the DMU_{j0}. The figure below shows CRS - output-oriented model:

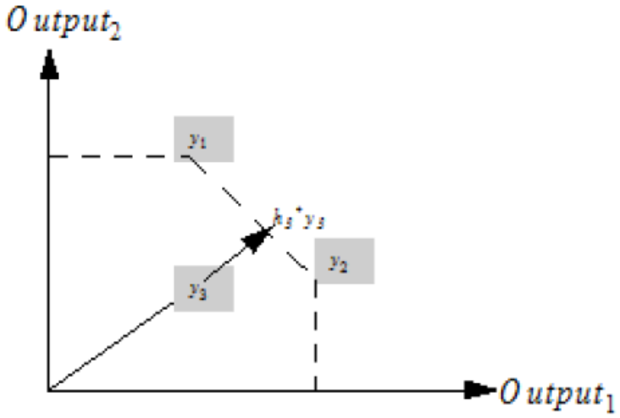

Figure 4: CRS - output-oriented Model (Output set of input x)

If we used the CRS output-oriented model to find h^* for output y_3 the value would be above one so the efficiency ($1/h^*$) would be less than one. This means that there is a possibility to expand y_3 radially without any increase in input. However, at the point $h_3^* y_3$ there is no ability to expand radially unless we increase input level, this means that the efficiency of $h_3^* y_3$ equal one and the value of h_3^* equal one. Also, since $h_3^* y_3$ is on the line of frontier $y_1 y_2$, y_3 can be measured in oppose of y_1 and y_2; hence DMUs are matched for y_3.

CRS also has an input-oriented model which can be formulated in the same manner as the output-oriented model. This model is identified below:

$$\min_{\lambda,h,s_i^-,s_r^+} \phi \quad (3.\ 20)$$

s.t.

$$\sum_j \lambda_j x_{ij} + S_i^- = \phi x_{ij0} \quad \forall i \quad (3.\ 21)$$

$$\sum_j \lambda_j y_{rj} - S_r^+ = y_{rj0} \quad \forall r \quad (3.\ 22)$$

$$S_i^+, S_r^- \geq 0 \quad \forall i, \forall r \quad (3.\ 23)$$

$$\lambda_j \geq 0 \quad \forall j. \quad (3.\ 24)$$

Same as h^*, consider ϕ^* is the optimum value of ϕ. The DMU_{j0} is Pareto efficient if two conditions are fellfield; first, the optimal value of ϕ (ϕ^*) is equal one and S_i^+ & S_r^- equal zero for all i and r. But the efficiency rate for the DMU_{j0} is ϕ^*.

3.1.2 BCC Models

Variable Returns to Scale (VRS) model was made by Banker, Charnes and Cooper (1984) (BCC). The figure below can show how VRS variance from CRS:

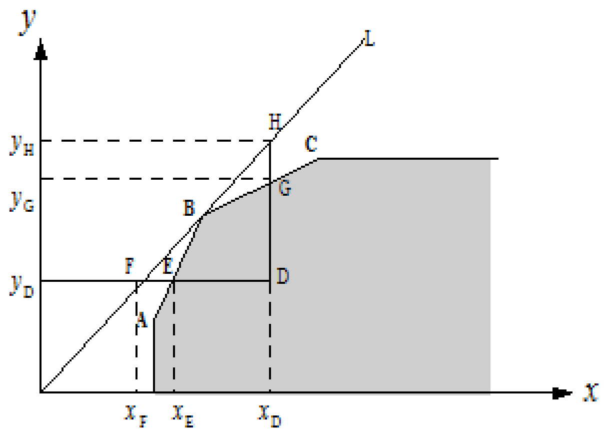

Figure 5: CRS and VRS Efficiency

The figure which has an input (x) and an output (y) axis shows the PPS limit for CRS represented by line L while the PPS limit is represented by ABC lines. As an example, an inefficient DMU_D with an input X_D and an output Y_D is introduced in the figure. The inefficiency can be calculated by match up with DMU_E for VRS and DMU_F for CRS because they have the same amount of output. Also, the efficiency rate can be calculated by dividing the input level for DMU_E with input level DMU_D. The result will show for VRS input efficiency rate. The same thing can be done with DMU_F and DMU_D to get CRS input efficiency rate. On the other hand, the measurement of inefficiency and efficiency rate related to the output can be found by applying the same method with DMU_G for VRS and DMU_H for CRS.

BCC expands the input and output oriented CRS models to measure VRS efficiency using convexity constraints. The convexity constraints for the VRS are in the models shown below.

For VRS input-oriented model:

$$\min_{\lambda,\phi,S_{\mathrm{i}}^{-},S_{\mathrm{r}}^{+}} \phi \tag{3. 25}$$

s.t.

$$\sum_j \lambda_{\mathrm{j}} x_{\mathrm{ij}} + S_{\mathrm{i}}^{+} = \phi x_{\mathrm{ij0}} \quad \forall i \tag{3. 26}$$

$$\sum_j \lambda_{\mathrm{j}} y_{\mathrm{rj}} - S_{\mathrm{r}}^{-} = y_{\mathrm{rj0}} \quad \forall r \tag{3. 27}$$

$$\sum_j \lambda_{\mathrm{j}} = 1 \tag{3. 28}$$

$$S_{\mathrm{i}}^{+}, S_{\mathrm{r}}^{-} \geq 0 \quad \forall i, \forall r \tag{3. 29}$$

$$\lambda_{\mathrm{j}} \geq 0 \ \ \forall j. \tag{3. 30}$$

For VRS output-oriented model:

$$\max_{\lambda,\theta,S_{\mathrm{i}}^{-},S_{\mathrm{r}}^{+}} \theta \tag{3. 31}$$

s.t.

$$\sum_j \lambda_{\mathrm{j}} x_{\mathrm{ij}} + S_{\mathrm{i}}^{+} = x_{\mathrm{ij0}} \quad \forall i \tag{3. 32}$$

$$\sum_j \lambda_{\mathrm{j}} y_{\mathrm{rj}} - S_{\mathrm{r}}^{-} = \theta y_{\mathrm{rj0}} \quad \forall r \tag{3. 33}$$

$$\sum_j \lambda_{\mathrm{j}} = 1 \tag{3. 34}$$

$$S_{\mathrm{i}}^{+}, S_{\mathrm{r}}^{-} \geq 0 \quad \forall i, \forall r \tag{3. 35}$$

$$\lambda_{\mathrm{j}} \geq 0 \ \ \forall j. \tag{3. 36}$$

These models show that VRS models have variety inefficiencies between inputs and outputs not like CRS who have equal input and output efficiency only (condition of convexity) (Emrouznej & Cabanda, 2015).

3.1.3 CCR Vs BCC Models

CCR models differ than BCC models in many ways that make CCR models more desirable, and this paper used the CCR models for the reasons mentioned below.

Firstly, CCR models have less calculating size than BCC, which make it easier to use. Secondly, BCC models do not care about the effect of scale size by just contrast the DMUs with almost equal scale. But usually, the small units are not equal in quality with large units, and if there any contrast between them, it will twist the calculations of comparative efficiency.

Thirdly, the calculation for the CCR input and output models are the same which mean we can solve only one model and give a conclusion for both sides while in BCC model we can have the conclusion only in the model we solve. Finally, the CCR is not affected by scale transformation because the scaled DMU stay the same while it can simply affect the BCC model efficiency calculations (Martić, Novaković, & Baggia, 2009).

3.1.4 Used Models

In this paper, the model that is used to analyze the efficiency is input-oriented CRS model which includes equations (3.5-3.8) where the DMU solved using certain weight for each input and output and finding the efficiency of each DMU

Using the efficiency frontier and the input oriented-CRS envelopment model, which is presented using the equations (3.20-3.24) the values of slacks and lambda are obtained.

The cross efficiency is a method where every efficiency for each DMU is calculated using the optimal weights of the other DMUs; these calculations can be done using the equation below:

$$Eff_{\mathrm{kr}} = \frac{\sum_r u^*_{\mathrm{rk}} y_{\mathrm{rj}}}{\sum_i v^*_{\mathrm{ik}} x_{\mathrm{ij}}}, \forall j, \forall k \ \{k=1, \ldots, n\} \tag{3. 37}$$

Where u^*_{rk}, v^*_{ik} represent the optimal weight for the DMU_k, the DMU_k is the decision making unite in the column for the cross efficiency matrix, and DMU_j is the row-unit (Zhu, 2014).

DEA can be used to determine the values in which the DMU can reach its optimum wither it was inputs or outputs value these values can be found by the efficiency rate and values of additional variables $s-$ and $s+$.

Since h^* is efficiency rate for the input-oriented model, the optimal value can be found for the input-oriented CCR model by:

$$\sum_j x^*_{\mathrm{ij0}} = x_{\mathrm{ij0}}\, h^* - s_{\mathrm{i}}^{-} \tag{3. 38}$$

$$\sum_j y^*_{\mathrm{rj0}} = y_{\mathrm{rj0}} + s_{\mathrm{r}}^{+}. \text{ (Kočišová, 2004).} \tag{3. 39}$$

Where x^*_{ij0}, y^*_{rj0} represent the target values in which the DMU_{j0} become efficient.

3.2 Data Collection

The data was taken from Boytek company which produce and sell unsaturated polyester for different uses. These data were gathered during the period 2014-2016, and they are divided in months. The data are divided into:

a) Labor.

b) Food.

c) Security.

d) Electricity.

e) Water.

f) Natural Gas.

g) Repair for Machines.

h) Building & Vehicle Insurance.

i) Management.

j) Sales & Marketing.

k) Research & Development.

l) Consulting.

m) Vehicle Gasoline.

n) Cost of raw materials.

o) Selling products.

In order to calculate the efficient use of the DEA models, we firstly used a single unite for inputs and outputs to be able to determine the efficiency. In this paper, the type of data collected for inputs and outputs were in US dollar currency, where the cost of products during the month are collected for each category while also having the total profit from selling products.

For simplicity, satisfy the rule of thumb and to close the gap in the size of the data in some of the inputs. Some of these categorize are summed into groups and put into the PIM-DEA as a single input. While the total profit of selling was included as an output. Also, the research and development (R&D) sector were reversed to include it in the model as an output in which the cost of R&D in each month are subtracted from the highest cost value in the entire range of 2014-2016.

These new groups are presented as follows:

- Consumables:

Consumables consist of food and water which are used during breaks and lunchtime.

- Energy Consumption:

Energy consumption includes any procedure or mechanism that use petroleum sources in which they are used to make and deliver the products, such as electricity, natural gas and vehicle gasoline.

- Safety:

Safety consists of individual and building protection from any bad scenario that can happen, and it includes security, repair & vehicle insurance and repair for machines.

- Administration:

The administration is divided into consulting and management where these two provide policies, order and control in the factory.

After the summary of some groups, there are seven inputs and two outputs included in this paper, and according to the rule of thumb, the number of DMUs must exceed or equal the total of inputs and outputs multiply by three $\{n \geq 3x(m+s)\}$. Since there are 36 DMU with six inputs and two output, then the rule of thumb is satisfied.

The difference in currency during the period 2014-2016 is low. In this paper the difference in the currency is neglect, and the inputs and outputs are transformed in the currency in United States dollar

Chapter 4

RESULTS

The results were obtained by using PIM-DEA, where the data was divided into seven inputs and two outputs. This chapter will show the results of this analysis in tables with an explanation of the values contain within. The efficiency, weights, cross efficiency, lambda, slack and target are the models used below.

4.1 Efficiency

Table (6) below shows the efficiency of each month, which can help to determine the efficient DMUs using the inputs and outputs that most suits them individually. The efficiency values obtained using the CCR model in PIM-DEA software. These values can help the company to identify easily which one of the previous months had the most profit with the least cost.

Table 6: DMUs Efficiencies

Name	**Efficiency**	**Name**	**Efficiency**
DMU01	100	DMU19	100
DMU02	100	DMU20	100
DMU03	99.45	DMU21	90.62
DMU04	95.37	DMU22	89.44
DMU05	100	DMU23	94.82
DMU06	100	DMU24	95.18
DMU07	98.26	DMU25	85.59
DMU08	96.85	DMU26	82.62
DMU09	100	DMU27	84.69
DMU10	99.85	DMU28	89.09
DMU11	100	DMU29	88.29
DMU12	98.82	DMU30	84.53

DMU13	90.19	DMU31	80.84
DMU14	94.61	DMU32	88.52
DMU15	90.27	DMU33	84.42
DMU16	91.53	DMU34	87.03
DMU17	93.52	DMU35	90.62
DMU18	90.36	DMU36	87.16

Table 6 shows the efficiency in percentage (%) where the DMUs that have 100% efficiency are considered to be efficient month such as DMU01 which mean the company gain maximum profit with minimum cost. Otherwise, the DMU is not efficient and the percentage of cost that can be avoided equally to the same percentage of the difference between the efficient DMUs and that inefficient DMU like DMU03 with the amount of profit that can be gained equal to 0.15%.

Efficient DMUs lay in the efficient frontier plan, which means that these months were efficient, and no extra cost was spent while having maximum profit. Also, the R&D is a reversed output which means that the more output value, the lower the cost will be.

The table (6) above shows that there are 8 DMUs have 100% efficiency which is 22% of the total DMUs, and the lowest DMU inefficiency is DMU31 where the efficiency value equal 80.84%.

The line chart below represents the efficiency of DMUs during the selected period.

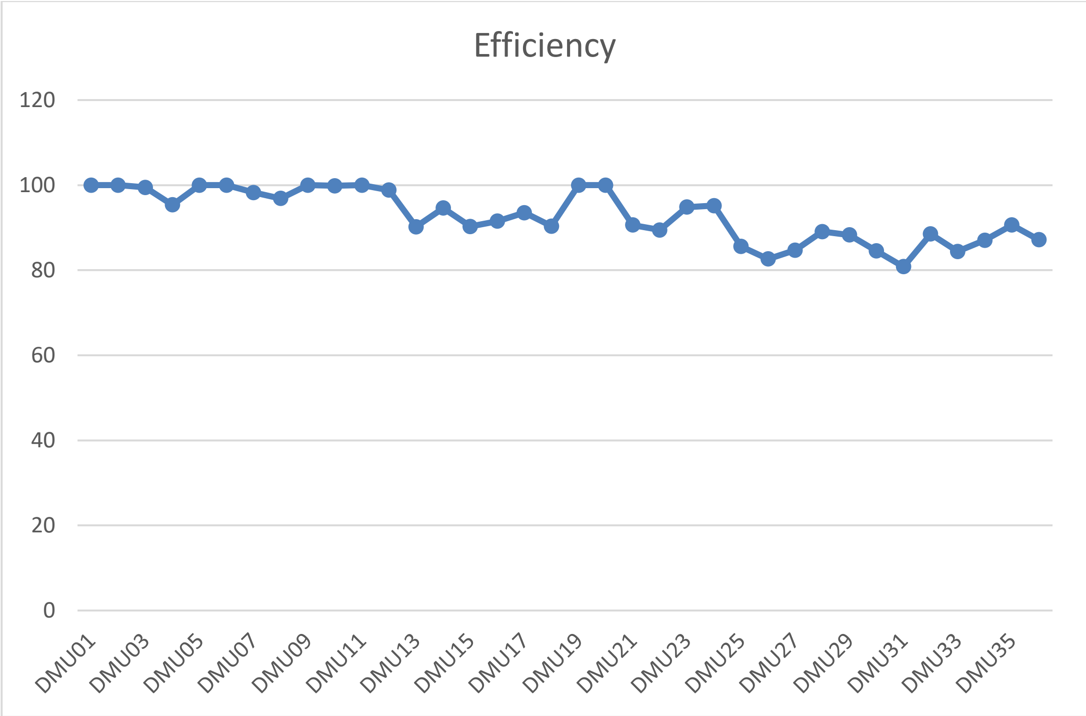

Figure 6: Efficiency Chart

The efficiency is close to become linear in the first year and start fluctuating as time goes by. There is a weird pattern which is after two months that have 100% efficiency, there is drop for two months two like DMU01, DMU02 which are efficiently followed by DMU03 and DMU04 that has a 99.45% 95.37% efficiency value.

According to the chart, there are general decreasing in the efficiency values in each year where the last year (2016) contain DMUs with minimum values of efficiency which can also indicate that the efficiency is going to drop in the years that came after this period that is being analyzed and there must be actions to take in order to prevent that.

4.2 Weights

The table below shows different weights given for inputs and outputs for each DMU. These values determine the significance of each input and output for every single DMU. Where the input or output with the most weight is the one contributing to the highest in calculating the efficiency of the DMU and the least weight are the lowest contributor.

Table 7: Weights of Inputs & Outputs

Name	Labor	consumables	Energy consumption	Safety	Administration	Sales & Marketing	cost of raw materials	selling products ($)	R&D (output)
DMU01	0	0	0.13	0	0.38	0	0.7	1.12	0.06
DMU02	0	0	1.18	0	0	0	0	0.7	0.43
DMU03	0	0.59	0	0	0	0	0.87	1.18	0.02
DMU04	0	0.31	0	0.03	0	0	1.05	1.2	0.03
DMU05	0	0	0.04	0.04	0.34	0	0.81	1.13	0.05
DMU06	0	0	0.32	0	0.48	0	0.38	1.03	0.1
DMU07	0	0	0	0	0	0	1.54	1.43	0.1
DMU08	0	0	0	0	0	0.01	1.3	1.27	0
DMU09	0	0	0.3	0	0.44	0	0.35	0.95	0.1
DMU10	0	0.34	0	0.03	0	0	1.16	1.33	0.03
DMU11	0	0	0.31	0	0.47	0	0.37	1	0.1
DMU12	0.42	0	0	0.5	0.57	0	0	0.94	0.23
DMU13	0	0	0	0	0	0	1.32	1.28	0
DMU14	0	0	0.14	0	0.02	0	1.01	1.1	0.05
DMU15	0	0	0	0	0	0	1.36	1.32	0
DMU16	0	0	0	0.01	0	0	1.4	1.31	0.08
DMU17	0	0	0.66	0	0	0	0.59	1.06	0.16
DMU18	0	0	0.16	0	0	0	1.08	1.17	0.06
DMU19	0	0	0.65	1.78	0	0	0	0.8	0.92
DMU20	0	0	0.33	0	0.48	0	0.38	1.04	0.11
DMU21	0	0	0.19	0	0	0	1.28	1.39	0.07
DMU22	0	0	0.08	0	0	0	1.14	1.19	0
DMU23	0	0	0.15	0	0	0	1.02	1.1	0.05
DMU24	0	0	0.63	0	0	0	0.56	1.02	0.16
DMU25	0	0	0	0	0	0	1.32	1.28	0
DMU26	0	0	0	0	0	0	1.19	1.16	0
DMU27	0	0	0	0	0	0	1.11	1.08	0
DMU28	0	0	0	0	0	0	1.1	1.07	0
DMU29	0	0	0.06	0	0.03	0	0.96	1.02	0
DMU30	0	0	0	0	0	0	1.13	1.1	0
DMU31	0	0	0	0	0	0	1.65	1.53	0.1
DMU32	0	0	0.07	0	0	0	0.97	1.01	0
DMU33	0	0	0	0	0	0	1.57	1.53	0
DMU34	0	0	0.05	0	0.03	0	0.93	0.98	0
DMU35	0	0	0.06	0	0	0	0.94	0.98	0
DMU36	0	0	0.06	0	0	0	0.95	0.99	0

The weights that are distributed in the inputs and outputs are considered as a sign on the contribution of the input or the output as mentioned before. For example, DMU01 (January 2014) have zero weights in inputs (Labor, Consumables, Safety, Sales & Marketing) which means that they did not contribute in the efficiency evaluation for

DMU01 while the output R&D have low weight (0.06) which means that the contribution of this output in the efficiency measurement is not significant as the selling products that have high weight (1.12). The same thing is applied in all DMUs where if the input or output have weight value bigger than zero, then it is contributing to the evaluation of the efficiency.

We can also notice that some DMUs are depending only on the cost of raw materials as input and selling products as an output like DMU25 (January 2016), DMU26 (February 2016) .... Also, DMU02 (February 2014) deepened only on energy consumption as input for efficiency evaluation.

The chart below represents the total weights for each input and output that was used for the DMUs.

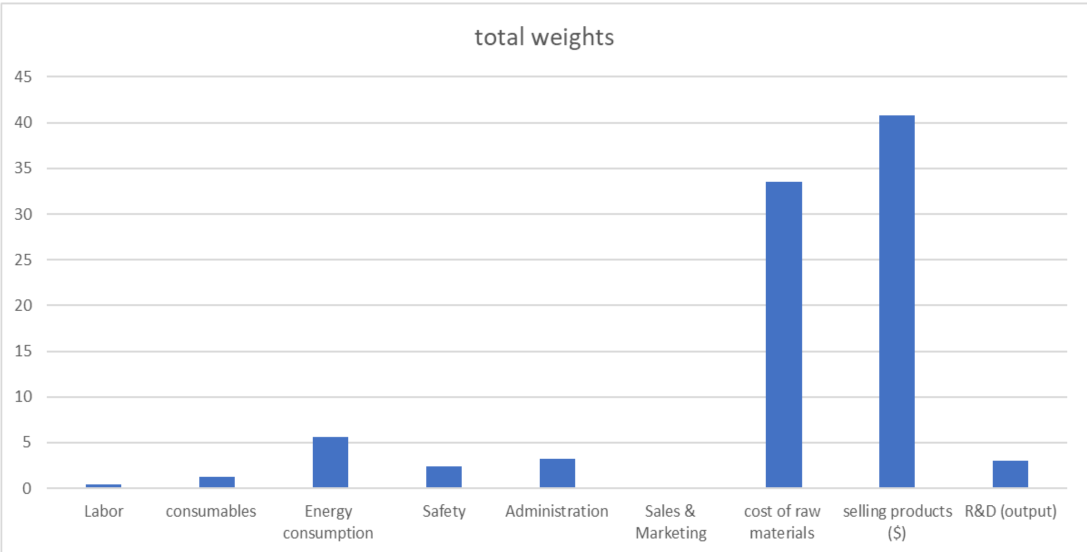

Figure 7: Total Weights of Inputs and Outputs

According to this figure, the most input that contributed in efficiency measurement is the cost of raw materials with a total weight of {33.49} while the lowest inputs are consumables, labor and sales & marketing where their total weights are {1.24},{0.42}and{0.01} accordingly. This means that the company should focus on reducing the cost of raw materials since it has the most weighted input by all DMUs, followed by energy consumption, administration, safety, consumables, labor, sales & marketing where the last two are affecting only on one input each.

The most significant output is the Selling products where the total weight given to each DMUs are {40.79} while R&D has a total weight of {3.01} which mean that the company should focus on improving the profit coming from selling products more than the R&D.

4.3 Cross Efficiency

The table in appendix (A) shows the measurement of DMUs efficiency after using the weights of every DMU in the fraction of the cross efficiency. The table is calculated by solving each DMU n time using the weights which was evaluated using n LPs. This method has existed to overcome the weight flexibility problem where it can ignore some input and outputs. The cross efficiency can also determine the DMU that can be used as a reference among the efficient DMUs. This help the company to have an optimal production process and performance.

Appendix (A) show DMUs evaluated using cross efficiency where the efficient DMUs are the units which have efficiency value of 100% and indicate that their performance using the weights of the inputs and output from the selected DMU are optimal.

The efficient DMU that have 100% efficiency values more than other efficient DMUs are the unit that has the best performance than the other efficient DMUs, using this information, a bar chart is presented below where the DMUs that have efficiency values equal 100% are mentioned in the bar chart and the total numbers of cells that has the value 100% in each column.

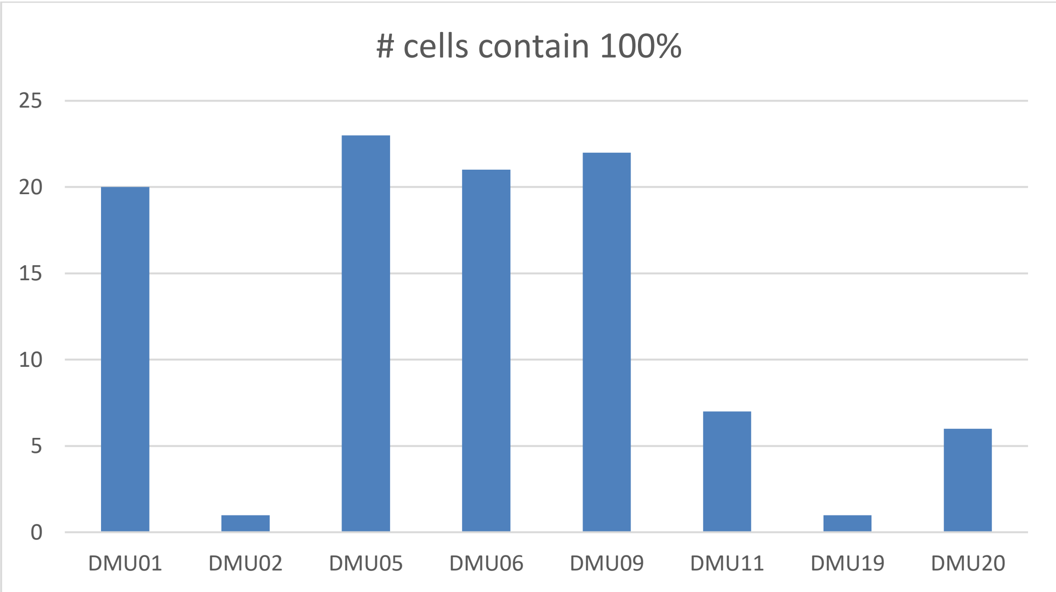

Figure 8: Number of Cells That Contain 100% Efficiency

We can notify that the efficient DMUs are the same units that are considered efficient using CRS input model, which confirm our results regarding the efficient DMUs. On the other hand, DMUs that have more numbers of efficient cells have better efficiency than the other DMUs. According to that, DMU05 (May 2014) is the most efficient DMU and the most appropriate as a reference unit in order to increase the performance of the other DMUs since it has a total of 23 cells with an efficiency score of 100% like [DMU04, DMU05…] while other units such as DMU09 (September 2014) and DMU06 (June 2014) are close to DMU05 with the total number of cells 22 and 21 respectively.

4.4 Lambda

The lambda values (λ) which can be found using the dual model of CCR are presented in the table below; these values indicate the score in which an inefficient DMU will compare itself with the efficient DMU in order to reach optimality. This can provide assistance in having one or more DMUs as a reference for improving the efficiency of all inefficient DMUs, which can increase company performance.

Table 8: Lambda Values

Name	DMU01	DMU02	DMU05	DMU06	DMU09	DMU11	DMU19	DMU20
DMU01	1	0	0	0	0	0	0	0
DMU02	0	1	0	0	0	0	0	0
DMU03	0.03	0	0	0.2	0.64	0	0	0
DMU04	0.03	0	0.71	0.09	0.06	0	0	0
DMU05	0	0	1	0	0	0	0	0
DMU06	0	0	0	1	0	0	0	0
DMU07	0.71	0	0	0.05	0	0	0	0
DMU08	0.22	0	0.67	0	0	0	0	0
DMU09	0	0	0	0	1	0	0	0
DMU10	0.39	0	0.1	0.22	0.13	0	0	0
DMU11	0	0	0	0	0	1	0	0
DMU12	0	0	0.11	0.28	0.08	0.51	0	0
DMU13	0.78	0	0.04	0	0	0	0	0
DMU14	0.18	0	0.01	0.26	0.44	0	0	0
DMU15	0.59	0	0.2	0	0	0	0	0
DMU16	0.6	0	0.16	0.02	0	0	0	0
DMU17	0	0	0	0.18	0.53	0	0	0.13
DMU18	0	0	0.39	0.06	0.37	0	0	0
DMU19	0	0	0	0	0	0	1	0
DMU20	0	0	0	0	0	0	0	1
DMU21	0	0	0.52	0.09	0.1	0	0	0
DMU22	0	0	0.53	0	0.29	0	0	0
DMU23	0	0	0.24	0.02	0.62	0	0	0
DMU24	0	0	0	0.06	0.76	0	0	0.05
DMU25	0.78	0	0	0	0	0	0	0
DMU26	0.36	0	0.48	0	0	0	0	0
DMU27	0.87	0	0.05	0	0	0	0	0
DMU28	0.97	0	0	0	0	0	0	0
DMU29	0.03	0	0.9	0	0.07	0	0	0
DMU30	0.34	0	0.56	0	0	0	0	0
DMU31	0.55	0	0	0.04	0	0	0	0
DMU32	0	0	0.79	0	0.21	0	0	0
DMU33	0.39	0	0.25	0	0	0	0	0
DMU34	0.02	0	0.84	0	0.15	0	0	0
DMU35	0	0	0.78	0	0.26	0	0	0
DMU36	0	0	0.95	0	0.07	0	0	0

Based on the table above, values of lambda are ranging between 0-1 for each DMU. Which mean if the value of lambda equal zero the inefficient DMU does not compare itself with the efficient DMU in that column where if it was positive then the inefficient

DMU compare itself with the efficient DMU of that column. We should notice that the more the value of lambda the more the efficient DMU are best suited as a reference for that inefficient DMU.

When the value of lambda is one then the DMU that is being compared is the same efficient DMU in the column. Such as DMU01 (January 2014) and DMU02 (February 2014). For example, DMU03 (March 2014) can be compared with DMU01 (January 2014), DMU06 (June 2014) and DMU09 (September 2014) where the values of lambda equal 0.03,0.2 and 0.64 respectively, and since DMU09 has the biggest value of lambda it is considered that the DMU09 are the best reference for DMU03 in order to increase its performance.

Since the values of lambda are different from in each efficient DMU, the table below shows the best reference DMUs for each DMUs according to their lambda values.

Table 9: The Best Efficient DMU as a Reference According to Lambda

DMU	Best reference	DMU	Best reference
DMU01	DMU01	DMU19	DMU19
DMU02	DMU02	DMU20	DMU20
DMU03	DMU09	DMU21	DMU05
DMU04	DMU05	DMU22	DMU05
DMU05	DMU05	DMU23	DMU09
DMU06	DMU06	DMU24	DMU09
DMU07	DMU07	DMU25	DMU01
DMU08	DMU05	DMU26	DMU05
DMU09	DMU09	DMU27	DMU01
DMU10	DMU01	DMU28	DMU01
DMU11	DMU11	DMU29	DMU05
DMU12	DMU11	DMU30	DMU05
DMU13	DMU01	DMU31	DMU01
DMU14	DMU09	DMU32	DMU05
DMU15	DMU01	DMU33	DMU01

DMU16	DMU01	DMU34	DMU05
DMU17	DMU09	DMU35	DMU05
DMU18	DMU05	DMU36	DMU05

Also, a bar chart is presented below, which contain the total number each time efficient DMU has the highest lambda value.

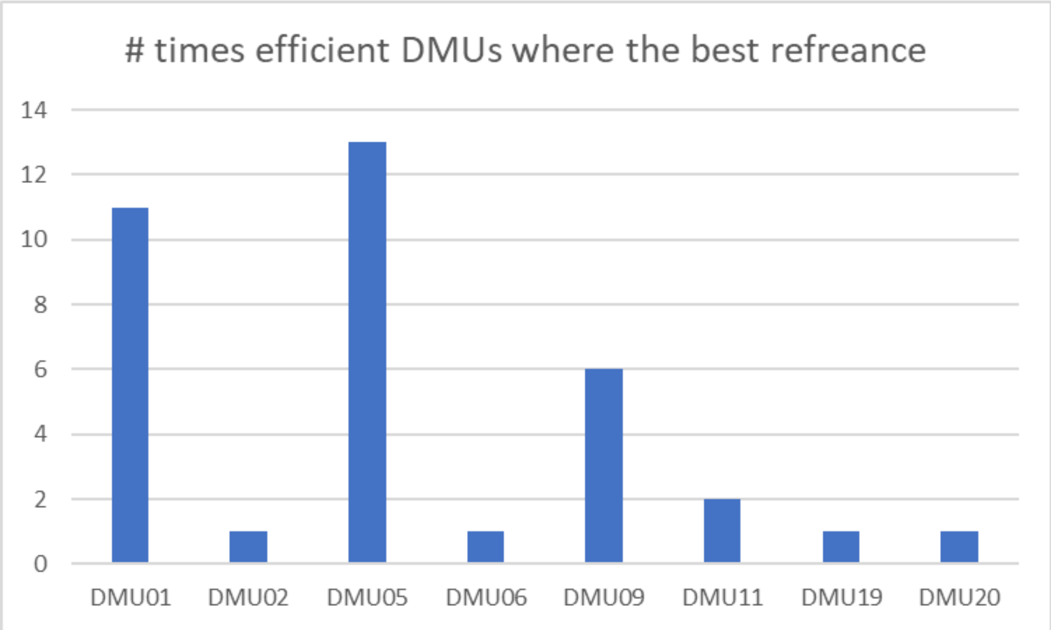

Figure 9: Number of Times DMU Identified as a Best Reference

According to the figure above, DMU05 (May 2014) has the most numbers referred DMU with 13 DMUs [DMU04, DMU05, DMU08…] giving it the highest lambda value, then DMU01 (January 2014) with 11 and so on. In conclusion, DMU05 (May 2014) is the best benchmark for inefficient DMUs.

4.5 Slack

The table below shows the value of slacks for each input and output, Which can help increase the performance of the company. Slack can give information about the range in order for the company to reach efficiency by improving its inputs and outputs values.

Table 10: Slack Values

Name	Labor	Consumbles	Energy consumption	Safety	Administration	Sales & Marketing	cost of raw materials	selling products ($)	R&D (output)
DMU01	0	0	0	0	0	0	0	0	0
DMU02	0	0	0	0	0	0	0	0	0
DMU03	0.09	0	0.13	0.09	0.05	0.16	0	0	0
DMU04	0.04	0	0.05	0	0.05	0.01	0	0	0
DMU05	0	0	0	0	0	0	0	0	0
DMU06	0	0	0	0	0	0	0	0	0
DMU07	0.31	0.04	0.11	0.27	0.19	0.1	0	0	0
DMU08	0.06	0.06	0.05	0.12	0.06	0	0	0	0.03
DMU09	0	0	0	0	0	0	0	0	0
DMU10	0.27	0	0.08	0	0.13	0.04	0	0	0
DMU11	0	0	0	0	0	0	0	0	0
DMU12	0	0.02	0.04	0	0	0.01	0.03	0	0
DMU13	0.1	0.18	0.02	0	0.08	0.12	0	0	0.17
DMU14	0.08	0.16	0	0.7	0	0.14	0	0	0
DMU15	0.11	0.19	0	0	0.1	0.14	0	0	0.03
DMU16	0.13	0.25	0.03	0	0.12	0.18	0	0	0
DMU17	0.1	0.18	0	0.24	0.03	0.2	0	0	0
DMU18	0.11	0.1	0	0.3	0.04	0.22	0	0	0
DMU19	0	0	0	0	0	0	0	0	0
DMU20	0	0	0	0	0	0	0	0	0
DMU21	0.27	0.16	0	0.02	0.15	0.24	0	0	0
DMU22	0.11	0.25	0	0.17	0.03	0.18	0	0	0.12
DMU23	0.12	0.25	0	0.17	0.01	0.24	0	0	0
DMU24	0.13	0.26	0	0.03	0	0.26	0	0	0
DMU25	0.14	0.34	0.16	0.02	0.15	0.23	0	0	0.15
DMU26	0.08	0.27	0.09	0	0.07	0.18	0	0	0.16
DMU27	0.04	0.26	0.03	0	0.04	0.13	0	0	0.21
DMU28	0.04	0.27	0.01	0.17	0.04	0.12	0	0	0.5
DMU29	0.03	0.28	0	0.43	0	0.11	0	0	0.25
DMU30	0.06	0.31	0.04	0	0.06	0.14	0	0	0.22
DMU31	0.41	0.34	0.2	0	0.32	0.25	0	0	0
DMU32	0.01	0.32	0	0.47	0.02	0.2	0	0	0.55
DMU33	0.39	0.31	0.19	0	0.3	0.25	0	0	0.02
DMU34	0.02	0.32	0	0.23	0	0.17	0	0	0.61
DMU35	0.04	0.35	0	0.33	0.03	0.19	0	0	0.31
DMU36	0.02	0.29	0	0.41	0.04	0.17	0	0	0.55

Based on the table above, the value of slacks for inputs and outputs range between 0-0.7, efficient DMUs have slack values equal zero for both inputs and outputs, which mean that the inputs are minimized to its optimal value. There is no way to decrease the input value without changing the output level, while the outputs are maximized, and there is no way to increase the output without changing the input level.

The slack values can be used to give target value for each input and output. For example, in DMU03 (March 2014) the input Labor has a slack value equal 0.09 unite which mean that the value of input must be reduced by 0.09 unite in order to reach its optimal while input Consumables have zero slack which means there is no need to reduce its input since it reaches its optimum.

On the other hand, the slack values are zero the selling products has no slack value, which means that there is no way to increase the output without changing the input level. But DMU08 (August 2014) has a slack value equal to 0.03 unite for R&D, which means that R&D must increase its value by 0.03 unite to reach its optimal.

A total of slack values for each DMU are shown below to show the amount of inputs can be reduced or outputs that can be increased.

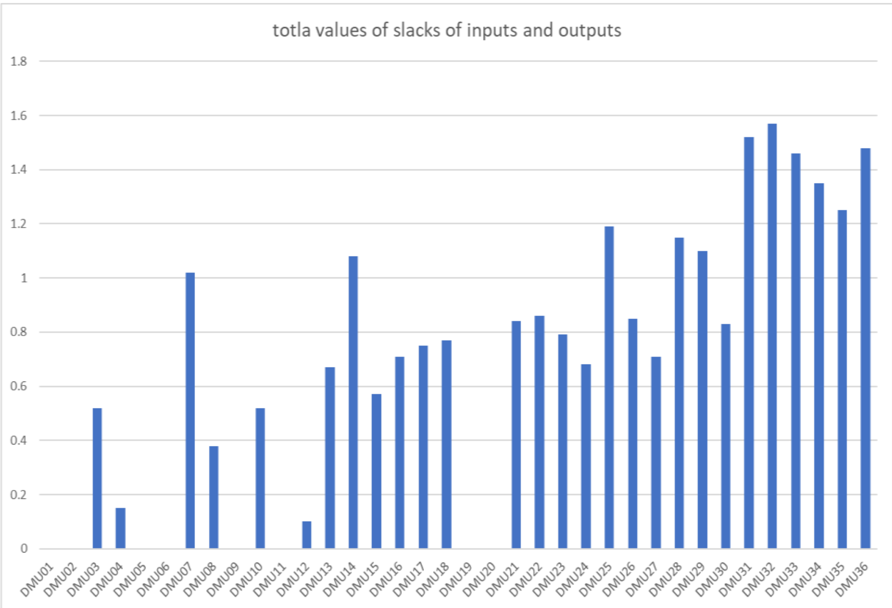

Figure 10: Total Values of Slacks of Inputs and Outputs

It can be shown in the table above that the DMUs with the zero total slack values are the efficient DMUs according to the efficiency table (6), DMU12 (December 2014) have the lowest total slack of 0.1 which mean that it needs to decrease its input or increase its output by 0.1 unite. While DMU04 (April 2014) has total slack of 0.15, which mean that the slack that needs to be increased or decreased according to the type of slack is 0.15 and so on.

Selling products have no slack values, which mean that the output selling products reach its optimum value, and there is no increase can be done. Also, the slack can identify how much the DMUs are near the efficiency frontier, the DMUs with small slack values means that there are closer to reach optimum, and also means that the energy required to become efficient are less than the DMUs with more slack values.

4.6 Target

As mentioned before, the slack values can be used in order to set a target value to increase the efficiency of the DMU, the table in the appendix (B) shows the values of each input and output along with the target value that needs to be reached by input and output variables. Moreover, the gain % from decreasing the input and increasing the output.

Appendix (B) can be used in order to reach optimal efficiency for the DMU. For example, in DMU03 (March 2014) Labor has a value of 0.68, and the target value is 0.59 in which the input reaches its optimum, the difference in the actual value and the target value equal 0.09 which is the same as the slack value in table 13 and the gain for reaching the target value equal -13.46 %.the negative sign (-) indicate the amount of gain that is having from reaching the target.

In DMU08 (August 2014) output value for R&D equal 0.53 while the target value equals 0.56 with 0.03 difference between them and the gain equal 6.09%. the positive sign in the gain value indicates the amount of gain that is having from reaching target value.

We can summarize the DMUs in which their value and target value are the same, which mean there is no need to decrease the input or increase the output since it reaches its optimality.

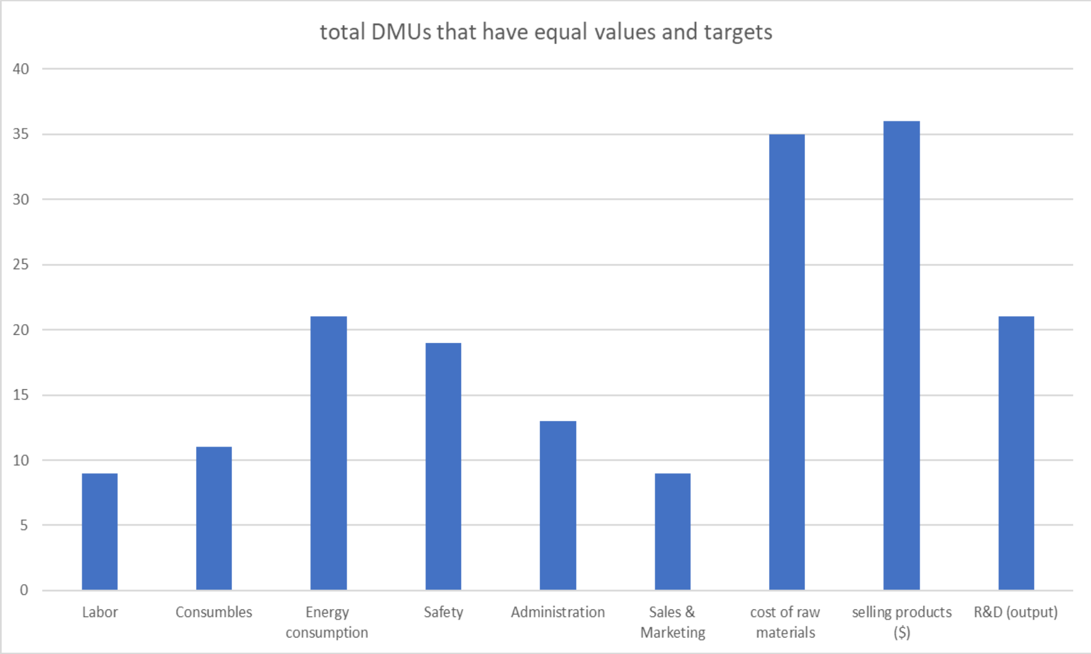

Figure 11: Total DMUs That Have Equal Values and Target Values.

These total values show that cost of raw materials have 35 DMUs which have equal values and target values, and there is no need to decrease the amount of cost in these DMUs while energy consumption has 21 DMUs that have the same values and target values, and so on, these also show that selling products are fulfilled in all the DMUs.

Chapter 5

CONCLUSION AND RECOMMENDATION

A small conclusion about this paper where the analysis that is done and mentioned in chapter 4 are summarized in this chapter. Also, the values in which the company should take into consideration in the next year are mentioned below, along with some recommendations that can be taken.

5.1 Conclusion

In this paper, the performance of a chemical company has been evaluated using Data Envelopment Analysis (DEA). The model that was used in the research is CCR input-oriented model with seven inputs which is (Labor, Consumables, Energy consumption, Safety, Administration, Sales & Marketing, cost of raw materials) and two outputs (Selling products, R&D).

Chapter 1 presents an introduction about the unsaturated polyester resin industry along with some information about the company and the challenges they encounter and the applied method on this research which is DEA with little information about the structure of this paper. Chapter 2 provides some articles that used DEA as a tool to improve the efficiency in the chemical sector. Chapter 3 gives basic information about the CCR model, which was used in this paper and the advantage of this model over BCC, also, how the data is collected and organized. Chapter 4 provides tables that include results of analyzing the data using PIM-DEA software and give a small explanation about these results.

In summary, the results show that DMUs which have the lowest cost with the most profit depending on the table (6) are DMU01 (January 2014), DMU02 (February 2014), DMU05 (May 2014), DMU06 (June 2014), DMU09 (September 2014), DMU11 (November 2014), DMU19 (July 2015), DMU20 (August 2015).

The weight of the inputs and outputs, which is an indication of their contribution to the efficiency evaluation are shown in table (7).

Cross efficiency values which determine the DMU that is most suitable to be used as a reference are shown in the appendix (A) where the results show that DMU05 (May 2014) are the best benchmark unit.

Lambda values which can indicate the best reference for each inefficient DMU are shown in the table (8) where it shows the DMU05 (May 2014) have the greatest number of DMUs that give it high lambda values.

While the slack in the table (10) shows the amount of value for inputs (outputs) that need to be reduced (increased) in order for the company to increase its efficiency and can be used to find the inputs and outputs target values.

Appendix (B) shows the value of each input and output along with the target value and the percentage of gain from reaching these target values.

5.2 Forecast

Taking into consideration the target values from the appendix (B) the amount of maximum cost can be accepted and the minimum profit for the next year in order to contain high-efficiency values for each month is shown in appendix (C).

Appendix (C) give values for each input and output in each month in order to reach optimality or near optimality. Using DEA target model can benefit in determining the input values needed to produce a certain amount of outputs where the more you can produce with less input are the better for the company taking into consideration the quality of the products. We should notify that R&D are a reversed output which mean that the values represent the difference between the monthly cost and the maximum cost calculated during the period 2014-2016.

Also, according to the efficiency table (6), cross efficiency table and lambda table (8) the DMU05 (May 2014) is one of the efficient DMUs and has the most number efficient values in cross efficiency analysis as well as having the most number of the highest lambda values from each inefficient DMUs. This means that DMU05 should be taken as a reference when changing the policies and actions of the company to increase efficiency since it has the results mentioned above. The policies and actions that are done during May 2014 should be replicated on the change in circumstances and the difference in the months and the production volume.

The weight table (7) shows that the order of the most significant inputs which are the cost of raw materials, energy consumption, administration, safety, consumables, labor, sales & marketing. So, in order to increase the company performance, there should be increased attention on improving the cost of raw materials because it has the most effect in the efficiency evaluation followed by energy consumption, administration, safety and so on. Also, the company should increase its profit of selling products since it has weight bigger that R&D, which mean it has more effect on the efficiency.

These values can assist the company in using their available input in a more efficient way and avoiding any extra cost needed to produce the output. The tables can also help in the decreasing values of efficiency that was noticed in the period 2014-2016.

5.3 Recommendation

The efficiency values for the company during the period 2014-2016 are above 80%, which means the company's performance is good. However, there is a room for improvement in the efficiency. Also, the efficiency values show a drop during the years, where 2016 have the lowest efficiency values.

Since the cost of raw materials has a significant effect in the efficiency value, a new supplier can offer raw materials cheaper than the suppliers that the company deals with. Also, a contract based with the supplier contain a huge amount of raw materials can make the supplier offer certain discounts. And a spot basis purchase can be made where the company keep in touch with other suppliers that can offer some raw materials at a low cost as well as finding the best path and method to receive the raw materials which can be researched as an efficiency evaluation for supply management.

Also, Boytek company is an international company which exports to 40 countries, an efficiency evaluation for the methods and the paths of the transportation can be done in order to decrease the cost of energy consumption along with sales & marketing. As well as investing in solar power and using sun panels on the roofs of the factories and the roof of car parking. The cost of labor can be reduced by avoiding overload manpower. Also, since the company has two factories in turkey, a separate efficiency evaluation can be done on both factories and compared between each other.

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APPENDICES

Appendix A: Cross Efficiency

Name	DMU01	DMU02	DMU03	DMU04	DMU05	DMU06	DMU07	DMU08	DMU09	DMU10	DMU11	DMU12	DMU13	DMU14	DMU15	DMU16	DMU17	DMU18	DMU19	DMU20	DMU21	DMU22	DMU23	DMU24	DMU25	DMU26	DMU27	DMU28	DMU29	DMU30	DMU31	DMU32	DMU33	DMU34	DMU35	DMU36
DMU01	100.0	95.3	95.8	91.9	98.8	100.0	88.2	92.7	100.0	93.3	100.0	96.4	85.4	94.6	85.7	85.7	92.1	88.5	76.3	96.9	83.5	86.8	94.2	94.8	76.8	77.5	81.8	85.0	86.0	80.1	64.7	84.1	69.1	83.0	87.3	82.2
DMU02	86.0	100.0	78.9	78.4	86.2	100.0	73.6	76.9	90.9	81.2	86.3	85.4	67.6	87.5	76.2	75.9	87.9	80.7	81.2	99.3	80.4	73.2	85.1	87.5	54.3	56.8	62.6	57.0	66.8	60.8	50.5	56.0	53.7	53.0	67.5	55.1
DMU03	100.0	96.1	99.5	94.1	98.3	100.0	95.4	92.2	100.0	99.7	97.6	94.5	79.5	86.5	78.8	76.8	81.9	84.3	67.2	83.7	79.5	75.8	82.2	81.9	67.9	68.5	72.4	75.8	74.7	69.5	60.5	73.3	65.4	71.9	75.1	73.0
DMU04	100.0	97.0	99.2	95.4	100.0	100.0	95.8	94.6	100.0	99.9	97.9	94.9	84.1	88.5	84.2	83.6	86.2	86.6	74.9	88.0	85.0	81.7	87.7	87.7	75.3	74.9	77.7	80.7	80.1	76.2	69.1	78.8	73.7	77.8	81.4	78.3
DMU05	100.0	95.6	96.8	93.5	100.0	100.0	89.0	93.9	100.0	94.8	100.0	96.6	86.2	92.1	86.4	86.8	91.2	88.0	77.7	95.5	84.8	87.1	93.9	94.7	78.9	79.3	82.5	85.2	85.8	81.5	67.7	84.1	72.2	83.8	87.5	82.6
DMU06	98.0	94.5	92.7	88.7	96.6	100.0	82.3	88.9	100.0	89.2	100.0	96.2	81.5	94.2	82.6	82.1	92.3	87.2	73.9	100.0	80.5	84.7	93.5	95.0	70.6	72.9	78.4	80.7	83.2	76.2	57.5	80.2	62.0	79.1	84.5	78.1
DMU07	100.0	98.7	97.5	95.0	99.7	100.0	98.3	96.4	97.5	99.4	96.0	93.6	88.8	93.4	90.0	91.5	90.7	89.1	84.0	91.3	90.1	87.5	93.0	92.6	84.4	81.3	83.3	85.7	86.2	82.8	80.8	84.2	84.1	82.6	87.8	83.3
DMU08	100.0	95.8	98.3	95.1	100.0	98.0	98.1	96.9	99.2	99.2	97.3	93.9	90.1	93.6	90.2	91.4	91.4	89.7	82.1	92.2	90.1	89.0	94.1	93.8	85.4	82.5	84.6	89.0	88.2	84.5	80.5	88.2	84.2	86.8	90.3	87.0
DMU09	98.0	94.5	92.7	88.7	96.6	100.0	82.3	88.9	100.0	89.2	100.0	96.2	81.5	94.2	82.6	82.1	92.3	87.2	73.9	100.0	80.5	84.7	93.5	95.0	70.6	72.9	78.4	80.7	83.2	76.2	57.5	80.2	62.0	79.1	84.5	78.1
DMU10	100.0	97.0	99.2	95.4	100.0	100.0	95.8	94.6	100.0	99.9	97.9	94.9	84.1	88.5	84.2	83.6	86.2	86.6	74.9	88.0	85.0	81.7	87.7	87.7	75.3	74.9	77.7	80.7	80.1	76.2	69.1	78.8	73.7	77.8	81.4	78.3
DMU11	98.0	94.5	92.7	88.7	96.6	100.0	82.3	88.9	100.0	89.2	100.0	96.2	81.5	94.2	82.6	82.1	92.3	87.2	73.9	100.0	80.5	84.7	93.5	95.0	70.6	72.9	78.4	80.7	83.2	76.2	57.5	80.2	62.0	79.1	84.5	78.1
DMU12	87.3	92.9	88.2	90.3	100.0	100.0	59.6	81.5	100.0	77.2	100.0	98.8	68.5	65.4	71.9	71.4	76.7	71.2	67.4	91.3	70.1	72.9	81.6	87.9	60.4	68.1	67.8	61.4	66.8	70.7	45.9	60.9	51.2	66.1	70.5	61.1
DMU13	100.0	95.8	98.3	95.1	100.0	98.0	98.1	96.8	99.1	99.2	97.3	93.9	90.2	93.6	90.3	91.5	91.5	89.8	82.3	92.3	90.3	89.1	94.1	93.9	85.6	82.6	84.7	89.1	88.2	84.5	80.7	88.3	84.4	86.9	90.4	87.1
DMU14	100.0	97.9	97.5	94.5	100.0	100.0	95.9	95.8	100.0	98.2	97.9	94.7	88.7	94.6	89.9	90.8	92.8	90.3	83.3	94.8	90.3	88.7	94.8	94.9	82.0	80.3	83.2	86.5	87.1	82.8	76.3	85.9	80.2	84.2	89.2	84.6
DMU15	100.0	95.8	98.3	95.1	100.0	98.0	98.1	96.8	99.1	99.2	97.3	93.9	90.2	93.6	90.3	91.5	91.5	89.8	82.3	92.3	90.3	89.1	94.1	93.9	85.6	82.6	84.7	89.1	88.2	84.5	80.7	88.3	84.4	86.9	90.4	87.1
DMU16	100.0	98.6	97.7	95.2	100.0	100.0	98.0	96.5	97.8	99.5	96.3	93.8	88.9	93.0	90.1	91.5	90.8	89.1	84.1	91.5	90.3	87.7	93.2	92.9	84.5	81.5	83.4	85.8	86.3	83.1	80.8	84.4	84.2	83.0	88.0	83.5
DMU17	95.4	98.1	91.5	88.9	96.0	100.0	86.6	89.1	100.0	91.8	96.2	92.7	81.9	93.7	85.7	85.7	93.5	88.7	82.5	100.0	88.0	85.3	93.8	95.2	70.4	71.6	76.5	77.7	81.6	75.6	63.9	78.3	68.1	76.0	83.8	76.6
DMU18	99.9	98.1	97.5	94.5	100.0	100.0	96.1	95.8	100.0	98.4	97.8	94.6	88.7	94.6	90.0	91.0	92.8	90.4	83.6	94.8	90.6	88.8	94.8	94.9	82.1	80.3	83.2	86.4	87.1	82.8	76.7	85.9	80.6	84.2	89.2	84.6
DMU19	70.1	99.9	75.1	90.3	100.0	100.0	50.6	71.2	87.2	79.5	84.4	88.2	54.1	43.7	66.7	68.0	62.0	57.4	100.0	80.7	86.3	59.6	68.7	80.1	47.5	56.9	50.0	33.9	44.1	58.6	51.4	30.8	58.5	35.9	47.4	33.1
DMU20	98.0	94.5	92.7	88.7	96.6	100.0	82.3	88.9	100.0	89.2	100.0	96.2	81.5	94.2	82.6	82.1	92.3	87.2	73.9	100.0	80.5	84.7	93.5	95.0	70.6	72.9	78.4	80.7	83.2	76.2	57.5	80.2	62.0	79.1	84.5	78.1
DMU21	99.9	98.1	97.5	94.5	100.0	100.0	96.1	95.8	100.0	98.4	97.8	94.6	88.7	94.6	90.0	91.0	92.8	90.4	83.6	94.8	90.6	88.8	94.8	94.9	82.1	80.3	83.2	86.4	87.1	82.8	76.7	85.9	80.6	84.2	89.2	84.6
DMU22	99.9	95.8	98.1	94.8	100.0	98.1	97.0	96.4	100.0	98.6	97.9	94.2	89.9	94.1	90.2	91.2	92.3	90.2	82.3	93.8	90.4	89.4	94.8	94.7	84.2	81.9	84.4	88.9	88.3	84.2	78.6	88.5	82.5	87.0	90.6	87.2
DMU23	99.9	98.1	97.5	94.5	100.0	100.0	96.1	95.8	100.0	98.4	97.8	94.6	88.7	94.6	90.0	91.0	92.8	90.4	83.6	94.8	90.6	88.8	94.8	94.9	82.1	80.3	83.2	86.4	87.1	82.8	76.7	85.9	80.6	84.2	89.2	84.6
DMU24	95.4	98.1	91.5	88.9	96.0	100.0	86.6	89.1	100.0	91.8	96.2	92.7	81.9	93.7	85.7	85.7	93.5	88.7	82.5	100.0	88.0	85.3	93.8	95.2	70.4	71.6	76.5	77.7	81.6	75.6	63.9	78.3	68.1	76.0	83.8	76.6
DMU25	100.0	95.8	98.3	95.1	100.0	98.0	98.1	96.8	99.1	99.2	97.3	93.9	90.2	93.6	90.3	91.5	91.5	89.8	82.3	92.3	90.2	89.1	94.1	93.8	85.6	82.6	84.7	89.1	88.2	84.5	80.7	88.3	84.4	86.9	90.4	87.1
DMU26	100.0	95.8	98.3	95.1	100.0	98.0	98.1	96.8	99.1	99.2	97.3	93.9	90.2	93.6	90.3	91.5	91.5	89.8	82.3	92.3	90.3	89.1	94.1	93.9	85.6	82.6	84.7	89.1	88.2	84.5	80.7	88.3	84.4	86.9	90.4	87.1
DMU27	100.0	95.8	98.3	95.1	100.0	98.0	98.1	96.8	99.1	99.2	97.3	93.9	90.2	93.6	90.3	91.5	91.5	89.8	82.3	92.3	90.3	89.1	94.1	93.9	85.6	82.6	84.7	89.1	88.2	84.5	80.7	88.3	84.4	86.9	90.4	87.1
DMU28	100.0	95.8	98.3	95.1	100.0	98.0	98.1	96.8	99.1	99.2	97.3	93.9	90.2	93.6	90.3	91.5	91.5	89.8	82.3	92.3	90.2	89.1	94.1	93.8	85.6	82.6	84.7	89.1	88.2	84.5	80.7	88.3	84.4	86.9	90.4	87.1
DMU29	100.0	95.6	98.1	94.7	100.0	98.2	96.5	96.3	100.0	98.3	98.1	94.5	89.7	94.1	89.9	90.8	92.2	90.1	81.6	93.9	89.8	89.3	94.8	94.7	84.0	81.8	84.4	88.9	88.3	84.1	77.6	88.5	81.6	87.0	90.5	87.1
DMU30	100.0	95.8	98.3	95.1	100.0	98.0	98.1	96.8	99.1	99.2	97.3	93.9	90.2	93.6	90.3	91.5	91.5	89.8	82.3	92.3	90.3	89.1	94.1	93.9	85.6	82.6	84.7	89.1	88.2	84.5	80.7	88.3	84.4	86.9	90.4	87.1
DMU31	100.0	98.7	97.5	95.0	99.7	100.0	98.3	96.4	97.5	99.4	96.0	93.6	88.8	93.4	90.0	91.5	90.7	89.1	84.0	91.3	90.1	87.5	93.0	92.6	84.4	81.3	83.3	85.7	86.2	82.8	80.8	84.2	84.1	82.6	87.8	83.3
DMU32	99.9	95.8	98.1	94.8	100.0	98.1	97.0	96.4	100.0	98.6	97.9	94.2	89.9	94.1	90.2	91.2	92.3	90.2	82.3	93.8	90.4	89.4	94.8	94.7	84.2	81.9	84.4	88.9	88.3	84.2	78.6	88.5	82.5	87.0	90.6	87.2
DMU33	100.0	95.8	98.3	95.1	100.0	98.0	98.1	96.8	99.1	99.2	97.3	93.9	90.2	93.6	90.3	91.5	91.5	89.8	82.3	92.3	90.3	89.1	94.1	93.9	85.6	82.6	84.7	89.1	88.2	84.5	80.7	88.3	84.4	86.9	90.4	87.1
DMU34	100.0	95.6	98.1	94.7	100.0	98.2	96.5	96.3	100.0	98.3	98.1	94.5	89.7	94.1	89.9	90.8	92.2	90.1	81.6	93.9	89.8	89.3	94.8	94.7	84.0	81.8	84.4	88.9	88.3	84.1	77.6	88.5	81.6	87.0	90.5	87.1
DMU35	99.9	95.8	98.1	94.8	100.0	98.1	97.0	96.4	100.0	98.6	97.9	94.2	89.9	94.1	90.2	91.2	92.3	90.2	82.3	93.8	90.4	89.4	94.8	94.7	84.2	81.9	84.4	88.9	88.3	84.2	78.6	88.5	82.5	87.0	90.6	87.2
DMU36	99.9	95.8	98.1	94.8	100.0	98.1	97.0	96.4	100.0	98.6	97.9	94.2	89.9	94.1	90.2	91.2	92.3	90.2	82.3	93.8	90.4	89.4	94.8	94.7	84.2	81.9	84.4	88.9	88.3	84.2	78.6	88.5	82.5	87.0	90.6	87.2
Average	97.9	96.5	95.6	93.0	98.9	99.2	91.5	93.2	99.0	95.6	97.2	94.2	85.3	91.0	86.6	87.2	90.0	87.4	80.5	93.6	87.2	85.7	92.1	92.9	78.2	77.5	80.3	82.7	83.6	79.9	71.7	81.8	75.8	80.7	85.6	80.7

Appendix B: Target

Name	DMU01	DMU02	DMU03	DMU04	DMU05	DMU06	DMU07	DMU08	DMU09	DMU10	DMU11	DMU12	DMU13	DMU14	DMU15	DMU16	DMU17	DMU18
Labor Value	0.69	0.69	0.68	0.68	0.68	0.68	0.85	0.69	0.68	0.85	0.69	0.68	0.74	0.73	0.73	0.73	0.73	0.74
Labor Target	0.69	0.69	0.59	0.61	0.68	0.68	0.52	0.61	0.68	0.57	0.69	0.67	0.56	0.61	0.55	0.53	0.58	0.55
Labor Gain(%)	0	0	-13.46	-10.47	0	0	-38.47	-12.29	0	-32.52	0	-1.18	-23.24	-16.54	-24.91	-26.62	-20.57	-25.22
Consumbles Value	0.5	0.5	0.47	0.49	0.53	0.49	0.43	0.54	0.56	0.43	0.55	0.54	0.66	0.66	0.66	0.71	0.71	0.59
Consumbles Target	0.5	0.5	0.47	0.47	0.53	0.49	0.38	0.46	0.56	0.43	0.55	0.52	0.41	0.47	0.4	0.39	0.48	0.44
Consumbles Gain(%)	0	0	-0.55	-4.63	0	0	-10.92	-13.74	0	-0.15	0	-4.12	-37.57	-29.04	-38.96	-44.26	-32.23	-26.01
Energy consumption Value	0.88	0.85	0.88	0.86	0.85	0.87	0.79	0.84	0.87	0.81	0.88	0.9	0.82	0.82	0.77	0.77	0.76	0.77
Energy consumption Target	0.88	0.85	0.75	0.77	0.85	0.87	0.67	0.77	0.87	0.73	0.88	0.85	0.72	0.77	0.69	0.68	0.71	0.7
Energy consumption Gain(%)	0	0	-14.98	-10.87	0	0	-15.34	-9.13	0	-10.22	0	-5.68	-12.45	-5.39	-9.98	-12.03	-6.48	-9.64
Safety Value	0.72	0.57	0.55	0.41	0.39	0.57	0.82	0.56	0.51	0.51	0.51	0.51	0.64	1.27	0.56	0.55	0.73	0.74
Safety Target	0.72	0.57	0.46	0.39	0.39	0.57	0.54	0.42	0.51	0.51	0.51	0.5	0.58	0.51	0.51	0.5	0.45	0.37
Safety Gain(%)	0	0	-16.72	-4.63	0	0	-34.6	-24.41	0	-0.15	0	-1.18	-9.81	-60.21	-9.73	-8.47	-39.38	-49.98
Administration Value	0.79	0.85	0.82	0.82	0.81	0.82	0.81	0.8	0.91	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
Administration Target	0.79	0.85	0.77	0.74	0.81	0.82	0.6	0.72	0.91	0.68	0.81	0.8	0.64	0.76	0.63	0.62	0.73	0.7
Administration Gain(%)	0	0	-7.03	-10.54	0	0	-25.67	-10.66	0	-15.94	0	-1.18	-20.04	-5.39	-22.16	-23.84	-9.6	-14.01
Sales & Marketing Value	0.72	0.71	0.74	0.66	0.69	0.67	0.65	0.64	0.67	0.62	0.74	0.71	0.78	0.79	0.78	0.81	0.85	0.85
Sales & Marketing Target	0.72	0.71	0.58	0.62	0.69	0.67	0.54	0.62	0.67	0.58	0.74	0.69	0.59	0.6	0.57	0.55	0.59	0.55
Sales & Marketing Gain(%)	0	0	-22.17	-5.7	0	0	-16.54	-3.15	0	-7.05	0	-2.54	-24.8	-23.66	-27.83	-31.26	-30.28	-35.41
cost of raw materials Value	0.84	0.82	0.83	0.8	0.83	0.87	0.65	0.77	0.98	0.72	0.94	0.93	0.76	0.86	0.74	0.71	0.85	0.81
cost of raw materials Target	0.84	0.82	0.82	0.76	0.83	0.87	0.64	0.74	0.98	0.72	0.94	0.89	0.69	0.82	0.66	0.65	0.8	0.73
cost of raw materials Gain(%)	0	0	-0.55	-4.63	0	0	-1.74	-3.15	0	-0.15	0	-4.1	-9.81	-5.39	-9.73	-8.47	-6.48	-9.64
selling products ($) Value	0.86	0.81	0.84	0.78	0.86	0.87	0.65	0.76	1	0.74	0.94	0.9	0.7	0.83	0.68	0.67	0.8	0.75
selling products ($) Target	0.86	0.81	0.84	0.78	0.86	0.87	0.65	0.76	1	0.74	0.94	0.9	0.7	0.83	0.68	0.67	0.8	0.75
selling products ($) Gain(%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R&D (output) Value	0.66	1	0.54	0.58	0.62	0.96	0.52	0.53	0.52	0.59	0.53	0.64	0.37	0.6	0.49	0.51	0.52	0.49
R&D (output) Target	0.66	1	0.54	0.58	0.62	0.96	0.52	0.56	0.52	0.59	0.53	0.64	0.54	0.6	0.52	0.51	0.52	0.49
R&D (output) Gain(%)	0	0	0	0	0	0	0	6.09	0	0	0	0	46.67	0	5.23	0	0	0

Name	DMU19	DMU20	DMU21	DMU22	DMU23	DMU24	DMU25	DMU26	DMU27	DMU28	DMU29	DMU30	DMU31	DMU32	DMU33	DMU34	DMU35	DMU36
Labor Value	0.84	0.74	0.83	0.75	0.76	0.76	0.79	0.79	0.79	0.79	0.8	0.8	1	0.77	0.99	0.81	0.82	0.82
Labor Target	0.84	0.74	0.49	0.56	0.6	0.6	0.53	0.57	0.63	0.67	0.68	0.61	0.4	0.67	0.44	0.69	0.71	0.69
Labor Gain(%)	0	0	-41.48	-25.29	-21.5	-21.37	-32.1	-27.79	-20.37	-15.55	-15.18	-23.12	-59.71	-13.05	-55.31	-15.92	-13.75	-15.28
Consumbles Value	0.7	0.77	0.59	0.78	0.77	0.8	0.85	0.85	0.85	0.85	0.91	0.91	0.78	0.96	0.76	0.99	1	0.95
Consumbles Target	0.7	0.77	0.38	0.45	0.48	0.5	0.39	0.43	0.46	0.48	0.53	0.46	0.29	0.53	0.33	0.54	0.56	0.54
Consumbles Gain(%)	0	0	-36.6	-42.84	-37.73	-37.59	-54.49	-49.63	-45.84	-42.96	-42.23	-49.26	-62.66	-44.77	-56.91	-45.75	-44.37	-43.49
Energy consumption Value	0.68	0.74	0.68	0.8	0.8	0.79	0.98	0.98	0.98	0.96	0.97	0.97	0.88	0.96	0.88	0.99	0.98	1
Energy consumption Target	0.68	0.74	0.61	0.71	0.75	0.75	0.68	0.72	0.8	0.85	0.85	0.77	0.51	0.85	0.56	0.86	0.89	0.87
Energy consumption Gain(%)	0	0	-9.38	-10.56	-5.18	-4.82	-30.41	-26.9	-18.22	-11.75	-11.71	-19.73	-41.92	-11.48	-36.64	-12.97	-9.38	-12.84
Safety Value	0.31	0.58	0.36	0.6	0.62	0.51	0.67	0.54	0.76	0.98	0.95	0.55	0.52	1	0.45	0.74	0.85	0.94
Safety Target	0.31	0.58	0.31	0.36	0.42	0.45	0.56	0.44	0.64	0.7	0.41	0.46	0.42	0.41	0.38	0.42	0.44	0.41
Safety Gain(%)	0	0	-13.73	-39.7	-33.11	-10.89	-16.99	-17.38	-15.31	-28.56	-56.87	-15.47	-19.74	-58.67	-15.58	-43.32	-48.5	-56.77
Administration Value	0.82	0.82	0.82	0.82	0.82	0.83	0.89	0.89	0.89	0.89	0.93	0.93	0.96	0.96	0.96	0.96	0.99	1
Administration Target	0.82	0.82	0.59	0.7	0.77	0.79	0.61	0.67	0.72	0.76	0.82	0.72	0.46	0.83	0.51	0.84	0.87	0.84
Administration Gain(%)	0	0	-27.46	-14.53	-6.37	-5.4	-31.56	-25.08	-19.6	-14.9	-11.71	-22.09	-52.04	-13.79	-46.6	-12.97	-12.26	-16.41
Sales & Marketing Value	0.81	0.93	0.81	0.84	0.88	0.9	0.92	0.93	0.93	0.91	0.91	0.91	0.82	0.99	0.84	1	1	1
Sales & Marketing Target	0.81	0.93	0.49	0.57	0.59	0.6	0.56	0.59	0.65	0.7	0.69	0.63	0.42	0.68	0.46	0.7	0.72	0.71
Sales & Marketing Gain(%)	0	0	-39.4	-32.42	-32.85	-33.32	-39.62	-36.66	-29.27	-23.88	-23.76	-30.45	-49.17	-31.17	-45.84	-29.98	-28.3	-29.42
cost of raw materials Value	0.65	0.96	0.68	0.82	0.87	0.9	0.76	0.84	0.9	0.91	0.95	0.89	0.61	0.97	0.64	0.99	1	0.99
cost of raw materials Target	0.65	0.96	0.61	0.74	0.82	0.85	0.65	0.69	0.76	0.81	0.84	0.75	0.49	0.86	0.54	0.86	0.91	0.86
cost of raw materials Gain(%)	0	0	-9.38	-10.56	-5.18	-4.82	-14.41	-17.38	-15.31	-10.91	-11.71	-15.47	-19.16	-11.48	-15.58	-12.97	-9.38	-12.84
selling products ($) Value	0.55	0.91	0.63	0.75	0.84	0.86	0.67	0.71	0.79	0.83	0.86	0.77	0.5	0.88	0.55	0.89	0.93	0.88
selling products ($) Target	0.55	0.91	0.63	0.75	0.84	0.86	0.67	0.71	0.79	0.83	0.86	0.77	0.5	0.88	0.55	0.89	0.93	0.88
selling products ($) Gain(%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R&D (output) Value	0.6	0.55	0.47	0.37	0.49	0.48	0.37	0.37	0.4	0.15	0.36	0.35	0.4	0.04	0.4	0	0.31	0.07
R&D (output) Target	0.6	0.55	0.47	0.49	0.49	0.48	0.51	0.53	0.6	0.64	0.61	0.57	0.4	0.59	0.42	0.61	0.62	0.63
R&D (output) Gain(%)	0	0	0	31.56	0	0	40.11	44.76	52.11	336.93	69.62	61.86	0	1290.15	5.01	397022934	102.72	747.79

Appendix C: Maximum Input/Minimum Output for the Next Year

maximum/minimum value of target for next year	January	February	March	April	May	June	July	August	September	October	November	December
maximum value for Labor	305916	329004	363636	386724	392496	352092	230880	386724	253968	398268	409812	398268
maximum value for Consumbles	13782.6	15196.2	16256.4	16963.2	18730.2	16256.4	10248.6	18730.2	11662.2	19083.6	19790.4	19083.6
maximum value for Energy consumption	186440.4	197407.4	219341.6	233050.5	233050.5	211116.3	139830.3	233050.5	153539.1	235792.2	244017.5	238534
maximum value for Safety	117320	92180	134080	146650	85895	96370	87990	85895	79610	87990	92180	85895
maximum value for Administration	101077	111019	119304	125932	135874	119304	76222	137531	84507	139188	144159	139188
maximum value for Sales & Marketing	33149.2	34925.05	38476.75	41436.5	40844.55	37292.85	24861.9	40252.6	27229.7	41436.5	42620.4	42028.45
maximum value for cost of raw materials	3971439	4215835	4643528	4949024	5132321	4582429	2993854	5254519	3299349	5254519	5560014	5254519
minimum value for selling products ($)	5992023	6349756	7065221	7422954	7691253	6886355	4471659	7870120	4918825	7959553	8317286	7870120
minimum value for R&D (output)	9537	9911	11220	11968	11407	10659	7480	11033	7854	11407	11594	11781