DEVELOPING A NEW METHOD IN EFFICIENCY MEASUREMENT PROBLEMS

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ABSTRACT

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Data Envelopment Analysis (DEA) is a powerful technique for relatively efficiency measurement and it is intensively used in different kind of disciplines but this technique has some drawbacks. In the conventional DEA technique, total number of inputs and outputs is determined by the number of evaluated firms. Therefore, this powerful efficiency measurement technique cannot be employed for limited number firm problems. DEA uses realized data so it can be used for objective evaluations. However, in some Occupational Health and Safety (OHS) and mining cases, subjective evaluation is also very important so it should be included in DEA analyses. To get rid of these drawbacks, a new technique is developed with integration of DEA and Analytical Hierarchy Process (AHP) and it is named as AHP.DEA Method. The developed method creates an opportunity using more inputs and outputs in the relatively efficiency measurement for limited number firm cases. Therefore, reliability of the estimation is increased with increasing the number of inputs and outputs in the estimations. The AHP.DEA technique also integrates both subjective opinion of experts and objective evaluation. Combination of them can give more consistent results when compared only subjective or objective evaluation methods. After the application of AHP.DEA method in mining and OHS industry, managers of mining companies can compare their organizations with the competitors or their branches and they can identify strengths and weakness of them. Therefore, quantity and quality of output may be increased while number of accidents is decreased and also new opportunities can be identified to upgrade current operations.

Keywords: Data Envelopment Analysis, Analytical Hierarchy Process, AHP.DEA Method, Efficiency Analysis

ÖZ

ETKİNLİK ÖLÇÜM PROBLEMLERİ İÇİN YENİ BİR METODUN GELİŞTİRİLMESİ

Erdem, Ömer
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Veri Zarflama Analizi (VZA) göreli etkinlik analizlerinde çok güçlü ve üstün olmasından dolayı birçok disiplinde ve çalışma alanında yoğun şekilde kullanılmaktadır. Ancak bu yöntem bazı dezavantajlara sahiptir. Geleneksel VZA yönteminde kullanılabilecek girdi ve çıktının sayısı değerlendirilen birim sayısı tarafından belirlenmektedir. Bu nedenden dolayı, bu kullanışlı ve güçlü yöntem sayıca az olan birimler için veya birim sayısı az olan organizasyonlar için kullanılamamaktadır. Ayrıca VZA, gerçekleşmiş veriler üzerinden işlem yaptığı için objektif değerlendirmeler elde edilmektedir. Ancak İş Sağlığı ve Güvenliği (İSG) ve madencilik alanlarında sübjektif değerlendirmeler de objektifler kadar önemlidir ve VZA uygulaması içinde yer almalıdır. VZA yönteminin sahip olduğu bu dezavantajların ortadan kaldırılması için VZA ve Analitik Hiyerarşi Süreci (AHS) yöntemlerinin birleştirildiği yeni bir metot geliştirilmiş ve bu metoda AHP.DEA ismi verilmiştir. Geleneksel VZA yöntemine göre, geliştirilen AHP.DEA metodunun yardımı ile sayıca az olan birimlerin göreli etkinlik değerlendirmesinde kullanılabilir girdi ve çıktı sayısını artırmaya fırsat tanımaktadır. Bu sayede elde edilen sonuçların güvenirliliği, girdi ve çıktı sayısının artması ile birlikte artış gösterecektir. Ayrıca AHP.DEA metodu uzmanlardan elde edilen sübjektif değerlendirmeler ile objektif sonuçları entegre etmektedir. Bu entegrasyon sonucunda elde edilen sonuçlar sadece sübjektif veya sadece objektif değerlendirmelere göre daha iyi sonuçlar verecektir. AHP.DEA metodunun madencilik ve İSG alanlarında uygulanması sonucunda şirketlerin karar vericileri kendi şirketlerini hem rakipleri hem de kendi şirketleri ile kıyaslayabilirler. Bu sayede şirketlerinin güçlü ve zayıf yönleri ortaya çıkarılabilir, üretim miktar ve kalitesi artırılırken kaza sayıları da düşürülebilir. Ayrıca mevcut durumu daha iyiye taşıyabilecek yeni fırsatlar ortaya çıkarılabilir.

Anahtar Kelimeler: Veri Zarflama Analizi, Analitik Hiyerarşi Süreci, AHP.DEA Metodu, Etkinlik Analizi

To my family

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LIST OF ABBREVIATIONS

OHS : Occupational Health and Safety
OSHA : Occupational Health and Safety Administration
DEA : Data Envelopment Analysis
DMU : Decision Making Unit
LP : Linear Programing
MPSS : Most Productive Scale Size
CRS : Constant Returns to Scale
VRS : Variable Returns to Scale
NIRS : Non-Increasing Returns to Scale
NDRS : Non-Decreasing Returns to Scale
GRS : Generalized Returns to Scale
SBM : Slack Based Model
DEA/AR : DEA Model with Assurance Region
AR I : Assurance Region Type I
AR II : Assurance Region Type II
CRDEA : Cone Ratio Data Envelopment Analysis
DEAHP : Data Envelopment Analytical Hierarchy Process
AHP : Analytical Hierarchy Process
CI : Consistency Index
AHP.DEA : A New Developed Model with Integration of AHP and DEA
IO-AHP.DEA : Input Oriented AHP.DEA Model
OO-AHP.DEA : Output Oriented AHP.DEA Model
I_E : Estimation Input Variable
I_D : Defined Input Variable
O_E : Estimation Output Variable
O_D : Defined Output Variable
TTK : Turkish Hard Coal Enterprise

CHAPTER 1

INTRODUCTION

Efficiency measurement supplies needed data and information to make final decisions about organizations. After applying an efficiency measurement technique, a manager is equipped with a snapshot of recent performance capabilities of an organization and tracks whether the recent performance is becoming better, staying the same or becoming worse for the next periods.

Recently, it has become very essential for organizations to grasp how their organization operated when compared with other similar organizations or competitors. This comparison can be administered by using some comparison concepts. Effective comparison methodology can be conducted by relative efficiency measurement methodology. This type of efficiency measurement is very simple and gives relevant and valuable information about the related production processes by analyzing inputs and outputs of the system.

Emphasis on the measurement and comparison of efficiency of relatively similar set of firms or units has become important due to the advances in the globalization and competition. Efficiency measurement plays an important role on the development of the firms, organizations and governments. In a simple expression, efficiency can be explained as the ratio of output to input. However, in the modern world the firms have multiple inputs and outputs so the traditional efficiency measurement becomes insufficient.

When the literature is analyzed, two main techniques can be used to measure the efficiency or productive efficiency. The first one is the parametric method and it is evidenced by econometric approaches. The other one is non-parametric method. The non-parametric method is superior to the parametric one because in the parametric methods, a priori assumption is needed but it is not required in the non-parametric one. In other words, parametrically driven inputs and outputs are not required in the non-parametric technique in order to measure the efficiency. Data Envelopment Analysis (DEA) is a main and powerful representative for the non-parametric approach. It can be applied to measure the relative efficiency of firms having multiple inputs and outputs. As a useful management tool, DEA can also measure targets of inefficient firms to increase efficiencies. Therefore, it also gives some idea to the managers how they manage the inefficient firms or Decision Making Unit (DMU).

DEA is used in different disciplines and over 50 industries for relative efficiency measurement problems. DEA gives valuable information about the cases and it also supplies information about the solution of the problems. DEA is a powerful relative efficiency measurement technique so it is used in different kinds of problems in various disciplines. DEA technique was applied by researchers in more than 5100 papers included in SCI and SSCI journals and numerous books are published about the different aspects of DEA application for different problems or cases.

1.1 Problem Statement

Although DEA is a powerful and useful management tool for relative efficiency measurement, it has also some drawbacks and it may not give reliable results in some situations. Some of the drawbacks were fixed by models developed by different researchers. For example, basic DEA method assigns unrealistic weight to inputs and outputs in the calculation stage of DEA. This problem was solved by some weight restriction models. In another example, DEA aims to maximize the output levels of the firms or organizations. However, in some problems, there may be undesirable outputs and they must be decreased to reach the efficient frontier. This problem has also been solved by undesired output model. Desirable and undesirable outputs can be used together in the same application with the help of undesired output model.

Nonetheless, there are two main unsolved drawbacks of DEA technique. The first one is that DEA cannot be applied for limited number DMUs because number of inputs and outputs are determined by number of DMUs. Therefore, all inputs and outputs are not used in the estimation procedure of DEA. In other words, some important inputs and outputs cannot be included in the calculations so reliable results may not be obtained from this usable technique. For example, it is desired that five firms are relatively compared so the expert can use maximum four variables as inputs and outputs. However, in most cases there are more than four crucial inputs and outputs. In the literature, there is not any model to increase the number of used inputs and outputs.

The second drawback is that DEA supplies objective results because it uses the realized inputs and outputs. Therefore, subjective evaluations may not be included in the estimation procedure of DEA. However, in some industries subjective evaluations are as important as the objective ones. For instance, subjective evaluation must be included in DEA applications to get more realistic and reliable results from the model for Occupational Health and Safety (OHS) mining industry.

DEA cannot be applied for some problems or cases because of these drawbacks. Power of DEA can be increased upon solving these drawbacks and the organizations, which have limited number DMUs, can benefit from the advantages of DEA technique.

DEA technique is not used widely in mining sector. There is few published material and basic DEA method has been used in these materials. Therefore, this powerful relative efficiency measurement technique does not take deserved importance in mining industry. Also, this technique is not applied widely for OHS cases. One of the main reasons of accidents in mining is wrong allocation of OHS inputs. The inputs should be distributed carefully with considering poverty of units. Also, the efficient usage of these inputs should be analyzed. However, this important management tool can supply valuable information to the managers and experts of organizations so frequency of usage of this technique should be increased.

1.2 Objectives of the Study

The objectives of this study are:

- To develop a new method to get rid of the two main drawbacks of DEA technique. Therefore, usage area of DEA is expanded and more organizations can use it.
- To test the new developed method with real OHS data whether it works or not.
- To introduce DEA and AHP.DEA techniques to mining and OHS areas to increase productivity of the organizations and to prevent accidents.

1.3 Research Methodology

In this study, to realize the objectives of the study, a new method is developed to eliminate the drawbacks of DEA technique. In the newly developed model, Analytical Hierarchy Process (AHP) and DEA are integrated to increase the power of DEA. Therefore, the new method is called as AHP.DEA method. AHP.DEA method allows using more inputs and outputs in limited number DMUs cases on the contrary to conventional DEA technique.

AHP.DEA model also evaluates the problem with considering both subjective and objective aspects of the problem because in the background of this technique, two powerful techniques namely Analytical Hierarchy (AHP) and DEA are integrated.

After applying AHP.DEA method, more reliable results can be obtained by using this technique. Such a technique does not exist in the literature. Therefore, this technique will be able to cover an important gap. In the DEA application stage of AHP.DEA, some advanced DEA models are exploited like weight restriction model and undesirable output model.

To test the newly developed method with real OHS data, Turkish Hard Coal Enterprise (TTK) is selected as a case study because it has only five establishments so it is a limited number DMUs case. The results of AHP.DEA are also discussed with the related OHS experts and managers of TTK.

1.4 Outline of the Study

This study is divided into five main chapters. After a brief introduction, in Chapter 2, a detailed literature survey is presented. In Chapter 3, there is detailed information about the developed method and its mathematical background is introduced. In Chapter 4, AHP.DEA technique is applied for the case study. In Chapter 5, obtained results are analyzed and some related discussions are presented. Finally, in Chapter 6, some conclusions are stated and some recommendations for further studies are given.

CHAPTER 2

LITERATURE SURVEY

Data Envelopment Analysis (DEA) is an application based on linear programming method. Main aim of developing DEA is relative efficiency measurement. It is very strong at relative efficiency measurement of firms which use identical inputs to produce identical outputs. History of DEA is started with Farrell (1957) as an idea. The basics of DEA model studies was constructed an article by Charnes *et al.*, (1978). Some DEA models have been developed since 1978. Recent and exhaustive materials on DEA can be found in some studies like Zhu (2009), DEA2010 (2010), Coelli *et al*., (2005), Ray (2004), Cooper *et al*., (2006) and Ramanathan (2003). In this section, a through literature survey about DEA are presented and in addition to this Analytic Hierarchy Process (AHP) applications in DEA models and DEA application about Occupational Health and Safety (OHS) in mines are placed in the last part of literature review section.

2.1 Basic Concepts of Efficiency Measurement

The main reason of efficiency measurement is to expose performance of firms or organizations. Therefore, this sub-topic includes literature review about performance, productivity, and efficiency measurements.

2.1.1 Performance Measurement

Performance measurement can be defined as the process by which businesses, governments, and other organizations develop some criteria for estimating the quality of their activities. These activities are based on goals of organizations. Performance measurement is a simple but effective approach for determining whether organizations meet objectives. To observe organizational advance to achieve organizational aims, performance measurement requires quantitative indications.

OFM (2009) made description of performance measurement in technical terms, and defines as;

“a performance measure is a quantifiable expression of the amount, cost or result of activities that indicate how much, how well and at what level, products or services are provided to customers during a given time period.”

In this description, “Quantifiable” indicates the description that can be counted more than once or measured using numbers. “Activities” is used for describing the work, business processes, *etc*. “Results” are what the organizations’ work is aimed to achieve determined goal. Some examples of performance measurement are annual coal production, number of acres cleared per year, *etc*.

Behn (2003) indicated that public managers use performance measurement because they can make some measures which are helpful in achieving eight managerial purposes. Therefore, performance measurement can be used to evaluate, control, budget, motivate, promote, celebrate, learn, and improve. In governmental organizations, assessment question of these purposes are presented in Table 1.

In addition, Neely (1999) pointed out performance measurement has become so popular recently due to there are seven primary reasons as the changing nature of work, increasing competition, specific improvement initiatives, national and international quality awards, changing organizational roles, changing external demands and the power of information technology.

Table 1 Eight Purposes that Public Managers Have for Measuring Performance (Behn, 2003)

The Purpose	***The public manager's question that the performance measure can help answer***
Evaluate	How well is my public agency performing?
Control	How can I ensure that my subordinates are doing the right thing?
Budget	On what programs, people, or projects should my agency spend the public's money?
Motivate	How can I motivate line staff, middle managers, nonprofit and for-profit collaborators, stakeholders, and citizens to do the things necessary to improve performance?
Promote	How can I convince political superiors, legislators, stakeholders, journalists, and citizens that my agency is doing a good job?
Celebrate	What accomplishments are worthy of the important organizational ritual of celebrating success?
Learn	Why is what working or not working?
Improve	What exactly should who do differently to improve performance?

Performance measurement is a powerful tool for managers because it gives important information about the organization's product, services and the processes thus helps understand, manage and improve. As indicated in OFM (2009) report, effective performance measurement can let us;

- monitor performance to judge how well the organization is working,
- know if the organization is meeting the defined goals and if its customers are satisfied,
- take action to change performance or improve efficiency if upgrade or development is necessary.

In addition to other writers, Zhu (2009) indicated that performance evaluation is an important and continuous factor for staying competitive with the others. This concept plays a crucial role in the high technology production environment and telecommunication. Performance evaluation motivates the firms to constantly evolve and improve their production process for survive in the competitive market. For example, they show up strengths and weakness of process, activity and operations of firm so the business can be modified to meet its costumers' requirements. Also, quantity and quality of output may be increased. New opportunities can be identified to upgrade current operations and processes and new products and processes can be created.

In conclusion, performance measurement supplies needed data and information to make final decisions about the organization. After applying a performance measurement technique, a manager is equipped a snapshot of recent performance capabilities of the organization and track whether the recent performance is becoming better, staying the same or becoming worse for the next periods.

“The best performance measures start conversations about organizational priorities, the allocation of resources, ways to improve performance, and offer an honest assessment of effectiveness” (OFM, 2009).

2.1.2 Productivity Measurement

Productivity can be defined as a measurement of the efficiency of production. The measurement of productivity is identified as a total output per one unit of a total input. Estimation of productivity is very easy process if there are single input and output. Nevertheless, it is a complicate process when there are multiple inputs and/or multiple outputs. At this situation, a powerful method must be used to aggregate the inputs/outputs into a single index.

In some situations, labor productivity was used instead of productivity. Importance of labor productivity was indicated by Freeman (2008) like that;

“Among other productivity measures such as multi-factor productivity or capital productivity, labor productivity is particularly important in the economic and statistical analysis of a country. Labor productivity is a revealing indicator of several economic indicators as it offers a dynamic measure of economic growth, competitiveness, and living standards within an economy. It is the measure of labor productivity which helps explain the principal economic foundations that are necessary for both economic growth and social development.”

However, Farrell (1957) stated that the average labor productivity perhaps the most popular method and efficiency of the organizations was figured out by measuring the average labor productivity. However, it is absolutely the least satisfactory one because there are some other important variables which affect the productivity. Also, Kabnurkar (2001) specified that this type of efficiency measurement was very popular but it had a main drawback. The drawback was that it ignored all inputs except labor and was found to be unsatisfactory when the process or organization being evaluated had multiple inputs and outputs.

Productivity of firms should be estimated with considering all related inputs and outputs. Therefore, more convenient productivity measurements can be conducted.

2.2 Efficiency Measurement

The aim of this topic is introducing measuring efficiency of establishments and companies which convert inputs to outputs. Efficiency measurement has been a popular subject of considerable interest as organizations have struggled to increase productivity (Cook and Seiford, 2009). One of the main performance measurement evaluations is estimation of efficiency of organizations or firms. This type of performance measurement is very simple and gives relevant and valuable information about the related processes of production by analyzing inputs and outputs of the system.

In the literature, productivity and efficiency are often used interchangeably but they are different concepts. Productivity is the ratio of outputs to inputs while efficiency indicates the extent to which time or effort is well used for the intended task or purpose. Also, Farrell (1957) made the description of efficiency as

“success of a firm in producing as large as possible an output from a given set of input”.

For example, a coal mine uses labor, equipment, capital, *etc.* as inputs and it produces coal as output. Performance of this coal establishment can be measured in many ways. However, in general means measure of performance is a productivity ratio. It is the ratio of outputs to inputs. If the ratio becomes large, it means better performance. In other words, the coal mine produces more coal with less labor, equipment, *etc*., if the ratio is bigger. In natural means, performance measurement is a relative idea. Therefore, when performance measurement is conducted, performance of a company can be compared with the previous years or it can be compared with another coal company for same year.

As pointed out by Kabnurkar (2001), some attempts were conducted to measure of efficiency since unsatisfactory characteristics of labor productivity measurement. These are the first steps of efficiency measurement and it is termed as indices of efficiency. In this concept, dimensions or units of inputs and outputs are given up and then dimensionless values are weighted and added. Therefore, it can be said that indices of efficiency include a comparison of weighed average of inputs with outputs.

Efficiency measurement studies are based on the paper published by Farrell (1957). As emphasized by Ertürk (2009), there were some studies about efficiency analysis before Farrell such as Debreu (1951) and Koopmans (1951). However, Farrell systematized the previous efficiency studies and decomposed efficiency into allocative efficiency and technical efficiency.

The traditional efficiency measurement is based on just a ratio of output over input as mentioned previously. However, this type of efficiency measurement has some important drawbacks. They are discussed below.

- Traditional efficiency measurement cannot handle with multiple inputs and outputs.
- In the presence of multiple inputs and outputs, varying units of the variables cannot be incorporated and each variables unit must be the same.
- The production process is affected by environmental factors. However, they cannot be easily modeled in traditional efficiency measurement.
- Real life scenarios that associate other process factors such as quality and outcomes cannot be easily associated in single ratio (Pasupathy, 2002).

2.2.1 Technical Efficiency and Price Efficiency

Farrell (1957) developed a new efficiency measurement method because of eliminating the drawbacks of conventional comparison methods. This method is based on the theory of efficient production function. Technical efficiency measurement is conducted by comparing a firm with a hypothetical perfectly efficient firm which is represented by the production function line as a frontier. There are perfect efficient firms on the frontier line or function. Their efficiency score is one or 100 percent. In other words, this function can be described as the collection of perfectly efficient firms which produce most reasonable output obtained from any given combination of inputs (Kabnurkar, 2001).

In Figure 1, SS’ line indicates the various combinations of X and Y inputs that perfectly efficient firms might use to produce output. Point Q represents an efficient firm since it is on the production frontier. Firm Q and Firm P use the two inputs in the same ratio because they are on the same line as 0P and its slope is same for Firm Q and P. However, Firm Q produces same output with Firm P but Firm Q uses 0Q/0P times as fewer inputs than Firm P. In other words, Firm Q producing 0P/0Q times as much output with using the same amount of inputs. Therefore, *technical efficiency* of Firm P can be defined as 0Q/0P (Farrell, 1957).

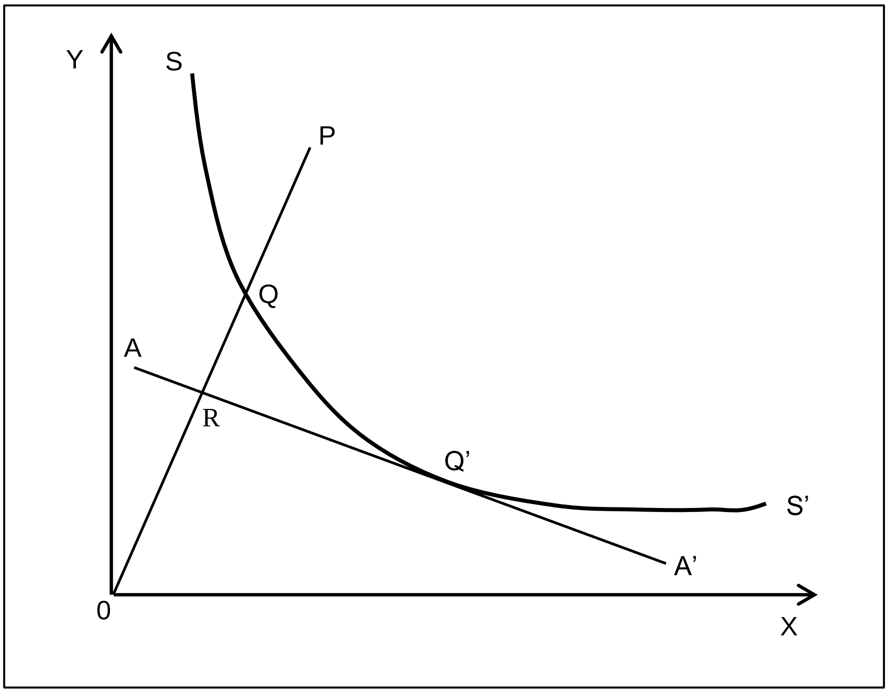

Figure 1 Production Function Line (Farrell, 1957)

Price efficiency is another important parameter for firms. The AA' line can be used to explain price efficiency of Firm Q. Slope of AA' is equal to the ratio of the prices of the Input X and Input Y. There is Firm Q' on the tangent point of SS' and AA' and it is operated at 100 percent technical efficiency as Firm Q. The costs of production at point Q' will be a fraction of 0R/0Q of those at Q. Therefore, *price efficiency* of Firm Q can be estimated as a fraction of 0R/0Q (Farrell, 1957).

Farrell (1957) also denoted that *overall efficiency* of a firm can be estimated by product of the technical and price efficiencies.

2.2.2 Allocative Efficiency

In the modern operations, cost and profit are very important concepts. Price information, cost minimization and profit maximization conjectures should be involved in the production measurement if they are available. In this concept, allocative efficiency should be involved beside technical efficiency. In other words, in allocative efficiency concept, input selection should be done for producing outputs with minimum input cost.

2.2.3 Feasible Production Set

Feasible Production Set can be defined as a zone on Figure 1. It includes all points between production frontier and x-axis.

2.2.4 Economy of Scale

It is supposed that if only a coal company produces little amount coal, the manager may prefer to do so labor intensively. However, more coal production level is reached in the coal mine if the manager prefers machine intensive or automated production type. Hence, the coal mine is able to produce more amount of coal as output in proportion to the related inputs. In other words, the coal mine can consume larger input but it produces more output for each unit of input. This concept is termed as Scale Economy. When Figure 2 is analyzed, some lines are drawn from origin to the particular data point. It can be said that slope (Y/X) of these lines indicates productivity of the firms. Slope of the Firm C is greater than the other ones. In other words, Firm C is at the technically optimal scale and Firm B has lower productivity when compared to it. If the Firm B is examined in this example, we reach an important conclusion. A firm or establishment may be technically efficient but this company may still need to improve its productivity.

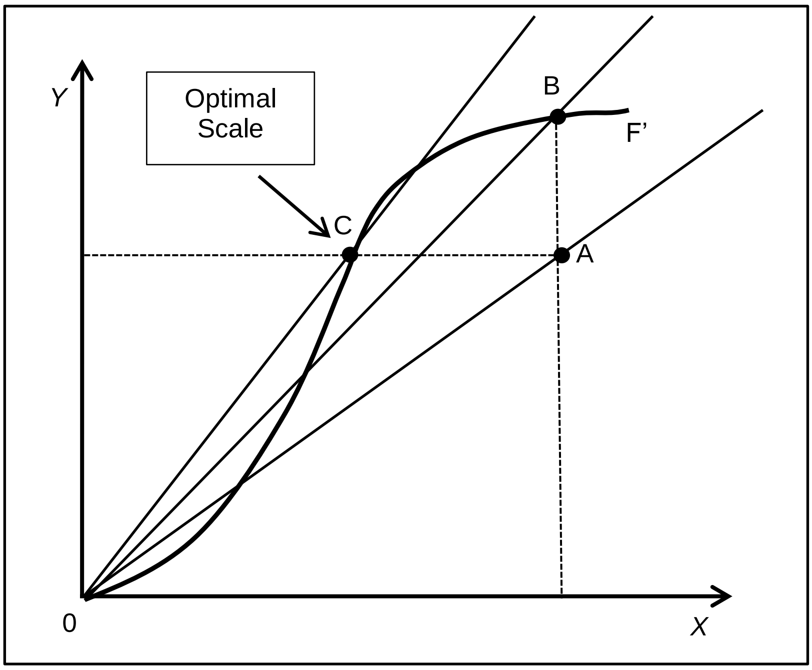

Figure 2 Productivity, Technical Efficiency and Scale Economies (Coelli *et al.*, 2005)

2.2.5 Technical Change

As mentioned previously, production frontier of an operation is affected by technology improvement. If the technology is used intensely in a firm, this firm can produce more output with the same amount of input. This situation is given on Figure 3. In this figure, the productivity frontier is upgraded from $0F_0$' to $0F_1$' by the technology improvement.

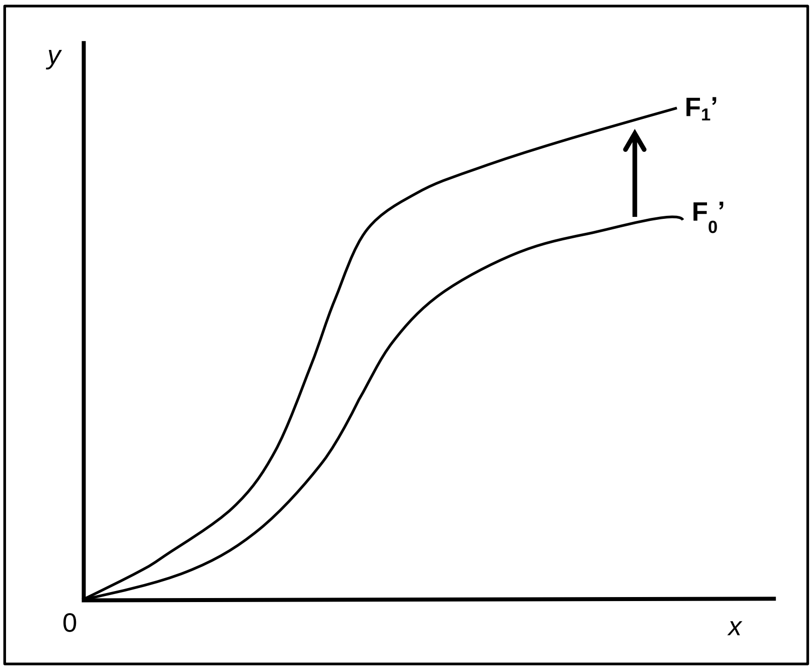

Figure 3 Technical Change between Two Periods

2.2.6 Total Factor Productivity (TFP)

This term can be clarified as productivity measurement which involves all related factors of production. These factors include all inputs and outputs in a multiple input and multiple output setting. Detailed information about TFP can be gained in some studies such as Coelli *et al*. (2005), Çimen (2011) and Aydeğer (2005).

2.3 Data Envelopment Analysis (DEA)

Nowadays, it has become very essential that organizations to grasp how their organization operated when compared to similar organizations. These organizations can be labeled as competitors. Effective comparison methodology can be conducted by relative efficiency measurement methodology.

There are two empirical methods for efficiency measurement as parametric and non-parametric approaches. In the parametric efficiency measurement, the production function is known or it can be determined statistically. Therefore, this type of measurement is preferred by economists. The important parametric methods are Ordinary Least Squares (OLS), Corrected Ordinary Least Squares (COLS), Modified Ordinary Least Squares (MOLS) and Stochastic Frontier Analysis (SFA) and they are based on econometrics. The main power of these methods is producing equality with random part and coefficients, so they are used to quantify the gap between estimated value and real one to estimate the efficiency level of units. Nonetheless, in many real cases the production function is not known. On the other hand, the production function is formed by using some observations as firms in the non-parametric method. Also, assumptions are not allowed to estimate the form of production function. There are two main non-parametric efficiency measurement methods namely Total Factor Productivity (TFP) and Data Envelopment Analysis. In relative efficiency measurement, the main advantage of them is that these methods do not assume any functional form, and efficiency score of a firm is estimated by comparing the performance of the other relevant firms. Current efficiency score of a firm can also be estimated by comparing the performance of the firm in the past (Ertürk, 2009).

To eliminate the drawbacks of traditional efficiency measurement and parametric techniques, a new non-parametric method was suggested by Farrell (1957). This idea was developed by Charnes *et al.* (1978) as Data Envelopment Analysis (DEA) as a non-parametric relative efficiency evaluation approach. DEA is a linear programing technique estimating a single measure for efficiency. DEA provides valuable information for multiple input and output efficiency comparison cases. At these comparison cases, a frontier function is estimated by using efficient firms. The firms are labeled as inefficient if they are not on the frontier line. Also, the level of inefficiency is measured by the unit's distance from the frontier line. One of the main advantages of DEA can be indicated what improvements can be made by inefficient firms to reach Pareto-Efficiency. In other words, DEA points out the level of resources saving and possible service improvements for each inefficient firm to become efficient one. DEA is a very powerful approach for efficiency comparison in the presence of multiple inputs and outputs. This type of comparison cannot be conducted by conventional ratio-based comparison methods. However, the main limitation of DEA is that it is does not provide a solution method for improving the performance of the efficient DMUs which form the frontier function (Sowlati, 2001). The relatively new analysis model DEA does not necessitate the user to prescribe weights to input and outputs and it also does not require prescribing the functional forms that are needed in statistical regression approaches (Cooper *et al*., 2006).

Function of efficiency frontier can be introduced with an example. After plotting the related data (number of employees vs. sales) of eight DMUs, each point is connected to the origin. Therefore, slope of the lines indicate that the sales per employee and the highest such slope is attained by the line from the origin through B as presented in Figure 4. Slope of this line is the biggest one. Therefore, this line is called the "efficient frontier." It should be noticed that efficient frontier touches at least one point and the other points are on or below this frontier. Name of DEA comes from this property since such an efficient frontier is said to be envelop these points in mathematical parlance. It is assumed that the frontier is effective in the range of interest and it is called the Constant Returns to Scale (CRS) assumption. Based on this assumption, firm B is the only one efficient firm (efficiency is 1 or 100%) and the others are inefficient. Efficiency level of the others can be measured relative to B by (Cooper *et al*., 2006) as;

$$0 \leq \frac{Sales\ per\ Employee\ of\ Others}{Sales\ per\ Employee\ of\ B} \leq 1$$

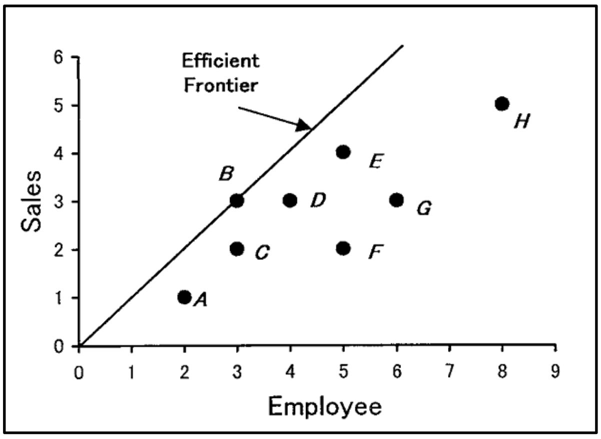

Figure 4 Efficient Frontier (Cooper *et al*., 2006)

In DEA expression, business operations, processes or firms are represented as Decision Making Unit (DMU). A set of input and output is prepared for each DMU for multiple performance measurements. It is considered that number of DMU is n. Each firm, DMU$_j$ (j = 1,….,n), uses m inputs, x_{ij} (i = 1,….,m) to produce s output, y_{rj} (r = 1,….,s). As seen on Figure 5, the best practice frontier or efficient frontier is identified by n firms (Zhu, 2009). S is an inefficient firm because it is not on the efficient frontier line. The distance between S and frontier determines the efficiency level of S. Firm S can become efficient one if it decreases Input 2 usage while Input 1 remains same (S_1). The second alternative is that it may decrease the amount of Inputs 1 and 2 (S_2). The last alternative is S_3. In this scenario, Input 1 is decreased while Input 2 usage level is not changed. This example is based on two input and one output case. If the number of input and output increases the solution becomes complex and more dimensional.

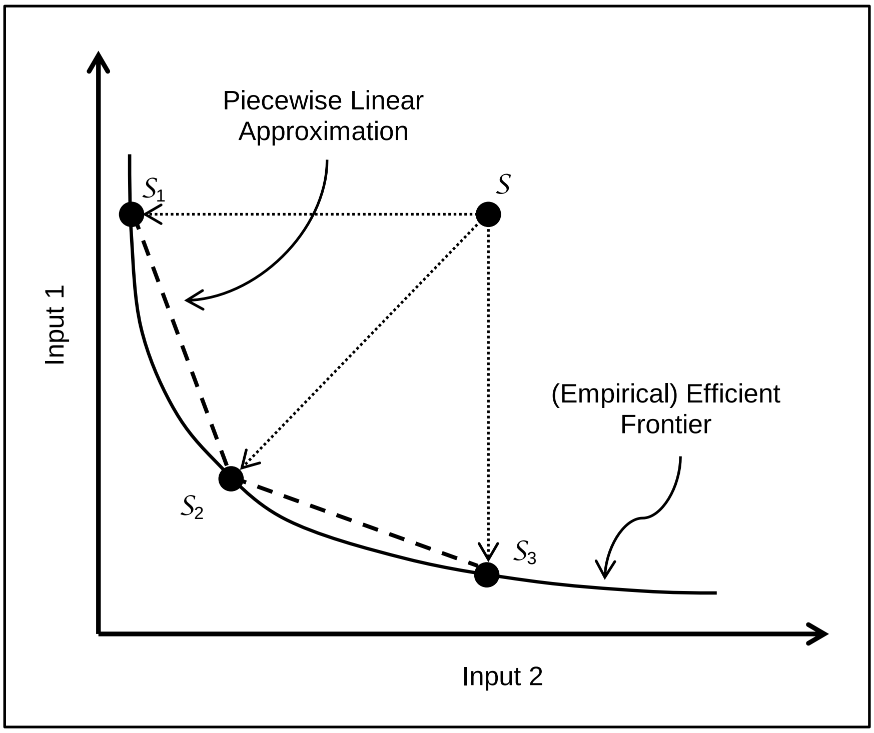

Figure 5 Efficient Frontier (Modified from Zhu (2009))

As DEA is a relative efficiency measurement technique, the models are developed based on fractional mathematical programs because definition of efficiency is output over input. It must be considered that solution of this type of fractional mathematical models is generally difficult. Therefore, they are converted to simpler formulations like Linear Programming (LP) formats to solve the models easily. The simplest way to convert the fractional formulations to LP format is to normalize either the numerator or the denominator of the fractional programming objective function (Ramanathan, 2003).

There are some DEA models for different kind of study field. Most convenient one should be selected for each application. DEA models can be classified in two categories namely basic models and advanced models. The basic models have been developed in the beginning.

Later some advanced models have been introduced. These models are developed for different study purposes in DEA.

2.3.1 Input and Output Orientation Approaches in DEA

In DEA approach, there are two conventional orientation models, namely input-oriented and output-oriented models. In the input-oriented models, output values are fixed and inputs values are adjusted to estimate maximum efficiency score. Input-oriented approach was also used in the article of Farrell (1957) to estimate technical efficiency. Inversely, the main aim of output-oriented approach is maximizing the output values so the input values are fixed. It was emphasized by Ertürk (2009) that input-oriented models are suitable for answering the question that “How much should input quantities be reduced without changing the output level?”, whereas output-oriented models can be used to answer the question “How much should output quantities be increased without changing the input level?”.

A new orientation approach is developed namely non-orientation besides conventional ones. This approach is used when it is not decided which orientation approach is suitable for the studied model. Also some new advanced orientation approaches were developed by Gang and Zhenhua (2011) for some extreme performance evaluation cases. They are;

- modified input-oriented,
- modified output-oriented,
- input-prioritized non-orientation,
- output-prioritized non-orientation and
- generalized priority non-orientation

The importance of the new advanced orientation approaches is that the modified input-oriented and modified output-oriented super efficiency models overcome some problems related with the conventional super efficiency models. The non-orientation with generalized priority is a generalized form of other orientation approaches (Gang and Zhenhua, 2011).

2.3.2 Returns to Scale Approaches in DEA

There are two basic Returns to Scale (RTS) approaches in DEA models. They are Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS). In CRS, it is assumed that all firms are operating at the optimal scale. On the other hand, in VRS concept, it is assumed that firms are not operated in optimal scale because of some problems such as management, regulation, *etc*. Besides CRS and VRS, non-increasing (NIRS), non-decreasing (NDRS) and generalized (GRS) are developed to solve different type of problems.

2.3.2.1 Constant Returns to Scale

The first DEA model is developed by Charnes, Cooper and Rhodes in 1978 with CRS approach. CRS is also named as CCR which is composed of capital letters of the authors. Formulation of output maximization CCR DEA model can be represented in Equation 1 (Charnes *et al.*, 1978).

$$\left.\begin{aligned}
&\max\ z = \sum_{j=1}^{J} v_{jm} y_{jm} \\
&\textit{subject to} \\
&\sum_{i=1}^{J} u_{im} x_{im} = 1 \\
&\sum_{j=1}^{J} v_{jm} y_{jn} - \sum_{i=1}^{J} u_{im} x_{in} \le 0; \qquad n = 1,2,K,N \\
&v_{jm},\ u_{im} \ge \varepsilon; \quad i = 1,2,K,I \quad j = 1,2,K,J
\end{aligned}\right\} \qquad (1)$$

where
y_{jm} = is j^{th} output of the m^{th} DMU,
v_{jm} = is the weight of that output,
x_{im} = is i^{th} input of the m^{th} DMU,
u_{im} = is the weight of that input,
y_{jn} and x_{in} are j^{th} output and i^{th} input, respectively, of the n^{th} DMU,
ε is very small positive number,
It is noted that n includes m.

In the same methodology, input minimization CCR DEA model can be represented in Equation 2 (Ramanathan, 2003).

$$\left.\begin{aligned}
&\min z' = \sum_{j=1}^{J} u'_{im} x_{im} \\
&\textit{subject to} \\
&\sum_{i=1}^{J} v'_{jm} y_{jm} = 1 \\
&\sum_{j=1}^{J} v'_{jm} y_{jn} - \sum_{i=1}^{J} u'_{im} x_{in} \le 0; \qquad n = 1,2,K,N \\
&v'_{jm},\ u'_{im} \ge \varepsilon; \quad i = 1,2,K,I \quad j = 1,2,K,J
\end{aligned}\right\} \qquad (2)$$

As emphasized in the study of Ertürk (2009), “the CRS models may underestimate the company’s pure technical efficiency by benchmarking it against dissimilar and, presumably, more scale-efficient comparators. To eliminate this shortcoming we should loose the restriction on returns to scale”.

2.3.2.2 Variable Returns to Scale

The Variable Returns to Scale (VRS) was developed by Banker *et al.*(1984) since the CRS model can be applied if the studied all firms are operated in optimal scale. However, in the VRS model, it is assumed that firms are not operated in optimal scale because of some problems such as management, regulation, *etc*. The VRS is also known as BCC model. This name comes from the capital letters of the developer scientists.

One of the touchstones in the improvement of DEA theory is development of the VRS model. After the VRS model, scale efficiencies of the firms could be estimated. As Ramanathan (2003) stated that the CCR model (without the convexity constraint) estimates the gross efficiency of a DMU. Gross efficiency includes technical efficiency and scale efficiency. It can be described as that technical efficiency is the efficiency in converting inputs to outputs. Scale efficiency recognizes that economy of scale cannot be reached at all scales of production. The VRS model considers the variation of efficiency with respect to the scale of operation. Therefore, it measures pure Technical Efficiency. Frontier of CRS and VRS is also different because of the difference between the concepts. This situation is demonstrated in Figure 6.

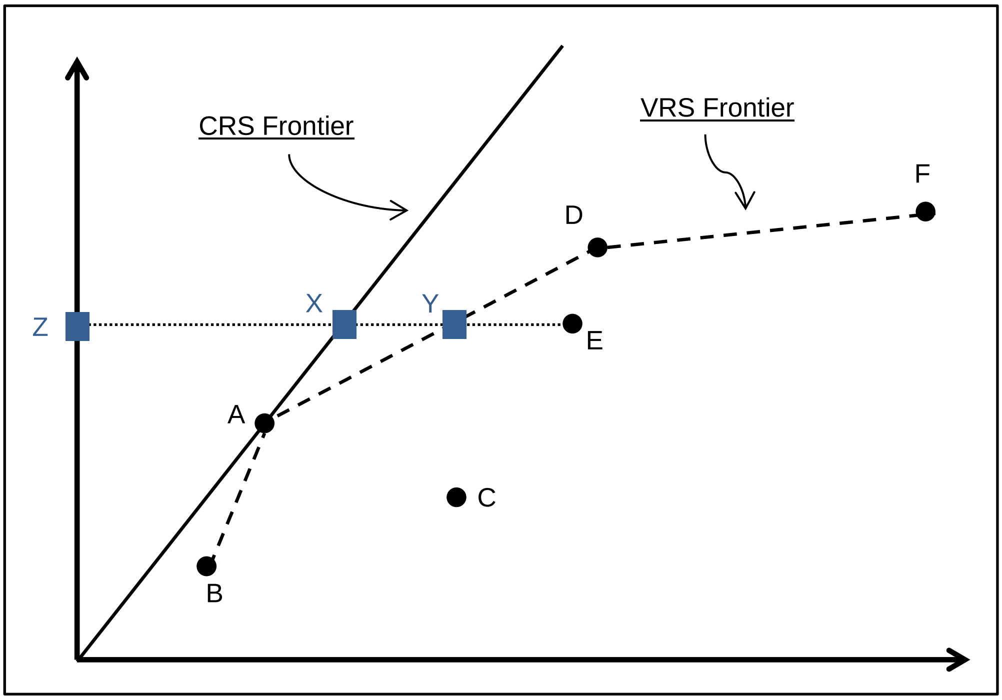

Figure 6 CRS and VRS Frontiers

The CRS and VRS frontiers for the six Firms A, B, C, D, E and F are shown in Figure 6. In CRS approach, only Firm A is efficient and the others are relatively inefficient ones. On the other hand, in VRS approach, four firms (Firm B, A, D, F) are considered as 100% efficient. This situation indicates that the inefficiencies assigned to Firms B, C, D, E and F in CRS approach is due to their scales of operation.

CRS Efficiency of Firm E (Technical and Scale Efficiencies) can be estimated as;

$$CRS\ Efficiency\ of\ Firm\ E = \frac{ZX}{ZE} \tag{3}$$

VRS Efficiency of Firm E can be estimated as;

$$VRS\ Efficiency\ of\ Firm\ E = \frac{ZY}{ZE} \tag{4}$$

Scale efficiency of the Firms can be estimated after the estimation of CRS and VRS efficiency scores. CRS includes technical and scale efficiencies while VRS includes only technical efficiency. Therefore, scale efficiency of Firm E can be estimated as;

$$Scale\ Efficiency\ of\ Firm\ E = \frac{ZX}{ZY} \qquad (5)$$

When the Equation 5 is considered, it can be said that CRS efficiency of firms is always less than or equal to VRS efficiencies of the firms. If CRS and VRS efficiency scores are equal, it indicates that this firm is operated in Most Productive Scale Size (MPSS). Firm A is operated in MPSS as seen on Figure 6.

“Thus, other things being equal, the VRS technique gives the highest efficiency score, while the CRS technique gives the lowest score” (Ramanathan, 2003).

2.3.3 DMUs Set and Input/Output Selection

Selection of DMUs set and their related inputs and outputs is a very important process for DEA applications. Çimen (2011) highlighted when the DMUs are selected to performance evaluation, they must be carefully examined because DMUs must have similar functions and intended to same target. Also, they should be operated under the same market and operating conditions. The DMUs should be similar enough in terms of their production patterns. In other words, they should transform same inputs into same outputs and should be operated in comparable environments. However, there may be some differences as density and size. Two main DMU selection principles can be indicated as;

- Each DMU should be responsible for its inputs as used resources and its produced outputs, and
- Number of DMUs should be sufficient since there should be significant production possibility in frontier estimation.

Beside DMUs selection, determination process of input and output variables of selected DMUs has also a vital role on the significance of the performance evaluation study. There is a strong relation between number of DMU and total number of input and output variables. Nataraja and Johnson (2011) demonstrated that any guidance for the specification of the input and output variables is not provided by DEA. It is left to the users’ discretion, expertise, and judgments. However, some problems may arise during the input and output variable selection. They may be the unavailability of data, high dimensional production processes, and irrelevant inputs or outputs.

Input and output variable selection is a crucial procedure since DEA is a non-parametric approach and loses discriminatory power as the dimensionality of the production space increases. In other words, “if the number of inputs and outputs increases, the observations in the data set are projected in an increasing number of orthogonal directions and the Euclidean distance between the observations increases”. This situation results in many observations or DMUs lying on the frontier function. Therefore, DEA loses its discriminatory power (Nataraja and Johnson, 2011). Detailed information about the side effects of dimensionality can be found in the study of Fried *et al*. (2008).

There are some opinions to solve the problem of determination of number of DMUs based on number of input and output variables. Bowlin (1987, 1999) and Vassiloglou and Giokas (1990) proposed that number of DMUs should be at least three times of total number of inputs and outputs. On the other hand, Norman and Stoker (1991) stated that this number should be at least 20 as it relies on redundancy of number of input and output. However, Çimen (2011) and Boussofiane *et al*. (1991) emphasized that DMU number should be at least total number inputs and outputs plus one. In other words, number of input, output and DMU are defined as $\imath$, o, and $\mathcal{DMU}$ respectively. Therefore, minimum number of DMU can be formulated as $\mathcal{DMU} = (\imath + o) + 1$.

The other important point about the selection of input and output variables is that the numerical values of them must be positive. After the publishing of the original model in 1978 by Charnes *et al*., they made a minor modification on the original model (Charnes *et al*., 1979). In the original model, as traditional LP model, there is a constraint as that the decision variables are non-negative. In other words, these variables can be either positive or zero. However, after defining the minor modification by the authors, decision variables of the DEA models are strictly positive values. The replacement of non-negativity constraints (Equation 6) is done with the strict positivity constraints (Equation 7). This modification restricted the input and output values such in Equation 8 (Ramanathan, 2003).

$$v_{VA,A}, u_{CAP,A}, u_{EMP,A} \geq 0 \tag{6}$$

$$v_{VA,A}, u_{CAP,A}, u_{EMP,A} > 0 \tag{7}$$

$$v_{VA,A}, u_{CAP,A}, u_{EMP,A} > \varepsilon \tag{8}$$

In Equation 8, ε is an infinitesimal or non-Archimedean constant. It is usually the order of 10^{-5} or 10^{-6}. Ramanathan (2003) emphasized that this non-Archimedean infinitesimal is not a number. Although it cannot be approximated by any finite valued number, standard linear programming models need this infinitesimal. It is represented in the form of a small number.

2.3.4 Weight Restriction Models in DEA

Most methodological extensions of Data Envelopment Analysis are resulted by the application of the method on real life problems. One of these developments in DEA is restrictions on the weights attached to the input/outputs of DMUs. Nowadays, weights restrictions and value judgments cover a considerable part of the DEA research literature. However, there is not an agreement on this topic (Allen *et al*., 1997).

In the calculations, the typical DEA models use variable weights. These weights are derived directly from the related data set. There is no need to set weights as a priori. Therefore, DEA can define weights in the estimation of the possible optimum outcome for each DMU. In another words, the output/input ratio is maximized relative to other DMUs under the conditions like that all data and weights are non-negative, the values lay between zero and unity (one) and the same weights are applied to all (Manzoni, 2007). In some situations, DEA may define zero or unrealistic weights to inputs and outputs to maximize the output/input ratio. Hence, incorrect estimations may be achieved. Also Allen *et al*., (1997) contributed that the estimated weights can be inconsistent with prior knowledge or accepted views on the relative values of the inputs and outputs. For instance, in the first application of DEA conducted by Charnes *et al*., (1978), “Program follow through” in the USA performance is evaluated. An analysis of the data shows that many DMUs are rated efficient by using their output weight solely on “self-esteem” and ignoring performance on mathematics and verbal reasoning. To overcome this situation a weight restriction extension can be integrated to DEA model. Weight restriction methods can be categorized in three main groups as;

- Direct Restrictions on the Weights
    - Assurance Region Type I (ARI)

    - Assurance Region Type II (ARII)
    - Absolute Weight Restriction
    - Preference (Weighted) Weight Restriction
- Adjusting the Observed Input/Output Levels
    - Cone-Ratio Approach
- Restricting the Virtual Inputs and Outputs

2.3.4.1 Direct Restriction on the Weights

In this methodology, bound of inputs/outputs are defined in the model. Therefore, lower and upper limits of them are determined by user. There are three sub-groups of direct restriction. These are assurance region type I, assurance region type II and absolute weight restriction.

Assurance Region Type I (ARI):

Formulation of ARI is given in Equation 9. This formulation is modified from the study of Allen *et al*., (1997). M1 is the basic DEA model developed by Charnes *et al*., (1978) for assessing the relative efficiency of DMU j_0 without row (i) and (ii). Main characteristics of ARI are presented in the rows (i) and (ii). In this equation and constraints, *N* $(j = 1,\ldots,N)$ is number of DMU, varying amounts, X_{ij}, of m different inputs $(i = 1,\ldots,m)$ to produce varying quantities, y_{rj}, of s different outputs $(r = 1,\ldots,s)$. In general, these quantities are assumed to be strictly positive such as $x_{ij} > 0$ and $y_{rj} > 0,\ \forall i, r, j$. u_r and v_i are the weights assigned to the r^{th} output and the i^{th} input respectively. κ, α, and β are user-defined constants to reflect weight restriction or value judgments. They represent the relative importance of the inputs or outputs. μ is output value and ε is a non-Archimedean infinitesimal.

$$\left.\begin{array}{llll}
\text{Primal, M1} & \textit{Maximize} & \sum_{r=1}^{s} u_{rj_0} & \\
& \textit{subjected to} & \sum_{i=1}^{m} v_i x_{ij_0} = C, & \\
& & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, \quad j = 1, \ldots, N, & \\
& & \kappa_i v_i + \kappa_{i+1} v_{i+1} \le v_{i+2} & \text{(i)} \\
& & \alpha_i \le \dfrac{v_i}{v_{i+1}} \le \beta_i & \text{(ii)} \\
& & -v_i \le -\varepsilon \quad i = 1,\ldots,m & \\
& & -\mu_r \le -\varepsilon \quad r = 1,\ldots,s &
\end{array}\right\} \qquad (9)$$

As Allen *et al*., (1997) indicated that ARI restrictions are developed to incorporate into the analysis the relative ordering of the inputs or outputs. Thompson *et al.* (1990) termed row (i) and row (ii) restriction as "*Type I Assurance Region"*. Similar form of row (i) restriction type was used by Thompson *et al.* (1986) and Kornbluth (1991) in their studies. The row (ii) type ARI is used more than the other in the literature. It reflects marginal rates of substitution. It should be noted that the bound values depend on scale of the input and output values of

DMUs. In ARI methodology, the bounds are defined based on only expert opinion or expert opinion association with price/cost information of inputs and outputs. Kornbluth (1991) and Beasley (1990) used only expert opinion in their studies and Thompson *et al*. (1990,1992) defined the bounds by expert opinion based on price/cost information about inputs and outputs.

Assurance Region Type II (ARII):

Linear programming formulation of this restriction method is given in Equation 10. Abbreviations of it given in the ARI topic except for ɣ (at row (iii)) which is user specified constant. It reflects the relative importance of inputs and outputs. Name of this type of restriction was given by Thompson *et al.* (1990).

Primal, M2

$$\left.\begin{array}{llll} \textit{Maximize} & \sum_{r=1}^{s} u_{rj_0} & & \\ \textit{subjected to} & \sum_{i=1}^{m} v_i x_{ij_0} = C, & & \\ & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, & j = 1, \ldots, N, & \\ & \gamma_i v_i \geq u_r & & \text{(iii)} \\ & -\nu_i \leq -\varepsilon & i = 1, \ldots, m & \\ & -\mu_r \leq -\varepsilon & r = 1, \ldots, s & \end{array}\right\} \qquad (10)$$

In the paper of Thanassoulis *et al.* (1995), it can be observed that ARII may render M2 infeasible. Also, the same relative efficiency scores can be produced when switching from an input orientation model to output orientation model or vice versa when a DEA linear model including ARII restriction. ARII is sensitive to the scale of DMUs. Therefore, ARII is not approved in the literature. Thompson *et al.* (1994) used ARII in comparing worldwide major oil companies and Thanassoulis *et al.,* (1995) integrated this restriction method to analyze output quality in health care (Allen *et al.*, 1997).

Absolute Restrictions:

This restriction technique is one of the earliest applied one. The main logic of absolute restriction is imposing absolute lower and upper bounds on input and output as given in Equation 11 and Equation 12 (Cook and Seiford, 2009).

$$P_{1r} \leq \mu_r \leq P_{2r} \qquad (11)$$

$$Q_{1i} \leq \vartheta_i \leq Q_{2i} \qquad (12)$$

Dyson and Thanassoulis (1988) published a paper which explores the consequences of total weight flexibility in DEA, and it suggests one possible way of limiting such flexibility as absolute restriction. The paper discusses the interpretation and usefulness of the information obtained from DEA assessments involving weights constraints. Also, Cook *et* *al*. (1990) and Roll and Wade (1991) published papers examined the use of such absolute limits in the context of evaluating highway maintenance units with using absolute restriction.

Preference (Weighted) Weight Restriction:

Another weight restriction method is preference (weighted) method. In this method, weights can be assigned to inputs and outputs according to their relative importance as seen in the Equation 13.

$$\left.\begin{array}{l} \min p = \dfrac{1-\dfrac{1}{m}\displaystyle\sum_{i=1}^{m}\dfrac{w_i s_i^-}{x_{i0}}}{1+\dfrac{1}{s}\displaystyle\sum_{r=1}^{s}\dfrac{w_r s_r^+}{y_{r0}}} \\[3em] \displaystyle\sum_{i=1}^{m} w_i = m \\[2em] \displaystyle\sum_{r=1}^{s} w_r = s \end{array}\right\} \qquad (13)$$

Both ARII and Preference Weight Restriction methods have relative importance parameters. However, there is an important difference between inputs and outputs considered. On the other hand, in Preference Weight Method, preference weights between inputs and outputs are integrated independently in the model. Detailed information about this type of weight restriction can be obtained from Wong and Beasley (1990), Zhu (1996), Karsak and İşcan (2010).

2.3.4.2 Adjusting the Observed Input/Output Levels

This type of restriction method is also known as Cone-Ratio Approach. It was developed by Charnes *et al.* (1990). Allen *et al.* (1997) indicated that an artificial data set is generated and this set produces the same relative efficiency scores as application ARI of row 2 in Primal M1. The primal Cone-Ratio DEA (CRDEA) model is given in Equation 14 (adapted from Allen *et al.* (1997), much information about the background of it can be obtained in this publication).

$$\left.\begin{array}{lll} \text{Cone-Ratio Primal} & \textit{Maximize} & u^T Y_0 \\[1em] & \textit{subject to} & v^T X_0 = 1, \\[1em] & & -v^T X + u^T Y \leq 0, \\[1em] & & v \in V, \quad u \in U \end{array}\right\} \qquad (14)$$

In real application, this type of restriction method may be difficult because user should create an artificial data set related with the actual inputs and outputs of DMUs. This method can be applied DMUs whose all data and information is available.

2.3.4.3 Restricting the Virtual Inputs and Outputs

This type of restriction method was developed by Wong and Beasley (1990). The main principle of it is that although actual or real DEA weights are not restricted, the proportion of the total virtual output of DMU *j* devoted to output *r*, (for instance the “importance” attached to output *r* by DMU *j*), can be bounded or restricted between [Φ_r, Ψ_r]. In this range, the bounds, Φ_r and Ψ_r are defined by user based on expert opinion (Allen *et al*., 1997). The restriction mechanism for r^th^ output of DMU j is given in Equation 15.

$$\phi_r \le \frac{u_r y_{rj}}{\sum_{r=1}^{s} u_r y_{rj}} \le \psi_r \tag{15}$$

Restricting the virtual inputs and outputs methodology is used seldom in the literature. Therefore, more studies should be completed to investigate the limitations and advantages of it. Much information can be supplied from Wong and Beasley (1990) and Beasley (1990).

2.3.5 Undesirable Output Model in DEA

Main aim of DEA is estimation of the relative efficiency of DMUs. In this analysis, an efficient frontier is defined by using the DMUs and relatively inefficient DMUs should reach to the efficient frontier by either decreasing the used inputs or increasing the current output level. However, in most real cases, there are desirable (good) and undesirable (bad) inputs and outputs in the same problem. In the basic DEA model, decreases in outputs are not allowed. If a case includes an undesirable output, this output should be decreased to reach the efficient frontier but standard DEA model does not allow output decrease. Seiford and Zhu (2002) used a paper mill production example to describe this phenomenon. During paper production, undesirable outputs of pollutants such as biochemical oxygen demand, suspended solids, particulates, and sulfur oxides are formed. The undesirable pollutants should be decreased to improve the efficiency level of the mill if inefficiency exists in the production. The improvement in the efficiency level can be done if the undesirable and desirable outputs should be treated differently. In other words, desirable outputs should be increased while undesirable outputs should be decreased.

Some methods have been proposed by researches to utilize the undesirable outputs with desirable ones. The first one of them is that undesirable outputs should be utilized as input in the model. However, Seiford and Zhu (2002) indicated that, in this approach, the resulting DEA model does not reflect the true production process. The other proposed method is that the using “one divided by undesired output” instead of undesired output. However, in DEA models, it is suggested that input and output data should not be converted and they should be used as raw data as possible as to get more reliable results from the model. Another suggested method is using negative values of undesired output. This method is not taken into consideration because one of the main principles of DEA model is that input and output values must be positive. Charnes *et al*. (1978) developed the first DEA model and this model includes that the variable values must be equal or greater than zero. However, one year later, Charnes *et al*. (1979) published a paper. It indicates that if variables are equal to zero, some calculation mistakes may occur. Therefore, values of inputs and outputs must be greater than zero.

Färe *et al*. (1989) developed a new model for undesirable outputs. The new model is a non-linear DEA to model the paper production. In this approach, both desirable and undesirable outputs are used together. Therefore, the desirable outputs are increased and undesirable ones are decreased simultaneously in the model. Then, Seiford and Zhu (2002) developed an alternative methodology to utilize both desirable and undesirable outputs differently in the BCC model.

Chung *et al*. (1997) developed the radial undesirable model which is based on the directional distance function. The generalized equation (the undesirable radial model –non-oriented-) is given in Equation 16 (Gang and Zhenhua, 2011).

$$\left.\begin{array}{ll} & \min p = \dfrac{1-\alpha}{1+\dfrac{w_g\beta + w_b\gamma}{w_g + w_b}} \\ \\ \textit{subjected to} & (1-\alpha)x_0 - X\lambda - s^{-} = 0 \\ & Y^{g}\gamma - (1+\beta)y_0^{g} - s^{g+} = 0 \\ & Y^{b}\gamma - (1-\gamma)y_0^{b} + s^{b+} = 0 \end{array}\right\} \qquad (16)$$

In this equation, *g* indicates desirable (good) outputs, *b* indicates undesirable (bad) outputs, w_g and w_b indicate weight of desirable and undesirable outputs respectively.

The non-oriented undesirable non-radial (SBM) model is also given in Equation 17 (Gang and Zhenhua, 2011).

$$\left.\begin{array}{ll} & \min p = \dfrac{1-\dfrac{1}{m}\displaystyle\sum_{i=1}^{m}\dfrac{s_i^{-}}{x_{i0}}}{1+\dfrac{1}{s}\displaystyle\sum_{r=1}^{s}\dfrac{s_r^{+}}{y_{r0}}} \\ \\ \textit{subjected to} & x_0 - X\lambda - s^{-} = 0 \\ & Y^{g}\lambda - y_0^{g} - s^{g+} = 0 \\ & Y^{b}\lambda - y_0^{b} + s^{b+} = 0 \\ & \lambda, s^{-}, s^{+} \geq 0 \end{array}\right\} \qquad (17)$$

2.4 Analytical Hierarchy Process

Analytic Hierarchy Process (AHP) is a decision support tool which is developed by Thomas L. Saaty in the 1970s. This methodology can be used for modeling problems in the economic, social and management sciences. AHP is a multiple criteria decision making tool that can be used in almost all the approach related with decision making. Vaidya (2006) emphasized that AHP has been a tool used by decision makers and researchers since its development. It is one of the most widely used multiple criteria decision-making tools. Many distinguished studies conducted and published based on AHP. These studies include applications of AHP in different fields such as planning, selecting a best alternative, resource allocations, benchmarking, quality management, *etc*. Bhushan and Rai (2004) also contributed that the simplicity and power of the AHP have led to its common usage across multiple disciplines in every part of the world. It is also demanded by business, government, social studies, R&D, defense, and other disciplines involving decisions in which choice, prioritization or forecasting is needed.

The AHP technique provides a means of dividing the main problem into a hierarchy of sub-problems. Therefore, these sub-problems can be understood easily and subjectively evaluated. The subjective assessments are converted into numerical values and processed to rank each alternative on a numerical scale (Bhushan and Rai, 2004). Hierarchic structure of AHP method is given in Figure 7.

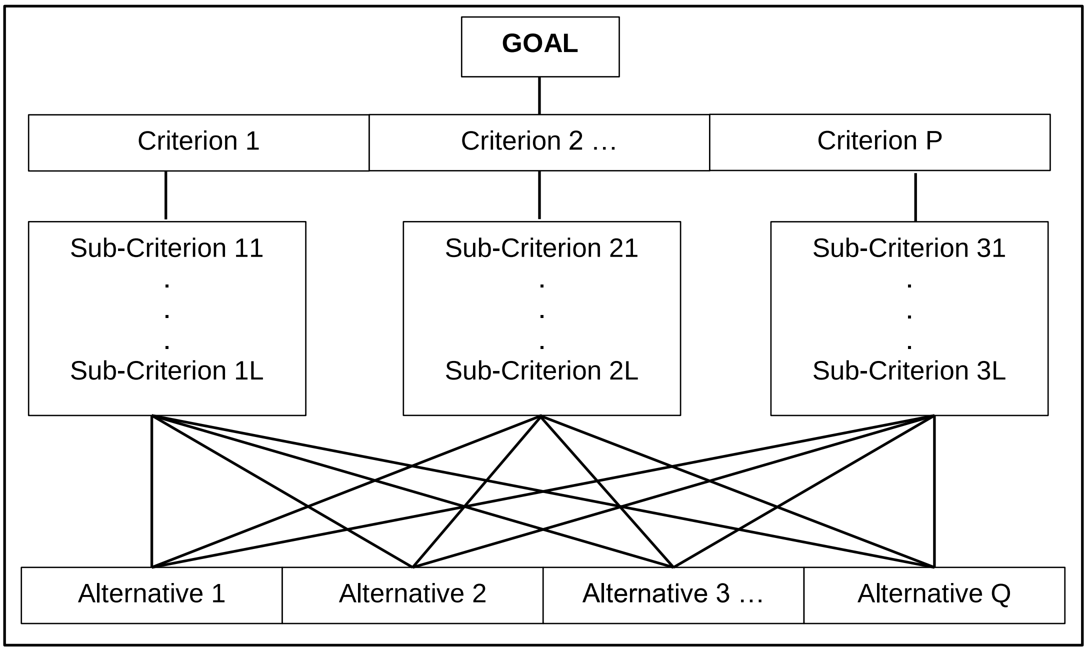

Figure 7 Generic Hierarchic Structure (Bhushan and Rai, 2004)

AHP requires a pair-wise determination of the relative importance of each of the criterion. In other words, the comparison of criterions and sub-criterions is conducted by a scale which is developed by Saaty (1980) as seen in Figure 8. Numerical values of the options on the scale are presented in Table 2.

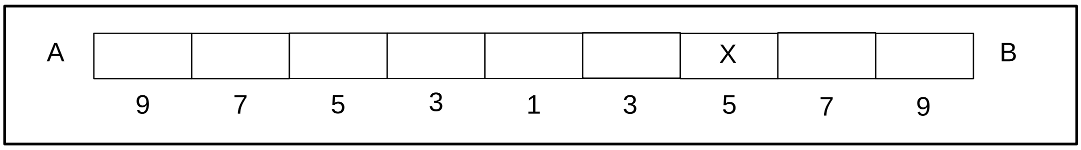

Figure 8 Scale for Pairwise Comparisons

Table 2 The Fundamental Scale of Absolute Numbers (Saaty, 2008)

Intensity of Importance	***Definition***	***Explanation***
1	Equal Importance	Two activities contribute equally to the objective
2	Weight or slight	
3	Moderate Importance	Experience and judgment slightly favor one activity over another
4	Moderate Plus	
5	Strong Importance	Experience and judgments strongly favor one activity over another
6	Strong Plus	
7	Very Strong or Demonstrated Importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, Very Strong	
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j,* then *j* has the reciprocal value when compared with *i.*	A reasonable assumption
1.1 – 1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

After the application of questionnaire study, the pairwise comparisons of various criteria are organized into a square matrix.

The principal eigenvalue and the corresponding normalized right eigen-vector of the comparison matrix give the relative importance of the criteria. The elements of the normalized eigenvector are termed weights with respect to the criteria or sub-criteria and scores with respect to the alternatives. After this process, consistency level of the matrix (n ordered) can be explored. If the consistency level is not sufficient, answers of the questionnaire may be re-examined. The Consistency Index (CI) can be obtained as $CI = (\lambda_{max} - n)/(n - 1)$. In this formulation, λ_{max} is the maximum eigenvalue of the matrix. This consistency index can be compared with a Random Matrix (RI). The ratio of CI/RI gives the

Consistency Ratio (CR) (Bhushan and Rai, 2004). Saaty (1990) suggested the value of CR should be less than 0.1.

2.5 Developed AHP and DEA Integrations in Literature

AHP and DEA are used together in the literature in two ways. In the first type integration, AHP is used to define the weight restrictions of inputs and outputs. Meanwhile in the second type of integration, DEA and AHP are combined as more complex than the previous one. It is called as Data Envelopment Analytical Hierarchy Process (DEAHP).

As mentioned in the previous topics, weight restriction is very important in DEA to prevent the unrealistic weights in DEA model results. In the literature, AHP is used to define the weight restrictions of inputs and outputs of the model. Yang and Kuo (2003) used this type of integration in their study. This study recommends a hierarchical AHP and DEA approach to solve a plant layout design problem. The qualitative performance measures are weighted by AHP application and then DEA is used to solve the multiple-objective layout problem. Karakoç (2003) used AHP to determine the constraints for weight restrictions in DEA model. The weight-restricted model by AHP is then applied to a data set. This data set was taken from the study of Beasley (1990). Then, the results are compared to that of the unrestricted DEA model. Similar study was published by Erpolat and Cinemre (2011). In this paper, benchmarking of various laptop brands and their models is conducted by two different DEA models. One of the models is unrestricted on weights while the other is not. In the weight restricted model, weights are estimated by AHP which allows including experts opinions in the weight restriction. Wang *et al.* (2008) proposed a DEA model with assurance region (AR) for priority derivation in the AHP. It is referred to as the DEA/AR model. In this model, boundaries of AR are defined by AHP. Mohajeri and Amin (2010) dealed with the problem of defining the optimum site for a railway station for the city of Mash-had using the methods of AHP and DEA.

The second way of DEA and AHP integration is DEAHP method which is a hybrid of DEA and AHP assumptions. In this assumption, the weights in pairwise comparison matrices of AHP are determined by DEA. AHP calculations are based on these weights. Therefore, the hybrid approach yields the most appropriate decisions by means of these weights (Eroğlu and Lorcu, 2007). DEAHP was developed by Ramanathan (2006) and in this study, “it is proved that DEA correctly estimates the true weights when applied to a consistent matrix formed using a known set of weights. DEA is further proposed to aggregate the local weights of alternatives in terms of different criteria to compute final weights”. Robustness through rank reversal properties of the DEAHP in decision making was explored in the study of Nachiappan and Ramanathan (2008). Real case applications of DEAHP are conducted by several researchers. For example, Sevkli *et al*. (2007) applied the DEAHP for supplier selection to BEKO which is a well-known Turkish company operating in the appliance industry. Also, Eroglu and Lorcu (2007) used DEAHP for investigating the pricing strategies in automobile sector in Turkey.

2.6 DEA Applications in OHS Discipline

Safety performance evaluation is a crucial part of safety management systems. The importance of safety performance is that it supplies valuable information on the system’s quality such as development, implementation and outputs. Therefore, it can be said that decision making in OHS is influenced by safety performance evaluation (Sgourou *et al*., 2010).

DEA is a relatively new methodology. Therefore, application of this useful method is not demanded sufficiently in OHS discipline. The first study about DEA about OHS discipline was published in 2001 by Feroz *et al.* (2001). In this study, DEA is used to examine the economic consequences of the Occupational Health and Safety Administration (OSHA) cotton dust standards. The precedence of this paper is economic results of an OHS standard. Therefore, accounting-based inputs of common equity, total assets, and production costs were minimized while total revenue was maximized. The writers indicated that DEA is a useful method as an alternative method of testing the economic results of laws and regulations as a conclusion.

In real means, the analysis of accident by DEA began in 2003. A paper was published in 2003 by Sarkar *et al*. (2003). It is also the first published material about DEA application of OHS in mines. The scientists conduct safety performance evaluation of underground coal mines in terms of productivity, efficiency, and profitability using DEA methodology and fuzzy set theory. The second OHS related paper was published by Tong and Ding (2008). This study is conducted on coal mine's efficiency assessment of safety input. Output oriented CCR model is selected to assess the safety performance of the coal mines. The scientists used seven inputs and three outputs to compare the annual mine safety performance of an operating coal mine between 2001 and 2005. The used inputs are the proportion of the professional staff assigned to safety, per-man costs associated with providing safety measures, the cost of providing protection equipment per-man, the costs of safety education and training per-man, the costs of safety management per-man, the total working time each man applies toward safety and the hours of safety training per-man. The defined outputs are the reduction of risk degree, the reduction in casualties and the ratio of reducing accident damage. As indicated, number of the inputs and outputs is ten while the number of DMUs is five. This means that this study is not appropriate the thumb rule of DEA which is that number of DMUs should be equal or greater than "*number of inputs + number of outputs -1"*. Therefore, the results may not be applicable because in this conditions number of efficient firms is decreased. In other words, some inefficient firms may become efficient.

One of them was published by Nissi and Rapposelli (2010). In this study, industrial accidents in European countries are analyzed with DEA. Performances of fifteen European countries for 2005 are examined with respect to the number of industrial accident. It is considered that three non-financial business sectors are selected as manufacturing, construction, and distribution trades. This case includes single input as number of person employed and two outputs as value added and number of industrial accidents resulting in three days or more off work. The used model is the modified input-oriented DEA model under a variable returns to scale assumption as a result of the large variation in size of the units. The second one was published by Abbaspour *et al*. (2010). The main objective of this study is developing a valid and an appropriate model based on DEA to assess efficiency and environmental performance of companies with concerning OHS and environmental management system principles. 12 oil and gas general contractors have been selected for the real case application. Two inputs and six outputs are used in this application. The third paper was published by El-Mashaleh *et al*. (2010). The aim of this paper is to benchmark safety performance of construction contractors with utilizing DEA. The proposed approach is conducted with using empirical data. It is collected from 45 construction contractors. After defining the inefficient contractors, the study provides quantitative guidance on how they are become efficient one. In this study, one input and five outputs are defined to benchmark 45 construction contractors. At first, accidents are categorized in to five groups as Type 1 Accident, Type 2 Accident, *etc*. Then input and outputs are defined. The input is expenses on safety as a percent of total revenues. The outputs are 1/Type 1 Accident, 1/Type 2 Accident, 1/Type 3 Accident, 1/Type 4 Accident and 1/Type 5 Accident. This study is one of the well developed and organized papers in DEA application in OHS Discipline. However, raw data is modified for DEA application but this operation is not suggested in the literature. The last one was published by Liao and Chen (2010). This study is about the issue on the annual performance evaluation of Taipei's occupational safety strategy in building industry using DEA. To analyze the performance of occupation safety strategy, one output as total death number and two inputs as the ratio of penalty to inspected number and the ratio of amercement to inspected number are utilized. This study involves the period between 1995 and 1999.

In the last year, 2011, four studies are published as DEA application in OHS discipline. The firs study was published by Beriha *et al.* (2011a). The main aim of the study is to develop appropriate construct to benchmark occupational health and safety performance in industrial setting. Therefore, the related deficiencies can be emphasized and relevant strategies and policies can be applied to improve the performance of the inefficient ones. In three industrial categories as construction, refractory, and steel, 30 Indian organizations are selected for comparison. Both CRS and VRS approaches of DEA are applied with four input and five outputs. Beriha *et al.* (2011b) published the simple version of the same study in a conference. Another publication was published by Genç and Hermanus (2011). This paper does not include DEA application but it indicates the importance of the benchmarking in mining industry. In the same year, a comprehensive study was conducted by Çimen (2011). This study includes the efficiency comparison of the eight establishments of the Turkish Coal Enterprises between 2006 and 2009. These efficiencies are analyzed by DEA, Super Efficiency (SE) and Malmquist Total Factor Productivity Index (MI) approaches. Efficiency values of the enterprises are analyzed in three different fields as production, revenue, and work safety.

CHAPTER 3

DEVELOPING AHP.DEA METHOD FOR LIMITED NUMBER DMUs PROBLEMS

It can be said that DEA is an excellent method for analyzing relative efficiency of organizations and it can be used when multiple inputs and outputs are present. This method generates an efficiency score for each DMU (Abbaspour *et al.*, 2010). The main advantage of DEA is performing benchmarking between the defined DMUs. Benchmarking methodology can be defined as a learning process. This process is based on the search for the best management or operating system in the market. After defining the best management system, it can be a reference point to the other DMUs for facilitating better. Therefore, they may perform better in control procedures, accident investigation techniques, ergonomically design of jobs, and self-assessment through identification of one's strengths and weaknesses (Beriha *et al*., 2011a). This is one of the advantages of DEA methodology. This methodology should be applied to all disciplines because of the powerful and applicable benefits. However, when the literature in different disciplines is analyzed, DEA is applied for DMU sets which include large number DMUs.

The advantage of using large number DMUs is that number of used input and output in the model can be large. If more inputs and outputs are used in a DEA model, more reliable results can be obtained because different kind of inputs and outputs are included in the calculations and different aspects of problem are included. Therefore, different properties of DMUs can be evaluated in the model to find out the relative efficiency of DMUs. Therefore, researchers prefer to analyze the problems with large number DMUs. For example, average number of used inputs and outputs of randomly selected 20 studies is found as 3.65 and 3.00 respectively. Also, average number of DMUs, analyzed in these studies, is found as 38.25. Detailed information is given in Table 3.

As a powerful and useful methodology, DEA should also be applied for limited number DMUs cases besides large number DMUs studies. However, application of DEA with limited number DMUs is not an easy process because large number of inputs and outputs can not be used due to limited number DMUs. Therefore, a new methodology is developed to assess the relative efficiency of limited number DMUs cases. The new developed methodology is named as AHP.DEA because it is developed with integration of AHP and DEA techniques. In the developed approach, AHP and DEA models are integrated to estimate the relative efficiency of limited number of DMUs.

In the AHP.DEA approach, subjective evaluation power of AHP is combined with objective evaluation power of DEA. Therefore, more convenient results can be obtained than classical DEA model because subjective evaluation of the inputs and outputs may be required for some problems. As mentioned in Chapter 2, AHP is a useful methodology in the multi-criteria decision making process based on subjectively evaluated pair-wise benchmarking.

The AHP.DEA method can be used to evaluate the efficient input usage by DMUs and also output production with minimum input level. These two types can be named as Input Oriented AHP.DEA (IO- AHP.DEA) and Output Oriented AHP.DEA (OO- AHP.DEA) respectively. Detailed information about both approaches of AHP.DEA methodology is supplied sections 3.1 and 3.2.

Table 3 Randomly Selected 20 Studies to Analyze the Number of DMUs, Inputs and Outputs

Study	Number of DMUs	Number of Inputs	Number of Outputs	Inputs + Outputs
Kulshreshtha and Parikh (2002)	17	3	1	4
Tsolas (2008)	15	4	1	5
Fang (2009)	25	3	3	6
Çimen (2011)	8	4	1	5
Byrnes *et al*. (1988)	113	9	1	10
Tsolas (2011)	15	3	1	4
Kasap (2010)	8	2	1	3
Mousavi-Avval *et al*. (2011)	130	8	1	9
Bowlin (1987)	7	3	4	7
Cristóbal (2011)	13	3	4	7
Mohammadi *et al*. (2011)	86	7	1	8
Thompson *et al*. (1994)	14	2	2	4
Brockett *et al*. (1997)	16	4	4	8
Goto and Tsutsui (1998)	23	4	2	6
Puig-Junoy (2000)	94	4	8	12
Sala-Garrido *et al*. (2012)	45	1	3	4
Chen and Sherman (2004)	16	4	9	13
El-Mashaleh *et al*. (2010)	45	1	5	6
Koch (2009)	43	2	6	8
Wu *et al*. (2012)	32	2	2	4
Average	38.25	3.65	3.00	6,65
Standard Deviation	37.35	2.13	2.43	2.78

3.1 Input Oriented AHP.DEA Method

In the IO-AHP.DEA approach, efficient usage of inputs by DMUs can be evaluated. Therefore, improper allocation of inputs can be prevented. For example, Tong and Ding (2008) indicated that frequent accidents occurs in coal mining operations in China due to improper assigning of safety inputs in these coal mines. After application of IO-AHP.DEA methodology, it can be revealed which DMUs use the inputs effectively or not. Some new input allocation procedures can be developed for inefficient DMUs after defining them. IO-AHP.DEA method gives some data or clues for improvement of inefficient DMUs. Therefore, the input allocation procedures can be applied based on the results of IO-AHP.DEA method.

If a DMU uses its inputs effectively, efficiency score of it is estimated as one in this approach. In the same manner, if a DMU cannot use the inputs efficiently, its score is less than one and this DMU should reallocate the inputs to reach the efficiency level of efficient DMUs. IO-AHP.DEA model can be applied in four steps to estimate the relative efficiency of DMUs. Detailed information about the steps is given below.

Step 1:

At first, AHP results or scores of each input should be estimated. These scores can be defined with a questionnaire, survey or a single evaluation form. These questionnaires include pairwise benchmark questions and they are answered by experts. The detailed information about these benchmarking and priority determination can be gained from Saaty (1980, 1990, and 2008) and Bhushan and Rai (2004). The AHP scores of inputs are illustrated in Table 4. In this table, AHP($Input_n$) is AHP evaluation score of nth input.

Table 4 AHP Scores of Inputs

AHP($Input_1$)
AHP($Input_2$)
$\vdots$
AHP($Input_n$)

Step 2:

After finding input priority scores with applying AHP, DEA should be applied to find out the efficiency scores of DMUs. There is a trick point in this step. In classical DEA application, some inputs and some outputs are defined and efficiency scores of DMUs are estimated in a single analysis. However, in AHP.DEA approach, there are multiple DEA implementations. In each analysis, DEA scores of a single input are estimated for each DMU. This procedure is applied multiple for each input as indicated in Table 5. In this table, DEA($Input_{En}$, DMU_m) is DEA Score of mth DMU for nth Input.

In this table, DEA scores of each DMU are estimated for $Input_E$ (estimation input variable) in a single analysis. In each analysis, this input is changed so that DEA scores of each DMU for each input are estimated and stored in database. Except for $Input_E$, the other inputs and outputs are same in each analysis to examine the effect of only $Input_E$ on the DEA score. I_D and O_D can be named as defined input and output variables respectively. They are same in each analysis. Number of $Input_E$, I_D and O_D are determined by the number of DMUs. Number of analysis can be found by product of number of Input$_E$ and number of DMUs.

In the application of DEA stage of AHP.DEA method, some advanced models can be adopted to the basic DEA technique. It is recommended that a suitable weight restriction model should be combined to prevent some inputs/outputs omitted by the model during estimation. Results of the AHP questionnaire results (in Step 1) can also be used in DEA application as a weight restriction data.

Table 5 DEA Results for Each DMU for Each Input$_E$

Number of Analysis	**Inputs**	**Outputs**	**DEA Results**
1	**Input**$_{\mathbf{E1}}$ & (I_{D1} & I_{D2} & …I_{Dn})	(O_{D1} & O_{D2} & …&O_{Dn})	**DEA**$_{(\text{Input}\mathbf{E1},\ \text{DMU1})}$
			DEA$_{(\text{Input}\mathbf{E1},\ \text{DMU2})}$
			⋮
			DEA$_{(\text{Input}\mathbf{E1},\ \text{DMUm})}$
2	**Input**$_{\mathbf{E2}}$ & (I_{D1} & I_{D2} & …I_{Dn})	(O_{D1} & O_{D2} & …&O_{Dn})	**DEA**$_{(\text{Input}\mathbf{E2},\ \text{DMU1})}$
			DEA$_{(\text{Input}\mathbf{E2},\ \text{DMU2})}$
			⋮
			DEA$_{(\text{Input}\mathbf{E2},\ \text{DMUm})}$
⋮	⋮	⋮	⋮
n	**Input**$_{\mathbf{En}}$ & (I_{D1} & I_{D2} & …I_{Dn})	(O_{D1} & O_{D2} & …&O_{Dn})	**DEA**$_{(\text{Input}\mathbf{En},\ \text{DMU1})}$
			DEA$_{(\text{Input}\mathbf{En},\ \text{DMU2})}$
			⋮
			DEA$_{(\text{Input}\mathbf{En},\ \text{DMUm})}$

Step 3:

In this step, AHP scores (Step 1) and DEA scores (Step 2) are integrated. Product of AHP(Input$_n$) and DEA$_{(\text{InputEn, DMUm})}$ gives the relative effective usage of nth input by mth DMU. Therefore, subjective and objective decision making tools are integrated to decide the relative efficiency model. Moreover, in AHP.DEA approach, expert opinion about the problem and objective data are both included in the analysis. This calculation is summarized in Table 6. In this table, AHP.DEA(Input$_{En}$, DMU$_m$) is product of AHP Score of nth Input and DEA Score of mth DMU for nth Input.

Table 6 AHP.DEA Score Estimation

Number of Analysis	Inputs	Outputs	AHP.DEA Results
1	**Input**$_{\mathbf{E1}}$ & (I_{D1} & I_{D2} & …I_{Dn})	(O_{D1} & O_{D2} & …&O_{Dn})	**AHP.DEA**$_{(\text{Input}\mathbf{E1},\ \text{DMU1})}$
			AHP.DEA$_{(\text{Input}\mathbf{E1},\ \text{DMU2})}$
			⋮
			AHP.DEA$_{(\text{Input}\mathbf{E1},\ \text{DMUm})}$
2	**Input**$_{\mathbf{E2}}$ & (I_{D1} & I_{D2} & …I_{Dn})	(O_{D1} & O_{D2} & …&O_{Dn})	**AHP.DEA**$_{(\text{Input}\mathbf{E2},\ \text{DMU1})}$
			AHP.DEA$_{(\text{Input}\mathbf{E2},\ \text{DMU2})}$
			⋮
			AHP.DEA$_{(\text{Input}\mathbf{E2},\ \text{DMUm})}$
⋮	⋮	⋮	⋮
n	**Input**$_{\mathbf{En}}$ & (I_{D1} & I_{D2} & …I_{Dn})	(O_{D1} & O_{D2} & …&O_{Dn})	**AHP.DEA**$_{(\text{Input}\mathbf{En},\ \text{DMU1})}$
			AHP.DEA$_{(\text{Input}\mathbf{En},\ \text{DMU2})}$
			⋮
			AHP.DEA$_{(\text{Input}\mathbf{En},\ \text{DMUm})}$

Step 4:

In the Step 4 as the last step, efficiency scores of IO-AHP.DEA are estimated for single period as a year, month, *etc*. This estimation is based on “AHP.DEA Results” column in Table 6. Sum of the AHP.DEA scores of a DMU from each input gives relatively efficiency score of this DMU. AHP.DEA score of DMU_1 can be found as;

$$AHP.DEA_{(DMU1)} = [AHP.DEA_{(Input\mathbf{E1},DMU1)} + AHP.DEA_{(Input\mathbf{E}2,DMU1)} + \ldots + AHP.DEA_{(Input\mathbf{E}n,DMU1)}]$$

Formulation of the procedure is also developed based on mathematics notations as given in Table 7. In this table, AHP(I_i) is AHP Score of i^{th} Input and DEA(I_i, DMU_m) is DEA Score of m^{th} DMU for i^{th} Input.

Table 7 Formulation for Estimating Efficiency Scores of Each DMU based on IO-AHP.DEA Method

DMU$_1$	$\sum_{i=1}^{n} AHP\left(I_i\right) \times DEA(I_i, DMU_1)$
DMU$_2$	$\sum_{i=1}^{n} AHP\left(I_i\right) \times DEA(I_i, DMU_1)$
$\vdots$	$\vdots$
DMU$_m$	$\sum_{i=1}^{n} AHP\left(I_i\right) \times DEA(I_i, DMU_m)$

IO-AHP.DEA method can also be used to analyze the multi period problems. DMUs can be benchmarked for several years, months, *etc*. Multi period IO-AHP.DEA formulation is also developed in mathematics notations as presented in Equation 18. This equation estimates the average IO-AHP.DEA score for a single DMU for K years or periods.

$$Average\,Efficieny\,Score\,of\ m^{th}\ DMU\ \ for\,K\,Years = \frac{\sum_{j=1}^{K}\sum_{i=1}^{n} AHP\left(I_{i,j}\right) \times DEA\left(I_{i,j}\ , DMU_{m,j}\right)}{K} \quad (18)$$

In this equation, AHP($I_{i,\,j}$) is AHP Score of ith Input at jth year (or period), DEA($I_{i,\,j}$, DMU$_{m,\,j}$) is DEA Score of mth DMU for ith Input at jth year (or period) and K represents number of year (or period).

3.2 Output Oriented AHP.DEA Method

In the OO-AHP.DEA methodology, DMUs can be evaluated based on their outputs. In other words, benchmarking of DMUs is conducted based on how they produce more output with minimum input usage. Therefore, after the applying OO-AHP.DEA methodology, it can be revealed which DMUs produce outputs effectively or not. Based on the results of OO-AHP.DEA, new technologies or applications can be used to increase the efficiency level of inefficient DMUs.

OO-AHP.DEA estimates the score of efficient DMUs as one. Also, if a DMU does not produce same amount output like efficient ones with same input usage, it is labeled as inefficient and its AHP.DEA score is estimated less than one by the OO-AHP.DEA methodology. Estimation procedure of this methodology is similar with IO-AHP.DEA ones. Therefore, its background is also explained in four steps.

Step 1:

Firstly, AHP results or scores of each output should be estimated. These scores can be defined with a questionnaire which includes pairwise benchmark questions. The representational AHP scores of outputs are illustrated in Table 8. In this table, AHP($Output_n$) is AHP evaluation score of n^{th} output.

Table 8 Estimated AHP Scores of Outputs

AHP($Output_1$)
AHP($Output_2$)
⋮
AHP($Output_n$)

Step 2:

After application of AHP method and finding out input priority scores, DEA should be applied to find out the efficiency scores of related outputs. In this step, there are multiple DEA implementations. In each implementation, DEA scores of a single output are estimated for each DMU. This procedure is applied multiple for each output as indicated in Table 9. In this table, DEA($Output_{En}$, DMU_m) is DEA Score of m^{th} DMU for n^{th} output.

In this table, DEA scores of each DMU are estimated for $Output_E$ (estimation output variable) in a single analysis. In each analysis, this output is changed so that DEA scores of each DMU for each output are estimated and stored in database. Except for $Output_E$, the other inputs and outputs are same in each implementation to examine the effect of only $Output_E$. I_D and O_D can be named as defined input and output variables respectively. They are fixed in each implementation. Number of $Output_E$, I_D and O_D are determined by the number of DMUs. Number of analysis can be found by product of number of $Output_E$ and number of DMUs.

It should be noted that all outputs may not be desirable at every applications. If a case includes one or more undesirable outputs, DEA model should be modified during the DEA score estimation procedure. Moreover, results of the AHP questionnaire results (in Step 1) can also be used in DEA application as a weight restriction data. As known, if a weight restriction method is not combined with DEA, some inputs/outputs weights become zero or unrealistic during the DEA process. Therefore, some inputs/outputs are omitted by the model during estimation.

Table 9 DEA Results for Each DMU for Output$_E$

Number of Analysis	Inputs	Outputs	DEA Results
1	(I_{D1} & I_{D2} & …I_{Dn})	**Output**$_{\mathbf{E1}}$ & (O_{D1} & O_{D2} & …&O_{Dn})	**DEA**$_{(\text{Input}\mathbf{E1},\ \text{DMU1})}$
			DEA$_{(\text{Input}\mathbf{E1},\ \text{DMU2})}$
			⋮
			DEA$_{(\text{Input}\mathbf{E1},\ \text{DMUm})}$
2	(I_{D1} & I_{D2} & …I_{Dn})	**Output**$_{\mathbf{E2}}$ & (O_{D1} & O_{D2} & …&O_{Dn})	**DEA**$_{(\text{Input}\mathbf{E2},\ \text{DMU1})}$
			DEA$_{(\text{Input}\mathbf{E2},\ \text{DMU2})}$
			⋮
			DEA$_{(\text{Input}\mathbf{E2},\ \text{DMUm})}$
⋮	⋮	⋮	⋮
n	(I_{D1} & I_{D2} & …I_{Dn})	**Output**$_{\mathbf{En}}$ & (O_{D1} & O_{D2} & …&O_{Dn})	**DEA**$_{(\text{Input}\mathbf{En},\ \text{DMU1})}$
			DEA$_{(\text{Input}\mathbf{En},\ \text{DMU2})}$
			⋮
			DEA$_{(\text{Input}\mathbf{En},\ \text{DMUm})}$

Step 3:

In this step, AHP scores (Step 1) and DEA scores (Step 2) are integrated. Product of AHP(Output$_n$) and DEA(OutputEn**,** DMUm) gives the relative effective usage of nth output by mth DMU. Therefore, subjective and objective decision making tools are integrated to decide the relative efficiency model. Moreover, in AHP.DEA approach, expert opinion about a problem and objective data are both included in the analysis. This calculation is summarized in Table 10. In this table, AHP.DEA(Output$_{En}$, DMU$_m$) is product of AHP Score of nth output and DEA Score of mth DMU for nth output.

Table 10 AHP.DEA Score Estimation

Number of Analysis	Inputs	Outputs	AHP.DEA Results
1	(I_{D1} & I_{D2} &…I_{Dn})	**Output$_{\mathbf{E1}}$** & (O_{D1} & O_{D2} & …&O_{Dn})	**AHP.DEA**$_{(\text{Output}\mathbf{E1},\ \text{DMU1})}$
			AHP.DEA$_{(\text{Output}\mathbf{E1},\ \text{DMU2})}$
			⋮
			AHP.DEA$_{(\text{Output}\mathbf{E1},\ \text{DMUm})}$
2	(I_{D1} & I_{D2} &…I_{Dn})	**Output$_{\mathbf{E2}}$** & (O_{D1} & O_{D2} & …&O_{Dn})	**AHP.DEA**$_{(\text{Output}\mathbf{E2},\ \text{DMU1})}$
			AHP.DEA$_{(\text{Output}\mathbf{E2},\ \text{DMU2})}$
			⋮
			AHP.DEA$_{(\text{Output}\mathbf{E2},\ \text{DMUm})}$
⋮	⋮	⋮	⋮
n	(I_{D1} & I_{D2} &…I_{Dn})	**Output$_{\mathbf{En}}$** & (O_{D1} & O_{D2} & …&O_{Dn})	**AHP.DEA**$_{(\text{Output}\mathbf{En},\ \text{DMU1})}$
			AHP.DEA$_{(\text{Output}\mathbf{En},\ \text{DMU2})}$
			⋮
			AHP.DEA$_{(\text{Output}\mathbf{En},\ \text{DMUm})}$

Step 4:

In the fourth step, efficiency scores of DMUs with OO-AHP.DEA are estimated for single period as a year, month, *etc*. This estimation is based on “AHP.DEA Results” column in Table 10. Sum of the AHP.DEA scores of a DMU from each output gives relative efficiency score of this DMU. AHP.DEA score of DMU_1 can be found as;

$$AHP.DEA_{(DMU1)} = [AHP.DEA_{(Output\mathbf{E1},DMU1)} + AHP.DEA_{(Output\mathbf{E}2,DMU1)} + ... + AHP.DEA_{(Output\mathbf{E}n,DMU1)}]$$

Formulation of OO-AHP.DEA method is also developed based on mathematics notations as given in Table 11. In this table, AHP(O_i) is AHP Score of i^{th} Output and DEA(O_i, DMU_m) is DEA Score of m^{th} DMU for i^{th} Output.

Table 11 Formulation for Estimating Efficiency Scores of Each DMU Based on OO-AHP.DEA Method

DMU_1	$\sum_{i=1}^{n} AHP\left(O_i\right) \times DEA(O_i, DMU_1)$
DMU_2	$\sum_{i=1}^{n} AHP\left(O_i\right) \times DEA(O_i, DMU_2)$
$\vdots$	$\vdots$
DMU_m	$\sum_{i=1}^{n} AHP\left(O_i\right) \times DEA(O_i, DMU_m)$

OO-AHP.DEA method can also be used to analyze the multi period problems. DMUs can be benchmarked for several years, months, *etc*. Multi period OO-AHP.DEA formulation is also developed in mathematics notations and it is presented in Equation 19.

$$Average\,Efficieny\,Score\,of\ m^{th}\ DMU\ \ for\ K\,Years = \frac{\sum_{j=1}^{K}\sum_{i=1}^{n} AHP\left(O_{i,j}\right) \times DEA\left(O_{i,j}\ , DMU_{m,j}\right)}{K} \qquad (19)$$

In this equation, AHP($O_{i,\ j}$) is AHP Score of i^{th} Output at j^{th} year (or period), DEA($O_{i,\ j}$, $DMU_{m,\ j}$) is DEA Score of m^{th} DMU for i^{th} Output at j^{th} year (or period) and K represents number of year (or period).

CHAPTER 4

A CASE STUDY: APPLICATION OF AHP.DEA MODEL TO OHS PERFORMANCE ASSESSMENT OF TTK ESTABLISHMENTS

The developed AHP.DEA model has been applied to a case study to check the validity of AHP.DEA model. Turkish Hard Coal Enterprise (TTK) is selected as a case study to apply Input and Output Oriented AHP.DEA methods.

4.1 Establishments of TTK

TTK is a state owned organization and it is responsible for the operation and administration of all hard coal and coal bed methane activities in Turkey. TTK produce hard coal in five production areas because of widely dispersed nature of the hard coal basins. These are Amasra, Armutçuk, Karadon, Kozlu, and Üzülmez. Location of these establishments and working area of TTK are presented in Figure 9 (Biçer, 2008). Number of worker and annual ROM coal production of the establishments are given in Table 12.

The main reason for selection of TTK is that it has five establishments and each establishment represents a DMU. Therefore, a limited number DMUs case can be analyzed with AHP.DEA models. In this case study, OHS performances of five establishments are evaluated. Some data about the establishments for 2007-2011 periods is provided for the evaluation.

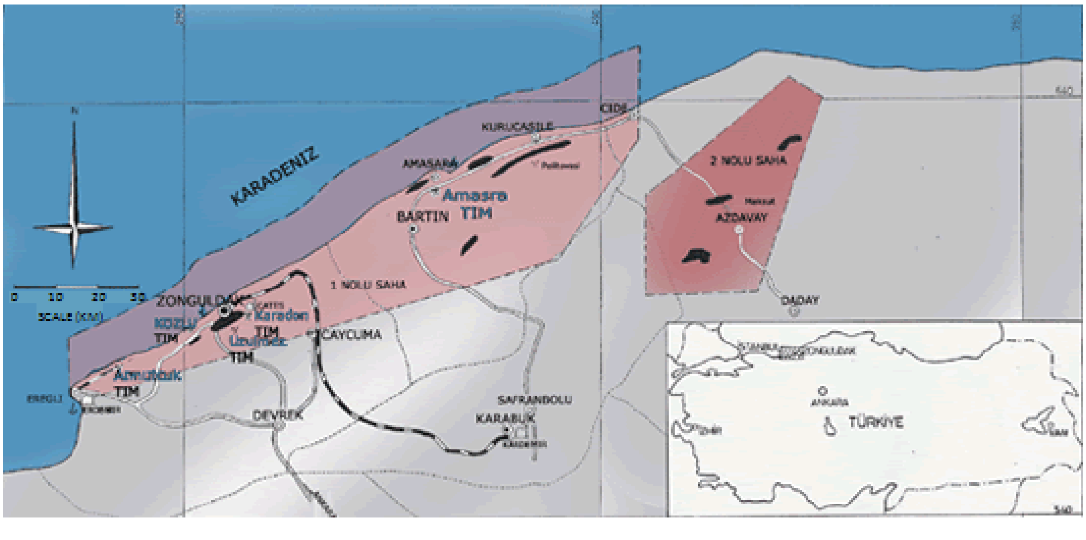

Figure 9 Working Area and Location of Establishments of TTK (TTK, 2013)

Table 12 TTK Establishments Operation Data for 2011

Name of Establishment	Number of Worker	Annual ROM Coal Production (ton)
Amasra	644	289,880
Armutçuk	1,144	257,785
Karadon	2,838	803,067
Kozlu	1,702	691,150
Üzülmez	1,801	571,300
Total	**8,129**	**2,613,182**

4.2 Specified Input and Output Variables

Some important OHS inputs and outputs are specified to be utilized in the case study. They cover five inputs and six outputs as shown in Table 13.

Table 13 Specified Inputs and Outputs

Inputs	Number of Worker
	Number of OHS Staff
	Annual OHS Expenditures
	Annual OHS Education Time
	Annual Effective Work Hour
Outputs	Annual Accident Number
	Annual Number of Death
	Annual Number of Injured Worker
	Annual Number of Lost Day
	Annual Accident Cost
	Annual ROM Coal Production

4.2.1 The Input Variables

Five OHS input variables are specified to apply AHP.DEA method as presented in Table 13. Some information about them is given below.

Number of Worker:

Number of worker is one of the most important input variables in OHS performance measurement. Number of worker also reflects the scale of establishments or firms. Moreover, number of worker affects number of accidents directly since accident occurrence probability is increased with the number of worker. Therefore, in this study, number of worker is used in all IO-AHP.DEA applications. In other words, as mentioned in Chapter 3, number of worker is determined as “Defined Input Variable” (I_D) and it is used in each IO-AHP.DEA application together with “Estimation Input Variable” (I_E) and thus, scale of the establishments is included in the calculations. Number of worker is also determined as I_D in the OO- AHP.DEA method due to the establishments scale concern. If scale of establishments is not included, some deviations may occur in the calculations.

Number of OHS Staff:

In the OHS performance evaluation, other important input variable is the number of OHS staff. Responsibilities of OHS staffs cover the areas such as the preparation of directions, supervising the operation and workers, removing the incidence factors. Therefore, OHS staffs play an important role on the occurrence and destructive effects of accidents.

Annual OHS Expenditures:

OHS expenditure variable is also another important factor. It includes considerations such as consumables outfits, capital expenditures. If an establishment spends more for the related OHS necessities, accident occurrence probability and destructive effect of accident is decreased. In TTK database, some OHS expenditures are not met by the establishments. These expenditures are done by head office. Therefore, these expenditures are distributed to the establishment according to the number of worker.

Annual OHS Education Time:

Education can be considered as the most important input variable in the OHS performance evaluation. Occurrence of accident is directly related with education of the workers. Therefore, comprehensive vocational training courses should be given to inexperienced workers. In addition, it should be conducted regularly for all workers to increase the awareness about the incidents and results of the accidents. If the education level of the workers is increased, number of accidents will decrease mutually.

Annual Effective Work Hour:

Annual effective work hour is estimated by the number of worker in an establishment. To calculate this value, de facto number of worker is multiplied by hour of shift. This input variable is also important to evaluate the accidents.

4.2.2 The Output Variables

Six OHS output variables are specified to apply AHP.DEA method as presented in Table 13. OHS output variables utilized in AHP.DEA method are introduced below.

Annual Accident Number:

Number of accident is one of the important output variables. If number of accidents is high, the rate of death and injured worker is increased. Therefore, it should be kept low. Some important accident precautions must be applied to decrease it. Moreover, the capital damage and financial loss increase proportionally with number of accidents.

Annual Number of Death:

Number of death can be considered as the most important output parameter in the OHS analyses. In the working environments, the most desired OHS criterion is that number of death is zero. Therefore, some related precautions must be taken to prevent the losing worker's life. Nevertheless, workers lose their life because of occupational accidents and occupational diseases.

Annual Number of Injured Worker:

This output parameter is also important as number of death. This category also includes the number of crippled worker because of occupational accidents. Quality of life of the crippled worker is also affected adversely.

Annual Number of Lost Day:

Number of lost day is one of the main output parameters to represent the all number of death and injuries. There are some approaches to estimate the lost day equivalent of death. For example, in Turkey, 7500 work day is estimated as lost day because of one death.

Annual Accident Cost:

When the OHS related studies are analyzed, generally input and output selection procedure is completed superficially. As an example of these situations, number of accidents is selected as output in some DEA studies but it may create some conflicts. For example, in X mining company, 10 accidents, resulted in arm or leg injuries, were occurred. On the other hand, in Y mining company, only one accident, resulted in death, was occurred. If only number of accident is used as output, the second one may become more efficient but it is not. Therefore, more prepotent and comprehensive outputs should be used together with number of accidents. Cost of accident can be an example for these outputs.

Güyagüler *et al.* (2005) noted that the average cost of a lost time accident varies from $7,000 to $13,000 and that of a fatality from $800,000 to $1,200,000 in USA. In addition to that, according to United States Department of Interior Bureau of Mines Report, in 1991, total cost of the accidents for underground and surface coal mining is $156,546,961 in USA.

To find the cost of accident a cost model has to be developed. Various parameters may be required for various cost models. This kind of data provides basic input for expected cost of injury or fatality. The considered cost elements are summarized as follows;

- Loss in personal income,
- Compensation of wages from state for disabling injury,
- Benefits for injuries resulting in death or permanent disability,

- Medical treatment and hospital care,
- Immediate and post-accident losses as a result of a fatality or amputation injury (including production loss),
- The investigation of a fatal accident
- Cost of lawsuits, loss of equipment, production loss due to permanent shutdown, temporary replacement of an injured miner, cost of long term follow up treatment, *etc.*

There are two cost categories in working environments. They are direct and indirect costs. The listed costs above are in direct cost category. Amount of the indirect cost category contains more considerations than direct costs. In the literature, this relationship is defined with an iceberg as presented in Figure 10. In some studies, direct cost is named as insured cost and indirect cost is named as uninsured cost.

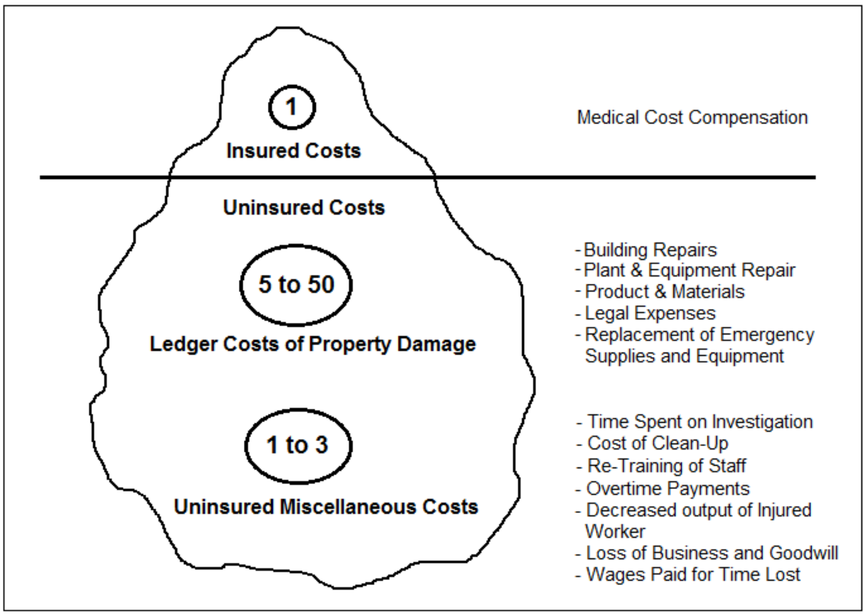

Figure 10 Accident Cost Iceberg

Annual ROM Coal Production:

Annual ROM coal production is not a direct OHS output parameter but it is selected to include the scale of the establishments in the calculations.

4.3 Related Data about the Specified Input and Output Variables

The related data about the specified input and output variables is taken from TTK database. The collected data set includes the related data for 2007-2011 periods. Therefore, last five years' OHS performance of TTK establishments is investigated by AHP.DEA method. The data about the specified input variables are presented in Table 14 - Table 18. In these tables, annual OHS expenditures includes sum of the operating and capital expenditures for OHS.

Table 14 Specified Input Variable Data for AMASRA Establishment

INPUT	2007	2008	2009	2010	2011
Number of Worker	656	587	650	643	644
Number of OHS Staff	46	46	42	36	47
Annual OHS Expenditures, TL	131.506	118.070	107.903	88.359	322.004
Annual OHS Education Time, hrs.	315	327	327	264	249
Annual Effective Work Hour, hrs.	1.558.942	1.415.925	1.568.047	1.454.882	1.423.582

Table 15 Specified Input Variable Data for ARMUTÇUK Establishment

INPUT	2007	2008	2009	2010	2011
Number of Worker	1.172	1.062	1.110	1.110	1.144
Number of OHS Staff	45	41	40	43	49
Annual OHS Expenditures, TL	315.616	213.613	184.265	152.533	480.940
Annual OHS Education Time, hrs.	192	162	315	255	261
Annual Effective Work Hour, hrs.	2.686.725	2.445.840	2.608.267	2.496.472	2.524.365

Table 16 Specified Input Variable Data for KARADON Establishment

INPUT	2007	2008	2009	2010	2011
Number of Worker	2.964	2.737	3.220	3.065	2.838
Number of OHS Staff	170	175	180	190	192
Annual OHS Expenditures, TL	637.822	550.525	534.535	421.184	1.494.187
Annual OHS Education Time, hrs.	504	549	828	1.107	1.116
Annual Effective Work Hour, hrs.	6.804.630	6.178.965	7.613.512	6.895.462	6.835.770

Table 17 Specified Input Variable Data for KOZLU Establishment

INPUT	2007	2008	2009	2010	2011
Number of Worker	1.564	1.410	1.752	1.752	1.702
Number of OHS Staff	37	55	63	70	86
Annual OHS Expenditures, TL	453.990	284.423	364.997	240.755	734.947
Annual OHS Education Time, hrs.	540	567	543	528	564
Annual Effective Work Hour, hrs.	3.635.835	3.289.485	4.154.925	3.941.670	3.842.332

Table 18 Specified Input Variable Data for ÜZÜLMEZ Establishment

INPUT	**2007**	**2008**	**2009**	**2010**	**2011**
Number of Worker	1.833	1.667	1.887	1.789	1.801
Number of OHS Staff	39	44	45	46	46
Annual OHS Expenditures, TL	300.926	335.303	313.251	245.840	621.293
Annual OHS Education Time, hrs.	823	823	741	609	660
Annual Effective Work Hour, hrs.	4.185.435	3.799.815	4.341.637	4.011.585	3.753.292

The data about the selected output variables about the five TTK establishments are presented in Table 19 - Table 23. In these tables annual accident cost indicates only sum of direct costs because there is no data related with indirect costs in TTK databases.

Table 19 Specified Output Variable Data for AMASRA Establishment

OUTPUT	**2007**	**2008**	**2009**	**2010**	**2011**
Annual Number of Lost Day	1.639	1.607	2.663	2.619	3.232
Annual Accident Number	141	138	211	267	251
Annual Number of Death	0	0	0	0	0
Annual Number of Injured Worker	141	138	211	267	251
Annual Accident Cost, TL	319.915	652.535	726.085	95.763	202.904
Annual ROM Coal Production, ton	194.739	203.073	239.598	287.630	289.880

Table 20 Specified Output Variable Data for ARMUTÇUK Establishment

OUTPUT	**2007**	**2008**	**2009**	**2010**	**2011**
Annual Number of Lost Day	154	9.758	2.625	4.827	4.191
Annual Accident Number	249	187	231	304	337
Annual Number of Death	0	1	0	0	0
Annual Number of Injured Worker	249	186	231	304	337
Annual Accident Cost, TL	302.637	265.872	504.979	497.573	190.031
Annual ROM Coal Production, ton	342.149	332.485	326.820	265.591	251.785

Table 21 Specified Output Variable Data for KARADON Establishment

OUTPUT	2007	2008	2009	2010	2011
Annual Number of Lost Day	33.024	34.251	52.514	36.795	24.188
Annual Accident Number	951	938	1.867	1.726	1.165
Annual Number of Death	2	2	4	2	1
Annual Number of Injured Worker	949	936	1.863	1.724	1.164
Annual Accident Cost, TL	2.020.617	1.639.349	2.518.732	943.979	1.413.857
Annual ROM Coal Production, ton	809.726	814.819	1.043.879	905.393	803.067

Table 22 Specified Output Variable Data for KOZLU Establishment

OUTPUT	2007	2008	2009	2010	2011
Annual Number of Lost Day	22.215	13.343	24.533	17.091	7.436
Annual Accident Number	414	280	624	601	491
Annual Number of Death	2	1	1	1	0
Annual Number of Injured Worker	412	279	623	600	491
Annual Accident Cost, TL	831.386	904.329	702.378	254.218	1.581.464
Annual ROM Coal Production, ton	555.430	518.230	653.700	683.150	691.150

Table 23 Specified Output Variable Data for ÜZÜLMEZ Establishment

OUTPUT	2007	2008	2009	2010	2011
Annual Number of Lost Day	16.080	30.816	11.077	24.937	32.936
Annual Accident Number	289	344	471	464	557
Annual Number of Death	1	3	0	2	3
Annual Number of Injured Worker	288	343	471	463	555
Annual Accident Cost, TL	1.576.788	1.274.381	1.075.155	1.531.507	1.867.893
Annual ROM Coal Production, ton	521.675	466.850	569.246	585.650	571.300

4.4 Applying AHP.DEA Method

AHP.DEA method is composed of three stages for single period evaluation. If a multi period case is analyzed, the fourth stage also should be considered. The first one is applying a survey or questionnaire with experts and evaluating the questionnaire with AHP technique. The second stage is relatively comparison of the DMUs with DEA technique. In the last one, results of AHP and DEA are integrated to estimate AHP.DEA score of each establishment.

4.4.1 Applying AHP Method

In the first stage of the AHP.DEA method, a questionnaire is prepared to determine the importance or priority rank of inputs and outputs. Therefore, after applying this questionnaire, corporate overview to OHS of TTK is obtained. In other words it is exposed which inputs and outputs are more important than the others for TTK. These questionnaires are given in Appendix A and Appendix B. It is decided that the questionnaire should be conducted with bureaucrats of TTK because the last decisions about the process of mining is given by them in state mining enterprises in Turkey. Also, in the equipment purchases and project modifications can be conducted after getting the bureaucrats' okay. Two instructors are also selected because they know the establishments and region very well and they study in OHS field in Bülent Ecevit (Karaelmas) University, Zonguldak. The list of participants is given below.

- 2 deputy of general managers,
- 1 head of OHS department,
- 5 establishments' managers,
- 2 professors

Then, a program is written on Excel® 2010 of Microsoft to calculate the average of the questionnaire answers. To apply AHP method, Expert Choice® of Expert Choice, Inc. (www.expertchoice.com) trial version is used and weights of each input and output are obtained. These weights are presented in Figure 11 and Figure 12 for inputs and outputs respectively. In the AHP method calculations, inconsistency should not be more than 0.1. However, in our estimation inconsistency is found as 0.11 for input case. The used number is average of 10 experts. Therefore, it is determined that difference of 0.01 is reasonable.

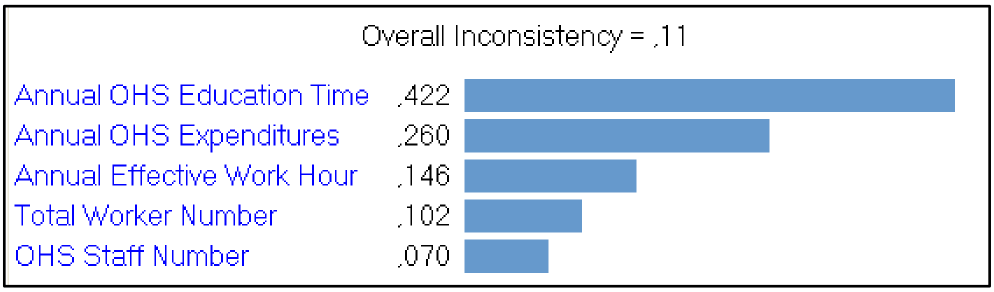

Figure 11 Estimated Input Weights by Questionnaire

As indicated in Figure 11, annual OHS education time is most important input variable for TTK. The second one is Annual OHS expenditures. It can be said that TTK wants to increase education level of the workers and also it wants equipping the establishments with safety tools to prevent the accidents.

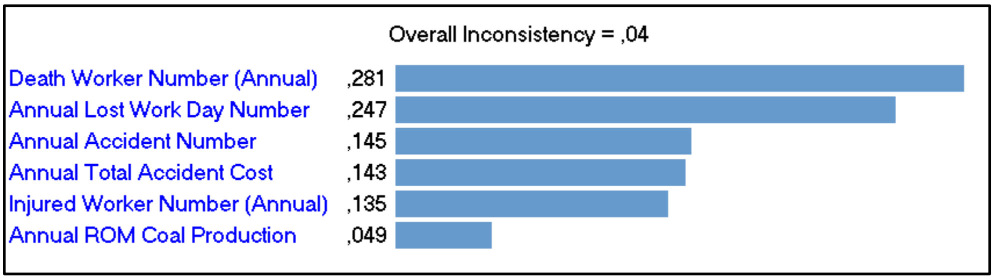

Figure 12 Estimated Output Weights by Questionnaire

Figure 12 states that the number of worker who died is most critical output variable for TTK. Moreover, rank of total accident cost is four. This means that TTK prefers losing money for workers' life. However, the mining zone is not suitable for mechanized mining. Therefore, a worker intensive method is applied in the area. This situation causes increase in the number of accident and some accidents result in death and injury.

The AHP scores input and output variables are used in the last stage for the integration of AHP and DEA methods. Also the estimated AHP scores are used in the DEA calculations for defining the preference weights of inputs and outputs in the DEA model. These means that estimated AHP scores are very important to get more reliable results from the AHP.DEA method.

4.4.2 Applying DEA Method

In this study, Input and Output Oriented AHP.DEA methods are applied for OHS performances of TTK establishments. Therefore, at the second stage of the study, DEA applications are conducted in two categories. The first one is DEA applications for estimating the DEA scores of input variables. On the other hand, in the second category, DEA applications are conducted to determine the DEA scores of output variables. In the 4.4.2.1 and 4.4.2.2 topics, these DEA applications and background of the DEA models are stated. Also, all DEA application results are presented in Appendix C.

4.4.2.1 Applying DEA Method for Input Variables

In this part, DEA applications are handled for estimating the DEA scores of each specified input. As mentioned previously, five OHS inputs are specified namely number of worker, number of OHS staff, annual OHS expenditures, annual OHS education time and annual effective work hour. Number of worker is selected as a defined input variable (I_D) and it is used in all DEA applications as input. Therefore, sizes of the establishments are included in the calculations. On the other hand, two outputs are determined as defined output variables in each DEA application for estimation of DEA scores of inputs. The defined input, estimation inputs and defined outputs are presented in Table 24. Estimation input variable is marked as bold in this table. As seen in this table, two inputs and two outputs are used in the calculations because total number of inputs and outputs should be maximum four since our DMUs' number is five. Annual ROM coal production and lost day is determined as defined output variable because ROM coal production represents the scale of the establishments. When the AHP results analyzed, the most important output is number of death and the second one is lost work day. Lost work days are result of deaths and injuries so it is determined as the second defined output variable.

Table 24 Estimation Input, Defined Inputs and Outputs for Input DEA Results

Number of DEA Application	**INPUTS**	**OUTPUTS**
1	Number of Worker & **OHS Staff**	ROM Coal Production & Lost Work Day
2	Number of Worker & **OHS Expenditure**	ROM Coal Production & Lost Work Day
3	Number of Worker & **OHS Education**	ROM Coal Production & Lost Work Day
4	Number of Worker & **Effective Work Hour**	ROM Coal Production & Lost Work Day

In the estimation of DEA scores of inputs some advanced models are integrated to the basic DEA model. Therefore, more reliable and realistic results can be obtained with the help of these advance models. The integrated basic and advanced models are introduced below.

Slack Based Model – SBM (Non-Radial) Distance Model

Radial distance model measures the necessary proportional improvements of relevant factors (inputs/outputs) for the evaluated DMU to reach the frontier. However in the OHS problems, number of accident may not be proportionally decreased with the increase in the OHS expenditures. There may be dramatically decrease in the accident as a result of high amount OHS expenditures. However, number of accident may continue to increase due to other factors in spite of high amount OHS expenditures. For instance, TTK may replace old OHS equipment and expend high amount money on OHS but number of accidents may keep increasing trend. Therefore, Non-Radial Distance Model is selected to get more realistic DEA scores for inputs. Non-radial model is also called Slack Based Model (SBM). It maximizes the average improvements of relevant factors (inputs/outputs) for the evaluation of DMU to reach the efficient frontier.

Input Oriented Model:

In the estimation of DEA scores of inputs, input-oriented DEA model is utilized. In the input-oriented models, output values are fixed and inputs values are adjusted to estimate maximum efficiency score. In this case, the defined output variables are selected as ROM coal production and lost work day.

Constant Returns to Scale:

In this study, Constant Returns to Scale (CRS) DEA methodology is conducted. As stated in the study of Cimen (2011), CRS is more conservative method than Variable Returns to

Scale (VRS). In VRS analysis, it is assumed that a DMU is efficient if pure technical efficiency condition is provided. However, pure technical and scale efficiency must be satisfied by a DMU to label efficient one this DMU in CRS analysis. One of the other important adverse effect of VRS is that a scale inefficient DMU could be efficient in VRS analysis, whereas in CRS analysis, in order to be accepted as efficient DMU, it must also be scale efficient. In the state mining organizations, carrying out the operations at appropriate scales is important. If an organization is operated with low capacity, CRS analysis may detect it during the model running. Therefore, CRS analysis is preferred for our model to evaluate the relative OHS efficiencies of TTK.

Undesirable Output Model:

In most OHS cases, there are desirable and undesirable outputs in the same problem. If these cases include an undesirable output, this output should be decreased to reach the efficient frontier. In other words, desirable outputs should be increased while undesirable outputs decrease during the calculations computed by the developed model. However, conventional DEA model is not capable of evaluation of undesirable outputs. Therefore, undesirable output model is integrated to the basic DEA model. Through the undesirable output model, the undesirable and desirable outputs may be treated simultaneously in the same model.

In the estimation of DEA scores of inputs, lost work day and ROM coal production are utilized as defined output variables. Annual ROM coal production is a desirable output and it should be increased to reach efficient frontier. Lost work day, by contrast, is an undesirable output model and it must be decreased by DMUs to become efficient one on the frontier.

Preference (Weighted) Model:

Preference model is one of the weight restriction models. In this model, lower and upper weight values of inputs and outputs are limited by preference model. During the preference model construction, results of AHP are used since preference model is based on the relative importance of inputs and outputs. The used preference model input and output weights are given in Table 25.

Preference weights of inputs are estimated by selecting the number of worker as reference variable because it represents the size or scale of establishments. AHP scores of the input variables are divided by the AHP score of number of worker to estimate the preference weights.

Table 25 Preference Weights of Inputs

Inputs	Preference Weight
Number of Worker	1.000
Number of OHS Staff	0.686
Annual OHS Expenditures	2.549
Annual OHS Education Time	4.137
Annual Effective Work Hour	1.431

Preference weights of inputs and outputs are estimated independently thus the values of input weights are not affected by values of output weights. By using preference weighted method, subjective opinion of TTK is included in the model for determining the weight restriction values. Therefore, more reliable and realistic DEA results can be obtained after running the model.

After determining the basic and advanced models, a professional software package, MaxDEA® 6.0 of Peking University, is used to run DEA models. In the DEA estimations of inputs, 20 different DEA models are run (four DEA applications for each year, 2007-2001).

DEA applications are conducted for the last five years for each establishment for input variables hence last five years are analyzed in detail. As given in Table 26 - Table 30, DEA score of each estimation input variable (I_E) is calculated for each establishment for each year. (I_E variables are marked as bold in these tables.) In other words, at the end of second stage of the AHP.DEA method, each establishment has a DEA score for each I_E per year.

Table 26 DEA Results of Inputs for Each Establishment for 2007

Number of DEA Application	Inputs	Outputs	DEA Scores	
1	Number of Worker & **OHS Staff**	Annual ROM Production & Lost Work Day	AMASRA	0.786
			ARMUTÇUK	1.000
			KARADON	0.585
			KOZLU	1.000
			ÜZÜLMEZ	1.000
2	Number of Worker & **Annual OHS Expenditure**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	1.000
			KARADON	0.796
			KOZLU	1.000
			ÜZÜLMEZ	1.000
3	Number of Worker & **Annual OHS Education Time**	Annual ROM Production & Lost Work Day	AMASRA	0.493
			ARMUTÇUK	1.000
			KARADON	0.908
			KOZLU	1.000
			ÜZÜLMEZ	0.476
4	Number of Worker & **Annual Effective Work Hour**	Annual ROM Production & Lost Work Day	AMASRA	0.961
			ARMUTÇUK	1.000
			KARADON	0.775
			KOZLU	1.000
			ÜZÜLMEZ	0.849

Table 27 DEA Results of Inputs for Each Establishment for 2008

Number of DEA Application	**Inputs**	**Outputs**	**DEA Scores**	
1	Number of Worker & **OHS Staff**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	0.855
			KARADON	0.681
			KOZLU	1.000
			ÜZÜLMEZ	1.000
2	Number of Worker & **Annual OHS Expenditure**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	0.854
			KARADON	0.812
			KOZLU	1.000
			ÜZÜLMEZ	0.764
3	Number of Worker & **Annual OHS Education Time**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	1.000
			KARADON	0.767
			KOZLU	1.000
			ÜZÜLMEZ	0.397
4	Number of Worker & **Annual Effective Work Hour**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	0.858
			KARADON	0.826
			KOZLU	1.000
			ÜZÜLMEZ	0.773

Table 28 DEA Results of Inputs for Each Establishment for 2009

Number of DEA Application	**Inputs**	**Outputs**	**DEA Scores**	
1	Number of Worker & **OHS Staff**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	1.000
			KARADON	0.743
			KOZLU	1.000
			ÜZÜLMEZ	1.000
2	Number of Worker & **Annual OHS Expenditure**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	1.000
			KARADON	0.879
			KOZLU	1.000
			ÜZÜLMEZ	0.818
3	Number of Worker & **Annual OHS Education Time**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	1.000
			KARADON	1.000
			KOZLU	1.000
			ÜZÜLMEZ	0.748
4	Number of Worker & **Annual Effective Work Hour**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	1.000
			KARADON	0.870
			KOZLU	1.000
			ÜZÜLMEZ	0.836

Table 29 DEA Results of Inputs for Each Establishment for 2010

Number of DEA Application	Inputs	Outputs	DEA Scores	
1	Number of Worker & **OHS Staff**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	0.626
			KARADON	0.634
			KOZLU	1.000
			ÜZÜLMEZ	1.000
2	Number of Worker & **Annual OHS Expenditure**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	0.535
			KARADON	0.660
			KOZLU	0.872
			ÜZÜLMEZ	0.732
3	Number of Worker & **Annual OHS Education Time**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	0.813
			KARADON	0.657
			KOZLU	1.000
			ÜZÜLMEZ	0.762
4	Number of Worker & **Annual Effective Work Hour**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	0.537
			KARADON	0.663
			KOZLU	0.875
			ÜZÜLMEZ	0.736

Table 30 DEA Results of Inputs for Each Establishment for 2011

Number of DEA Application	Inputs	Outputs	DEA Results	
1	Number of Worker & **OHS Staff**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	0.581
			KARADON	0.625
			KOZLU	1.000
			ÜZÜLMEZ	1.000
2	Number of Worker & **Annual OHS Expenditure**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	0.553
			KARADON	0.606
			KOZLU	1.000
			ÜZÜLMEZ	0.922
3	Number of Worker & **Annual OHS Education Time**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	0.739
			KARADON	0.609
			KOZLU	1.000
			ÜZÜLMEZ	0.721
4	Number of Worker & **Annual Effective Work Hour**	Annual ROM Production & Lost Work Day	AMASRA	1.000
			ARMUTÇUK	0.489
			KARADON	0.598
			KOZLU	1.000
			ÜZÜLMEZ	0.730

4.4.2.2 Applying DEA Method for Output Variables

Besides inputs, DEA applications are also conducted to estimate the DEA scores of six specified outputs named as annual death worker number, annual lost work day, annual accident number, annual accident cost, annual injured worker number and annual ROM coal production. Annual ROM coal production is selected as a defined output variable (O_D). Annual ROM coal production variable is selected to include the sizes of the establishments in the calculations. Number of workers and annual OHS education time are determined as defined input variables and they are used in each DEA application for the estimation of output scores. Number of workers also represents the scale of the establishments thus more realistic results can be obtained. After the AHP evaluation, it is seen that annual OHS education time is most important input variable for TTK. Therefore, annual OHS education time is selected as the other defined input variable. The defined inputs, estimation output and defined output are stated in Table 31. The estimation output variables are marked as bold in this table.

In the estimation of DEA scores of outputs, some advanced models are integrated to the basic DEA model, thus more reliable and realistic results can be obtained with the help of these advance models. They are explained below.

Table 31 Estimation Output, Defined Inputs and Outputs for Output DEA Results

Number of DEA Application	**Inputs**	**Outputs**
1	Number of Worker & OHS Education Time	ROM Production & **Annual Death Worker Number**
2	Number of Worker & OHS Education Time	ROM Production & **Annual Lost Work Day**
3	Number of Worker & OHS Education Time	ROM Production & **Annual Accident Cost**
4	Number of Worker & OHS Education Time	ROM Production & **Annual Injured Worker Number**
5	Number of Worker & OHS Education Time	ROM Production & **Number of Accident**

Slack Based Model – SBM (Non-Radial) Distance Model

As mentioned in the previous topic, SBM model is selected in the evaluation of output variables with DEA model.

Output Oriented Model:

In the estimation of DEA scores of outputs, output-oriented DEA model is utilized. In the output-oriented models, input values are fixed and output values are adjusted to estimate maximum efficiency score. Therefore, it can be obtained how maximum desirable output and minimum undesirable output can be reached with the present levels of the inputs.

Constant Returns to Scale:

Constant Returns to Scale is selected in the DEA score estimation of output variables due to the advantages that mentioned in section 4.4.2.1.

Undesirable Output Model:

In the evaluation of the outputs with DEA, undesirable estimation model is applied. As mentioned, in this study, only single output variable is desirable. The others are undesirable variables namely annual death worker number, annual lost work day, annual accident cost, annual injured worker number and number of accident. All of them must be decreased to reach the efficient frontier. Therefore, during the DEA score estimation of output variables, undesirable output model must be used during the model running.

Preference (Weighted) Model:

As similar to the previous application, preference model is integrated into the basic DEA model. Preference model is based on the importance of the outputs. Therefore, importance weights, which are estimated by AHP, are used to determine the preference weights. Some detailed information about this model is provided in the 4.4.2.1 topic.

Preference weights of outputs are estimated by selecting the annual ROM coal production as reference points and AHP scores are divided by the AHP scores of annual ROM coal production to estimate the preference weights of outputs and the preference weight of outputs are given in Table 32.

Table 32 Preference Weights of Outputs

Outputs	Preference Weight
Annual ROM Coal Production	1.000
Annual Accident Number	2.959
Annual Number of Death	5.735
Annual Injured Worker Number	2.755
Annual Lost Work Day	5.041
Annual Accident Cost	2.918

After determining the basic and advanced models, MaxDEA® 6.0, is used to run DEA models to estimate the DEA scores of output variables. In the DEA score estimation of inputs, DEA model is run 25 times for the evaluation of last five years and five output variables.

DEA score of each estimation output variable (O_E) is calculated for each establishment for each year. In other words, at the end of second stage of the AHP.DEA method, each establishment has a DEA score for each O_E for each year as given in Table 33 - Table 37. O_E scores are marked as bold in these tables

Table 33 DEA Results of Outputs for Each Establishment for 2007

Number of DEA Application	**Inputs**	**Outputs**	**DEA Scores**	
1	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Death Worker**	AMASRA	1.000
			ARMUTÇUK	1.000
			KARADON	0.537
			KOZLU	1.000
			ÜZÜLMEZ	0.538
2	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Lost Day**	AMASRA	0.702
			ARMUTÇUK	1.000
			KARADON	0.545
			KOZLU	1.000
			ÜZÜLMEZ	0.548
3	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Accident Cost**	AMASRA	0.759
			ARMUTÇUK	1.000
			KARADON	0.675
			KOZLU	1.000
			ÜZÜLMEZ	0.655
4	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Injured Worker**	AMASRA	0.882
			ARMUTÇUK	1.000
			KARADON	0.778
			KOZLU	1.000
			ÜZÜLMEZ	1.000
5	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Accident**	AMASRA	0.881
			ARMUTÇUK	1.000
			KARADON	0.775
			KOZLU	1.000
			ÜZÜLMEZ	1.000

Table 34 DEA Results of Outputs for Each Establishment for 2008

Number of DEA Application	Inputs	Outputs	DEA Scores	
1	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Death Worker**	AMASRA	1.000
			ARMUTÇUK	1.000
			KARADON	1.000
			KOZLU	1.000
			ÜZÜLMEZ	0.536
2	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Lost Day**	AMASRA	1.000
			ARMUTÇUK	1.000
			KARADON	0.756
			KOZLU	1.000
			ÜZÜLMEZ	0.575
3	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Accident Cost**	AMASRA	0.705
			ARMUTÇUK	1.000
			KARADON	0.690
			KOZLU	1.000
			ÜZÜLMEZ	0.653
4	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Injured Worker**	AMASRA	0.868
			ARMUTÇUK	1.000
			KARADON	0.724
			KOZLU	1.000
			ÜZÜLMEZ	0.836
5	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Accident**	AMASRA	0.867
			ARMUTÇUK	1.000
			KARADON	0.721
			KOZLU	1.000
			ÜZÜLMEZ	0.834

Table 35 DEA Results of Outputs for Each Establishment for 2009

Number of DEA Application	Inputs	Outputs	DEA Scores	
1	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Death Worker**	AMASRA	1.000
			ARMUTÇUK	1.000
			KARADON	1.000
			KOZLU	1.000
			ÜZÜLMEZ	1.000
2	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Lost Day**	AMASRA	1.000
			ARMUTÇUK	1.000
			KARADON	1.000
			KOZLU	1.000
			ÜZÜLMEZ	0.678
3	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Accident Cost**	AMASRA	0.675
			ARMUTÇUK	0.815
			KARADON	1.000
			KOZLU	1.000
			ÜZÜLMEZ	0.757
4	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Injured Worker**	AMASRA	1.000
			ARMUTÇUK	1.000
			KARADON	1.000
			KOZLU	1.000
			ÜZÜLMEZ	0.919
5	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Accident**	AMASRA	1.000
			ARMUTÇUK	1.000
			KARADON	1.000
			KOZLU	1.000
			ÜZÜLMEZ	0.917

Table 36 DEA Results of Outputs for Each Establishment for 2010

Number of DEA Application	Inputs	Outputs	DEA Scores	
1	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Death Worker**	AMASRA	1.000
			ARMUTÇUK	0.939
			KARADON	0.526
			KOZLU	1.000
			ÜZÜLMEZ	0.534
2	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Lost Day**	AMASRA	1.000
			ARMUTÇUK	0.706
			KARADON	0.607
			KOZLU	1.000
			ÜZÜLMEZ	0.604
3	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Accident Cost**	AMASRA	1.000
			ARMUTÇUK	0.616
			KARADON	0.661
			KOZLU	1.000
			ÜZÜLMEZ	0.594
4	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Injured Worker**	AMASRA	1.000
			ARMUTÇUK	0.826
			KARADON	0.700
			KOZLU	1.000
			ÜZÜLMEZ	1.000
5	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Accident**	AMASRA	1.000
			ARMUTÇUK	0.824
			KARADON	0.696
			KOZLU	1.000
			ÜZÜLMEZ	1.000

Table 37 DEA Results of Outputs for Each Establishment for 2011

Number of DEA Application	Inputs	Outputs	DEA Scores	
1	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Death Worker**	AMASRA	1.000
			ARMUTÇUK	0.649
			KARADON	0.516
			KOZLU	1.000
			ÜZÜLMEZ	0.525
2	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Lost Day**	AMASRA	1.000
			ARMUTÇUK	0.772
			KARADON	0.651
			KOZLU	1.000
			ÜZÜLMEZ	0.595
3	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Accident Cost**	AMASRA	1.000
			ARMUTÇUK	0.949
			KARADON	0.690
			KOZLU	1.000
			ÜZÜLMEZ	0.618
4	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Number of Injured Worker**	AMASRA	1.000
			ARMUTÇUK	0.744
			KARADON	0.728
			KOZLU	1.000
			ÜZÜLMEZ	0.835
5	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Accident**	AMASRA	1.000
			ARMUTÇUK	0.740
			KARADON	0.724
			KOZLU	1.000
			ÜZÜLMEZ	0.831

4.4.3 Integrating AHP and DEA Scores

In the third step of DEA.AHP method, AHP and DEA scores are integrated. To estimate the Input and Output Oriented AHP.DEA method, input scores and output scores are integrated independently. The integration progresses of IO and OO-AHP.DEA for this study are introduced in detail under the 4.4.3.1 and 4.4.3.2 topics respectively.

4.4.3.1 Integration of AHP and DEA Scores of Input Variables

AHP.DEA scores include both subjective and objective evaluations. Subjective evaluation opinion of related experts can be included with applying a questionnaire. Also objective evaluation of establishments can be conducted by applying DEA method with using the realized data. Combination of these methods can give more reliable results when compared to only subjective or objective evaluation methods. In the OHS environment in mining, subjective evaluation must be included in the estimations because of the nature of the operations. In this sector, there are many uncontrollable production factors. Therefore, single objective evaluation method also may not give reliable results. Subjective and objective evaluation methods should be integrated because of these reasons.

In this integration procedure, AHP scores of input variables and DEA results of input variables are combined. Therefore, AHP.DEA scores of each establishment for each input variable are estimated. These scores can be named as IO-AHP.DEA scores or results.

As seen in Table 38, IO-AHP.DEA score of Amasra establishment for Number of OHS Staff Input in 2007 is 0.055 while IO-AHP.DEA score of this establishment for Annual OHS Expenditure input variable is 0.260. This means that Amasra establishment has used Annual OHS Expenditure more efficiently than OHS Staff. AHP.DEA results of each establishment for each input variable are given in Table 38 - Table 42 for 2007-2011 periods.

Table 38 IO-AHP.DEA Scores for 2007

Number of Analysis	Inputs	Outputs	AHP.DEA Scores	
1	Number of Worker & **Number OHS Staff**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.055
			ARMUTÇUK	0.070
			KARADON	0.041
			KOZLU	0.070
			ÜZÜLMEZ	0.070
2	Number of Worker & **Annual OHS Expenditure**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.260
			ARMUTÇUK	0.260
			KARADON	0.207
			KOZLU	0.260
			ÜZÜLMEZ	0.260
3	Number of Worker & **Annual OHS Education Time**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.208
			ARMUTÇUK	0.422
			KARADON	0.383
			KOZLU	0.422
			ÜZÜLMEZ	0.201
4	Number of Worker & **Annual Effective Work Hour**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.140
			ARMUTÇUK	0.146
			KARADON	0.113
			KOZLU	0.146
			ÜZÜLMEZ	0.124

Table 39 IO-AHP.DEA Scores for 2008

Number of Analysis	Inputs	Outputs	AHP.DEA Scores	
1	Number of Worker & **Number OHS Staff**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.070
			ARMUTÇUK	0.060
			KARADON	0.048
			KOZLU	0.070
			ÜZÜLMEZ	0.070
2	Number of Worker & **Annual OHS Expenditure**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.260
			ARMUTÇUK	0.222
			KARADON	0.211
			KOZLU	0.260
			ÜZÜLMEZ	0.199
3	Number of Worker & **Annual OHS Education Time**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.422
			ARMUTÇUK	0.422
			KARADON	0.324
			KOZLU	0.422
			ÜZÜLMEZ	0.168
4	Number of Worker & **Annual Effective Work Hour**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.146
			ARMUTÇUK	0.125
			KARADON	0.121
			KOZLU	0.146
			ÜZÜLMEZ	0.113

Table 40 IO-AHP.DEA Scores for 2009

Number of Analysis	Inputs	Outputs	AHP.DEA Scores	
1	Number of Worker & **Number OHS Staff**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.070
			ARMUTÇUK	0.070
			KARADON	0.052
			KOZLU	0.070
			ÜZÜLMEZ	0.070
2	Number of Worker & **Annual OHS Expenditure**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.260
			ARMUTÇUK	0.260
			KARADON	0.229
			KOZLU	0.260
			ÜZÜLMEZ	0.213
3	Number of Worker & **Annual OHS Education Time**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.422
			ARMUTÇUK	0.422
			KARADON	0.422
			KOZLU	0.422
			ÜZÜLMEZ	0.316
4	Number of Worker & **Annual Effective Work Hour**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.146
			ARMUTÇUK	0.146
			KARADON	0.127
			KOZLU	0.146
			ÜZÜLMEZ	0.122

Table 41 IO-AHP.DEA Scores for 2010

Number of Analysis	**Inputs**	**Outputs**	**AHP.DEA Scores**	
1	Number of Worker & **Number OHS Staff**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.070
			ARMUTÇUK	0.044
			KARADON	0.044
			KOZLU	0.070
			ÜZÜLMEZ	0.070
2	Number of Worker & **Annual OHS Expenditure**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.260
			ARMUTÇUK	0.139
			KARADON	0.172
			KOZLU	0.227
			ÜZÜLMEZ	0.190
3	Number of Worker & **Annual OHS Education Time**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.422
			ARMUTÇUK	0.343
			KARADON	0.277
			KOZLU	0.422
			ÜZÜLMEZ	0.322
4	Number of Worker & **Annual Effective Work Hour**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.146
			ARMUTÇUK	0.078
			KARADON	0.097
			KOZLU	0.128
			ÜZÜLMEZ	0.107

Table 42 IO-AHP.DEA Scores for 2011

Number of Analysis	**Inputs**	**Outputs**	**AHP.DEA Scores**	
1	Number of Worker & **Number OHS Staff**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.070
			ARMUTÇUK	0.041
			KARADON	0.044
			KOZLU	0.070
			ÜZÜLMEZ	0.070
2	Number of Worker & **Annual OHS Expenditure**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.260
			ARMUTÇUK	0.144
			KARADON	0.158
			KOZLU	0.260
			ÜZÜLMEZ	0.240
3	Number of Worker & **Annual OHS Education Time**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.422
			ARMUTÇUK	0.312
			KARADON	0.257
			KOZLU	0.422
			ÜZÜLMEZ	0.304
4	Number of Worker & **Annual Effective Work Hour**	Annual ROM Coal Production & Annual Lost Work Day	AMASRA	0.146
			ARMUTÇUK	0.071
			KARADON	0.087
			KOZLU	0.146
			ÜZÜLMEZ	0.107

4.4.3.2 Integration of AHP and DEA Scores of Output Variables

In this integration procedure, AHP scores of output variables and DEA scores of output variables are multiplied. Therefore, an AHP.DEA score of each establishment for each output variable. This integration procedure can also be named as OO-AHP.DEA Method.

As given in Table 43, OO-AHP.DEA score of Amasra establishment for Annual Number of Death Worker output in 2007 is 0.281 while AHP.DEA score of this establishment for Annual Number of Lost Work Day output variable is 0.173. According to these findings, Amasra establishment is more efficient in reducing annual death worker number than reducing annual number of lost work day. In the calculations, undesirable output model is used in the DEA applications. Therefore, high efficiency score of annual number of death worker means low death worker number. AHP.DEA results of each establishment for each output variable are given in Table 43 - Table 47 for 2007-2011 periods.

Table 43 OO-AHP.DEA Scores for 2007

Number of Analysis	**Inputs**	**Outputs**	**AHP.DEA Scores**	
1	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Death Worker**	AMASRA	0.281
			ARMUTÇUK	0.281
			KARADON	0.151
			KOZLU	0.281
			ÜZÜLMEZ	0.151
2	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Lost Work Day**	AMASRA	0.173
			ARMUTÇUK	0.247
			KARADON	0.135
			KOZLU	0.247
			ÜZÜLMEZ	0.135
3	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Accident Cost**	AMASRA	0.109
			ARMUTÇUK	0.143
			KARADON	0.097
			KOZLU	0.143
			ÜZÜLMEZ	0.094
4	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Injured Worker**	AMASRA	0.119
			ARMUTÇUK	0.135
			KARADON	0.105
			KOZLU	0.135
			ÜZÜLMEZ	0.135
5	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Accident**	AMASRA	0.128
			ARMUTÇUK	0.145
			KARADON	0.112
			KOZLU	0.145
			ÜZÜLMEZ	0.145

Table 44 OO-AHP.DEA Scores for 2008

Number of Analysis	**Inputs**	**Outputs**	**AHP.DEA Scores**	
1	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Death Worker**	AMASRA	0.281
			ARMUTÇUK	0.281
			KARADON	0.281
			KOZLU	0.281
			ÜZÜLMEZ	0.151
2	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Lost Work Day**	AMASRA	0.247
			ARMUTÇUK	0.247
			KARADON	0.187
			KOZLU	0.247
			ÜZÜLMEZ	0.142
3	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Accident Cost**	AMASRA	0.101
			ARMUTÇUK	0.143
			KARADON	0.099
			KOZLU	0.143
			ÜZÜLMEZ	0.093
4	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Injured Worker**	AMASRA	0.117
			ARMUTÇUK	0.135
			KARADON	0.098
			KOZLU	0.135
			ÜZÜLMEZ	0.113
5	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Accident**	AMASRA	0.126
			ARMUTÇUK	0.145
			KARADON	0.105
			KOZLU	0.145
			ÜZÜLMEZ	0.121

Table 45 OO-AHP.DEA Scores for 2009

Number of Analysis	**Inputs**	**Outputs**	**AHP.DEA Scores**	
1	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Death Worker**	AMASRA	0.281
			ARMUTÇUK	0.281
			KARADON	0.281
			KOZLU	0.281
			ÜZÜLMEZ	0.281
2	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Lost Work Day**	AMASRA	0.247
			ARMUTÇUK	0.247
			KARADON	0.247
			KOZLU	0.247
			ÜZÜLMEZ	0.167
3	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Accident Cost**	AMASRA	0.097
			ARMUTÇUK	0.117
			KARADON	0.143
			KOZLU	0.143
			ÜZÜLMEZ	0.108
4	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Injured Worker**	AMASRA	0.135
			ARMUTÇUK	0.135
			KARADON	0.135
			KOZLU	0.135
			ÜZÜLMEZ	0.124
5	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Accident**	AMASRA	0.145
			ARMUTÇUK	0.145
			KARADON	0.145
			KOZLU	0.145
			ÜZÜLMEZ	0.133

Table 46 OO-AHP.DEA Scores for 2010

Number of Analysis	**Inputs**	**Outputs**	**AHP.DEA Scores**	
1	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Death Worker**	AMASRA	0.281
			ARMUTÇUK	0.264
			KARADON	0.148
			KOZLU	0.281
			ÜZÜLMEZ	0.150
2	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Lost Work Day**	AMASRA	0.247
			ARMUTÇUK	0.174
			KARADON	0.150
			KOZLU	0.247
			ÜZÜLMEZ	0.149
3	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Accident Cost**	AMASRA	0.143
			ARMUTÇUK	0.088
			KARADON	0.095
			KOZLU	0.143
			ÜZÜLMEZ	0.085
4	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Injured Worker**	AMASRA	0.135
			ARMUTÇUK	0.112
			KARADON	0.095
			KOZLU	0.135
			ÜZÜLMEZ	0.135
5	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Accident**	AMASRA	0.145
			ARMUTÇUK	0.119
			KARADON	0.101
			KOZLU	0.145
			ÜZÜLMEZ	0.145

Table 47 OO-AHP.DEA Scores for 2011

Number of Analysis	**Inputs**	**Outputs**	**AHP.DEA Scores**	
1	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Death Worker**	AMASRA	0.281
			ARMUTÇUK	0.182
			KARADON	0.145
			KOZLU	0.281
			ÜZÜLMEZ	0.148
2	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Lost Work Day**	AMASRA	0.247
			ARMUTÇUK	0.191
			KARADON	0.161
			KOZLU	0.247
			ÜZÜLMEZ	0.147
3	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Accident Cost**	AMASRA	0.143
			ARMUTÇUK	0.136
			KARADON	0.099
			KOZLU	0.143
			ÜZÜLMEZ	0.088
4	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Injured Worker**	AMASRA	0.135
			ARMUTÇUK	0.100
			KARADON	0.098
			KOZLU	0.135
			ÜZÜLMEZ	0.113
5	Number of Worker & Annual OHS Education Time	Annual ROM Coal Production & **Annual Number of Accident**	AMASRA	0.145
			ARMUTÇUK	0.107
			KARADON	0.105
			KOZLU	0.145
			ÜZÜLMEZ	0.120

4.4.4 Estimating AHP.DEA Scores of Establishments

Up to this topic, IO and OO-AHP.DEA scores of inputs and outputs are estimated. However, in the four and the last step of the procedure, IO and OO-AHP.DEA scores of each establishment are estimated. IO and OO-AHP.DEA scores are the summation of the IO and OO-AHP.DEA scores of an establishment for each input or output variables. Estimation of IO and OO-AHP.DEA scores of each establishment is presented in below.

IO-AHP.DEA Scores of Establishment:

In the IO-AHP.DEA application, input variable scores of each establishment are estimated. Each establishment has IO-AHP.DEA input scores which are estimated in section 4.4.3. The summation of these scores indicates the IO-AHP.DEA score of this establishment for a year. For example, IO-AHP.DEA scores of input variables of Amasra establishment for 2007 are;

Number of OHS staff : 0.055

Annual OHS Expenditure : 0.260

Annual OHS Education Time : 0.208

Annual Effective Work Hour : 0.140

Therefore, IO-AHP.DEA score of Amasra establishment for 2007 is 0.663 or 66.3%. In the AHP.DEA method, score of efficient establishments is one. However, some input variables are selected as Defined Input Variable (I_D) and it is not included in the estimation of IO-AHP.DEA score stage.

In this study, number of worker is selected as defined input variable. AHP score of this input is 0.102. This means that IO-AHP.DEA score of efficient establishment can be maximum 0.898 (1.000 - 0.102 = 0.898). In other words, 0.898 score means highest score and represents efficient DMUs. Therefore, after finding the IO- AHP.DEA scores of all establishments, they should be subjected to normalization. This process can be conducted as dividing each score by the highest one. For instance, normalized score of Amasra is 0.663/0.898 = 0.738 for 2007. IO-AHP.DEA scores of each establishment are presented in Table 48 - Table 52.

In 2007, Armutçuk and Kozlu establishments are efficient ones. They use their OHS inputs more efficiently than the others. Efficiency scores of Amasra and Üzülmez are almost same but Üzülmez establishment is the worst in the usage of OHS inputs since its efficiency score is 0.729.

Table 48 IO-AHP.DEA Scores of Establishments for 2007

Establishment	IO-AHP.DEA Score	Normalized IO-AHP.DEA Score
AMASRA	0.663	0.738
ARMUTÇUK	0.898	1.000
KARADON	0.744	0.829
KOZLU	0.898	1.000
ÜZÜLMEZ	0.655	0.729

In 2008, Amasra and Kozlu establishments are efficient ones in the usage of OHS inputs. Armutçuk is just below the efficient frontier. Üzülmez establishment is again the worst one in 2008 like 2007.

Table 49 IO-AHP.DEA Scores of Establishments for 2008

Establishment	**IO-AHP.DEA Score**	**Normalized IO-AHP.DEA Score**
AMASRA	0.898	1.000
ARMUTÇUK	0.829	0.923
KARADON	0.703	0.783
KOZLU	0.898	1.000
ÜZÜLMEZ	0.549	0.611

In 2009, Amasra, Armutçuk and Kozlu establishments are efficient ones. When the efficiency scores are analyzed, they are higher than the previous years. This means that efficiently usage of OHS inputs is increased at all establishments.

Table 50 IO-AHP.DEA Scores of Establishments for 2009

Establishment	**IO-AHP.DEA Score**	**Normalized IO-AHP.DEA Score**
AMASRA	0.898	1.000
ARMUTÇUK	0.898	1.000
KARADON	0.830	0.924
KOZLU	0.898	1.000
ÜZÜLMEZ	0.720	0.802

In 2010, efficiency scores of the establishments decreased compared to 2009 except for Amasra. Armutçuk and Karadon are the two worst establishments in that year. In the Armutçuk establishment, there is a dramatic decrease when compared to the previous years.

Table 51 IO-AHP.DEA Scores of Establishments for 2010

Establishment	**IO-AHP.DEA Score**	**Normalized IO-AHP.DEA Score**
AMASRA	0.898	1.000
ARMUTÇUK	0.604	0.673
KARADON	0.590	0.657
KOZLU	0.846	0.943
ÜZÜLMEZ	0.689	0.768

In 2011, IO-AHP.DEA scores indicate that the worst establishment is Karadon whose efficiency score is 0.608. On the contrary, Amasra and Kozlu are the efficient establishments. IO-AHP.DEA method has used all defined inputs in the calculation process. Therefore, in this study, five inputs and two outputs are included in the relative efficiency estimation of the limited number establishment case. However, in traditional DEA application only four inputs and outputs can be used for efficiency score estimation. Therefore, reliability of the estimation is increased with increasing the number of inputs and outputs in the estimation.

Table 52 IO-AHP.DEA Scores of Establishments for 2011

Establishment	**IO-AHP.DEA Score**	**Normalized IO-AHP.DEA Score**
AMASRA	0.898	1.000
ARMUTÇUK	0.568	0.632
KARADON	0.546	0.608
KOZLU	0.898	1.000
ÜZÜLMEZ	0.721	0.802

OO-AHP.DEA Scores of Establishment:

The same procedure is applied in the OO-AHP.DEA method as applied in the IO-AHP.DEA method. In this method, establishments are relatively compared with considering the outputs like number of accident, injured worker, accident cost, *etc.* OO-AHP.DEA scores of output variables of Amasra establishment for 2007 are;

Annual Number of Death Worker : 0.281

Annual Number of Lost Work Day : 0.173

Annual Accident Cost : 0.109

Annual Number of Injured Worker : 0.119

Annual Number of Accidents : 0.128

With the help of these scores, OO-AHP.DEA score of Amasra establishment for 2007 can be estimated as 0.810. However, some output variables are selected as Defined Output Variable (O_D) so OO-AHP.DEA score of these output variables can not be included in this calculation. In this study, annual ROM coal production is selected as defined output variable because scales of establishments are included in the calculations with selection of annual ROM coal production. AHP score of this output is 0.049. This means that OO-AHP.DEA score of efficient establishment can be maximum 0.951 (1.000 - 0.049 = 0.951) instead of one. Therefore, after finding the OO-AHP.DEA scores of all establishments, they must be normalized. For instance, normalized score of Amasra is 0.810/0.951 = 0.852. OO-AHP.DEA scores are given in Table 53 - Table 57.

In 2007, Armutçuk and Kozlu are the efficient establishments. This means that these establishments reached more desirable output level with less input usage.

Table 53 OO-AHP.DEA Scores of Establishments for 2007

Establishment	OO-AHP.DEA Score	Normalized OO-AHP.DEA Score
AMASRA	0.810	0.851
ARMUTÇUK	0.951	1.000
KARADON	0.599	0.630
KOZLU	0.951	1.000
ÜZÜLMEZ	0.660	0.694

In 2008, Armutçuk and Kozlu are again efficient ones. While, efficiency score of Amasra is close to the efficient frontier, efficiency score of Üzülmez establishment is worst one as 0.652.

Table 54 OO-AHP.DEA Scores of Establishments for 2008

Establishment	OO-AHP.DEA Score	Normalized OO-AHP.DEA Score
AMASRA	0.872	0.917
ARMUTÇUK	0.951	1.000
KARADON	0.769	0.808
KOZLU	0.951	1.000
ÜZÜLMEZ	0.620	0.652

In 2009, OO-AHP.DEA score of Karadon and Kozlu indicates that they are efficient establishments. The scores of Amasra and Armutçuk are close to the efficient frontier but Üzülmez establishment is worst one according to the accidents and costs. When compared to the previous years, efficiency scores are increased. This situation indicates that almost all establishment reach better output levels with less input consumption.

Table 55 OO-AHP.DEA Scores of Establishments for 2009

Establishment	OO-AHP.DEA Score	Normalized OO-AHP.DEA Score
AMASRA	0.905	0.951
ARMUTÇUK	0.925	0.972
KARADON	0.951	1.000
KOZLU	0.951	1.000
ÜZÜLMEZ	0.814	0.856

In 2010, Amasra and Kozlu establishments are relatively efficient establishments when compared to the others. Üzülmez establishment again has the worst relative efficiency score.

Table 56 OO-AHP.DEA Scores of Establishments for 2010

Establishment	**OO-AHP.DEA Score**	**Normalized OO-AHP.DEA Score**
AMASRA	0.951	1.000
ARMUTÇUK	0.757	0.796
KARADON	0.588	0.618
KOZLU	0.951	1.000
ÜZÜLMEZ	0.664	0.698

In 2011, OO-AHP.DEA scores indicate that Amasra and Kozlu are the efficient establishments. The worst one is Karadon establishment whose efficiency score is 0.639. OO-AHP.DEA method has used all defined outputs in the calculation process. Therefore, in this study, six outputs and two inputs are included in the relative efficiency estimation of the limited number DMUs case. However, in traditional DEA application maximum four input and output variables can be used for efficiency score estimation. Therefore, reliability of the estimation is increased with increasing the number of inputs and outputs in the estimation because different aspects of problem are included in the estimation procedure.

Table 57 OO-AHP.DEA Scores of Establishments for 2011

Establishment	**OO-AHP.DEA Score**	**Normalized OO-AHP.DEA Score**
AMASRA	0.951	1.000
ARMUTÇUK	0.717	0.753
KARADON	0.608	0.639
KOZLU	0.951	1.000
ÜZÜLMEZ	0.616	0.648

CHAPTER 5

RESULTS AND DISSCUSION

TTK is selected as a case study and its five establishments are evaluated for relatively efficiency measurement related with OHS performance in Chapter 4 comprehensively. Both IO and OO-AHP.DEA techniques are applied for 2007-2011 periods. After applying newly developed technique, much useful data is estimated about the establishments for the last five years. For example, it is investigated which establishments are successful at decreasing the number of accidents with lower OHS sources.

At OHS study field, scale of establishment is a crucial parameter at relatively efficiency measurement because in large scale establishments, probability of the accident occurrence is higher than the smaller ones. Therefore, in multiple scale problems, scales of the establishments should be represented in the calculations. In this study, scales of establishments are included in both IO and OO-AHP.DEA models in the applied case problem. Number of worker is selected as defined input variable to represent scale of establishments and it is used in all calculations. Similarly, Annual ROM coal production is included in OO-AHP.DEA method to represent the scale values in all calculations.

Results of the case study are presented in detail in Chapter 4 for IO and OO-AHP.DEA models. In this chapter, discussions are conducted about the results of case study in topic 5.1 and 5.2. One of the objectives of the case study is to test the validity of the newly developed model and validity of the model is discussed in topic 5.3.

5.1 Discussion on Results of IO-AHP.DEA Model

Annual IO-AHP.DEA results of five TTK establishments are given in Table 58. As seen in this table, averages of the annual scores are calculated for each establishment to find out the OHS efficiency performance of them for multiple periods.

As presented in Table 58, Kozlu establishment has the highest overall relatively efficiency score. This means that Kozlu establishment has used its OHS inputs or sources more efficiently than the others for the last five years. In spite of that, Üzülmez is the worst establishment if overall results are considered. Amasra and Kozlu establishments become relative efficient establishment four times and Armutçuk is efficient one two times but Karadon and Üzülmez are always inefficient establishment during last five years. It should not be forgotten that AHP.DEA model is based on DEA and efficient establishment can get maximum efficiency score as one or 100 % and if efficiency level of efficient establishment is increased, efficiency of score of efficient establishment is not changed (it is again one) but efficiency score of the inefficient one’s is decreased by the model. During the discussion of related tables and figures, this fact should be considered.

Table 58 IO-AHP.DEA scores of TTK Establishment

Establishment	2007	2008	2009	2010	2011	Overall
AMASRA	0.739	1.000	1.000	1.000	1.000	**0.948**
ARMUTÇUK	1.000	0.923	1.000	0.673	0.632	**0.846**
KARADON	0.829	0.783	0.924	0.657	0.608	**0.760**
KOZLU	1.000	1.000	1.000	0.943	1.000	**0.989**
ÜZÜLMEZ	0.729	0.611	0.802	0.768	0.802	**0.743**

Karadon and Üzülmez should evaluate the 2007-2011 period attentively to find out the adverse conditions which decrease the OHS efficiencies of them. Karadon and Üzülmez should take as reference the efficient ones during the evaluation of their OHS conditions. In DEA application stage of the AHP.DEA method, the needed improvements of inefficient establishments are calculated based on the efficient establishments. If these improvements are applied in the inefficient ones, they may increase their relative efficiency level and they can use their OHS inputs more effectively than previous years. For the case study, the needed improvements are presented in DEA result tables in Appendix C.

IO-AHP.DEA scores of TTK establishments are given in Figure 13. When this figure is analyzed year by year;

- In 2007, Armutçuk and Kozlu establishments are relative efficient. The relative worst one is Üzülmez. Amasra, Karadon and Üzülmez have used their OHS inputs relative inefficiently than Armutçuk and Kozlu.

- In 2008, Amasra and again Kozlu establishments are relative efficient. Üzülmez establishment still has the worst IO-AHP.DEA score. Relative efficiency scores of Armutçuk, Karadon and Üzülmez establishments are lower than the previous year.

- In 2009, Armutçuk, Karadon and Üzülmez establishments increase the level of relative efficiency level and IO-AHP.DEA scores of Amasra and Kozlu remain the same at relative efficient position.

- In 2010, there is a decrease at relative efficiency scores of all establishments except for Amasra. Amasra is still the relative efficient one. The decrease in the others indicates that Amasra establishment has used OHS inputs better than previous years. In other words, the other ones should take Amasra as a reference point to increase their input usage efficiency level.

- In 2011, Kozlu and Üzülmez have increased their IO-AHP.DEA scores and Kozlu becomes relative efficient one. Amasra is still efficient one. However, Armutçuk and Karadon have decreased the relative efficiency scores.

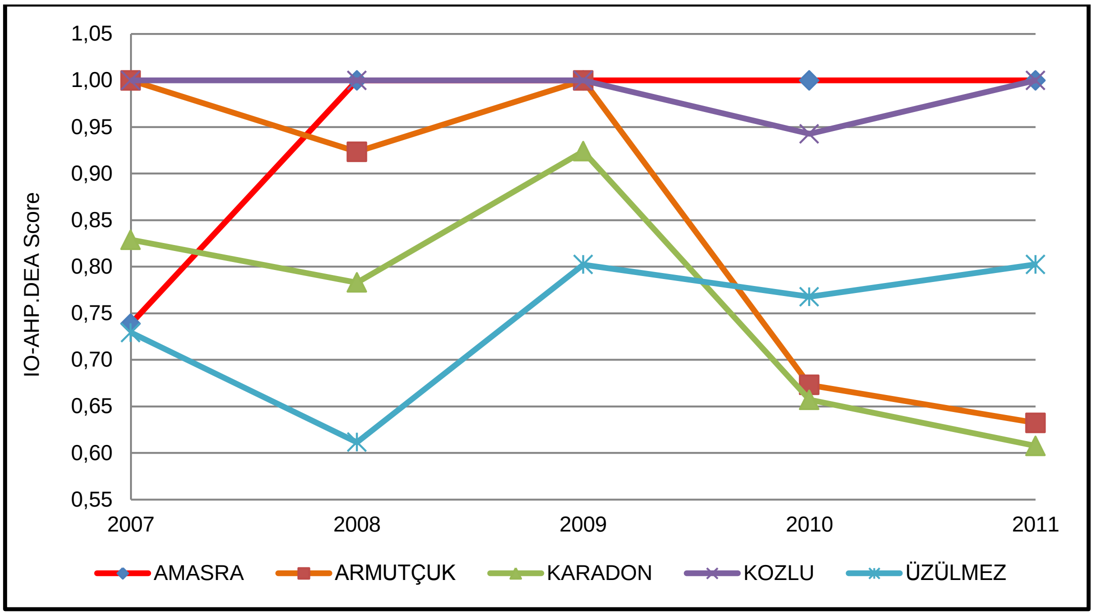

Figure 13 IO-AHP.DEA scores of TTK Establishment

When the Figure 13 is reviewed attentively, it can be observed that trends of IO-AHP.DEA scores of Armutçuk, Karadon and Üzülmez are parallel between 2007 and 2009. After 2009, relative efficiency level of Üzülmez becomes stable but Armutçuk and Karadon continue to decease as parallel from 2009 to 2011. This parallelism of three establishments cannot be a coincidence. It may be occurred because of the management of the establishments. In other words, almost same OHS decisions were determined and applied in these establishments. To get more argument about this situation, it should be investigated that when manager, deputy of manager and OHS directors of these establishments were changed. There is a considerable relationship between the relative efficiency level of the establishments and decisions of executives like amount of annual OHS investment, changing worker number as employing of hiring, *etc.*

Two scenarios can be clarified about the parallelism situation. The first one is that Armutçuk, Karadon and Üzülmez may not be managed properly. In other words, inputs might not be distributed appropriately in these establishments and almost same decisions might be applied in these establishments. Therefore, relative efficiency level of these establishments is parallel. The second one can be explained as that the efficiency of input usage of Amasra and Kozlu establishments affects the efficiency of the others in the negative way. In other words, relative efficiency of these establishments were increased enormously than the others and these high relative efficiency values were put pressure on the relative efficiency to the others. For example, the dramatic increase in the score of Amasra at 2008 hold down the relative efficiencies of Armutçuk, Karadon and Üzülmez so their relative efficiency scores of them are decreased. However, relative efficiency of Kozlu is not affected by the excessive increase of Amasra at 2008. Therefore, it can be said that Kozlu also increased its input usage performance at that year. Moreover, at 2010, there is a decrease in the relative efficiency score of Kozlu and this decrease affects the relative efficiency score of Üzülmez whose score is not decreased like Karadon and Armutçuk and it leaves the parallelism. Figure 13 indicates the relationship the interrelationship between the relative efficiencies of the establishments.

5.2 Discussion on Results of OO-AHP.DEA Model

Beside IO-AHP.DEA method, OO-AHP.DEA method is also used to evaluate the TTK establishments. In the OO-AHP.DEA technique, it is measured which establishment decrease the undesired outputs while increasing ROM coal production with consuming minimum input sources. The OO-AHP.DEA scores of each establishment are stated in Table 59 for 2007-2011 periods.

As stated in Table 59, Üzülmez establishment is the worst one when compared with the other competitors. However, Kozlu establishment is the most efficient ones and its relative efficiency score is 100% at each year. Amasra and Armutçuk establishments are efficient ones two times and Karadon is relative efficient one time. Similarly the IO-AHP.DEA result, Üzülmez is relatively inefficient establishment during 2007-2011 periods. Relative inefficient establishments, whose OO-AHP.DEA score is less than one, should adapt its OHS management with taking efficient ones as reference points.

Table 59 OO-AHP.DEA scores of TTK Establishment

Establishment	2007	2008	2009	2010	2011	Overall
AMASRA	0.851	0.917	0.951	1.000	1.000	**0.944**
ARMUTÇUK	1.000	1.000	0.972	0.796	0.753	**0.904**
KARADON	0.630	0.808	1.000	0.618	0.639	**0.739**
KOZLU	1.000	1.000	1.000	1.000	1.000	**1.000**
ÜZÜLMEZ	0.694	0.652	0.856	0.698	0.648	**0.710**

OO-AHP.DEA scores of TTK establishments are also given in Figure 14 as a graph. When this figure and Table 59 is analyzed year by year;

- In 2007, Armutçuk and Kozlu establishments are on the efficient frontier so they are relatively efficient when compared with the others. OO-AHP.DEA scores of Karadon and Üzülmez are lower ones.

- In 2008, Armutçuk and Kozlu are again relatively efficient establishments. Karadon started to use its OHS sources relatively more efficiently than the previous years but Üzülmez still the worst establishment.

- In 2009, Kozlu was the efficient establishment. Ascending trend of Karadon continued and it becomes relative efficient one with Kozlu. The ascent trend of Kozlu may be result of applying some important precaution to reduce the undesirable outputs and increasing ROM coal production.

- In 2010, Kozlu is the relative efficient establishment with Amasra. The ascent trend of Karadon is finished and it had the lowest score. When the input and output values of Karadon is analyzed it can be said that OHS performance in 2010 is better than 2009. However, Karadon was relatively worse than the others in 2010. In other words, other establishments OHS performance are better than Karadon.

- In 2011, Kozlu and Amasra were relative efficient establishments and Karadon had the lowest OO-AHP.DEA score.

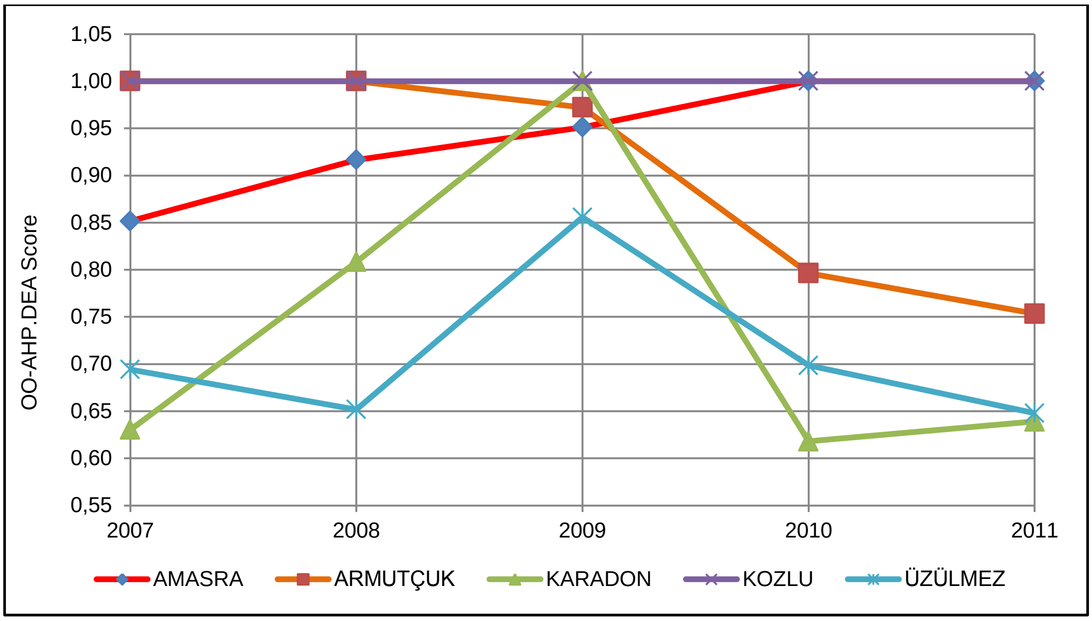

Figure 14 OO-AHP.DEA scores of TTK Establishment

Some establishments may increase their OHS performance with less undesirable outputs and more ROM coal production when compared with the previous year but their relative efficiency score may be worse than previous year. For instance, at 2010, Karadon had lower undesired output than 2009 but there is a decrease in the relative efficiency of Karadon. This situation is resulted from the dramatically increase in the effectively OHS management of Amasra and Kozlu establishments.

When the results of last year (2011) are investigated, Amasra and Kozlu establishments are relatively efficient and the others are relatively inefficient ones. Then, target values of Armutçuk, Karadon and Üzülmez can be obtained with AHP.DEA method. There are results of each DEA applications in the tables given in Appendix C. These tables include the target values for inefficient establishments. A sample table is given in Table 60 and it is for IO-AHP.DEA method estimation for 2011. Estimation input is annual effective work hour, defined input is number of worker and defined outputs are ROM coal production and annual lost work day in this table. The slack movement columns represent the target values for inefficient establishments for single DEA application.

Table 60 Sample DEA Application Table for IO-AHP.DEA for 2011

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (Effective Work Hour)	Slack Movement (Effective Work Hour)	Projection (Effective Work Hour)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	3	644	0	644	1423582	0	1423582	289880	0	289880	3232	0	3232
2	ARMUTCUK	0,489	AMASRA(0,869)	0	1144	-584,632	559,368	2524365	-1287865,09	1236499,91	251785	0	251785	4191	-1383,738	2807,262
3	KARADON	0,598	AMASRA(2,770)	0	2838	-1053,899	1784,101	6835770	-2891959,713	3943810,287	803067	0	803067	24188	-15234,252	8953,748
4	KOZLU	1	KOZLU(1,000)	0	1702	0	1702	3842332	0	3842332	691150	0	691150	7436	0	7436
5	ÜZÜLMEZ	0,73	AMASRA(1,971)	0	1801	-531,795	1269,205	3753292	-947674,515	2805617,485	571300	0	571300	32936	-26566,324	6369,676

After the estimation of the target values from each DEA application, they are used in AHP.DEA method to estimate single target value for inefficient establishment. The target value estimation procedure can be applied for both IO and OO-AHP.DEA methods.

In the target value estimation in IO-AHP.DEA method, the targets are collected from the DEA tables. The collected targets are shown in Table 63. As seen in this table, number of worker, ROM coal production and annual lost work day targets are estimated at each DEA application. Therefore, their weighed average value should be found. The weights are taken from the results of AHP application for inputs. As mentioned before, sum of AHP weights is one but number of worker variable is used as a defined input at each DEA application so it is not used as estimation input. Therefore, the other variables' AHP score should be normalized. Target values for Armutçuk, Karadon, and Üzülmez for the last year (2011) are given in Table 61, Table 62, and Table 63 respectively so managers of the establishments can modify their decisions with using these targets. IO-AHP.DEA target values represent the effective usage of inputs. Therefore, the target values should be reached by inefficient establishments to consume inputs more effectively.

When the IO-AHP.DEA targets of Armutçuk are explored as given in Table 61, this establishment should decrease number of worker as 532 worker and annual lost work day as 1,351 day. Annual effective work hour, annual OHS education time, annual OHS expenditure, and number of OHS staff may be also decreased as 1,287,865, 56, 213,200, and 19 respectively.

Table 61 Target Values of IO-AHP.DEA for Armutçuk for 2011

Estimation Input Name	***AHP Weights***	***Normalized AHP Weights***	**Annual Effective Work Hour**	**Annual OHS Education Time**	**Annual OHS Expenditure**	**Number of OHS Staff**	**Number of Worker**	**ROM Coal Production**	**Annual Lost Work Day**
Annual Eff. Work Hour	*0.146*	*0.163*	-1,287,865	-	-	-	-584	0	-1,384
Annual OHS Education Time	*0.422*	*0.470*	-	-56	-	-	-524	0	-1,482
Annual OHS Expenditure	*0.260*	*0.290*	-	-	-213,200	-	-524	0	-1,482
Number of OHS Staff	*0.070*	*0.078*	-	-	-	-19	-502	0	0
Weighted Averages :							-532	0	-1,351

IO-AHP.DEA target values of Karadon are given in Table 62. Some reduction can be conducted in worker number and annual lost work day as 948 and 15,406 respectively. Also, annual effective work hour, annual OHS education time, annual OHS expenditure, and number of OHS staff can be reduced as 2,891,960, 461, 602,125, and 92 respectively. It should be noted that ROM coal production need to be same when these reductions are conducted.

Table 62 Target Values of IO-AHP.DEA for Karadon for 2011

Estimation Input Name	***AHP Weights***	***Normalized AHP Weights***	**Annual Effective Work Hour**	**Annual OHS Education Time**	**Annual OHS Expenditure**	**Number of OHS Staff**	**Number of Worker**	**ROM Coal Production**	**Annual Lost Work Day**
Annual Eff. Work Hour	*0.146*	*0.163*	-2,891,960	-	-	-	-1,054	0	-15,234
Annual OHS Education Time	*0.422*	*0.470*	-	-461	-	-	-860	0	-15,548
Annual OHS Expenditure	*0.260*	*0.290*	-	-	-602,125	-	-1,054	0	-15,234
Number of OHS Staff	*0.070*	*0.078*	-	-	-	-92	-860	0	-15,548
Weighted Averages :							-948	0	-15,406

As presented in Table 63, Üzülmez establishment should decrease number of worker as 386 worker and also annual lost work day need to be reduced as 24,665 day. This establishment can also reduce annual effective work hour, annual OHS education time, and annual OHS expenditures as 947,675, 194, and 13,790 respectively to become relative efficient establishment. This establishment may not reduce the number of OHS staff.

Table 63 Target Values of IO-AHP.DEA for Üzülmez for 2011

Estimation Input Name	***AHP Weights***	***Normalized AHP Weights***	**Annual Effective Work Hour**	**Annual OHS Education Time**	**Annual OHS Expenditure**	**Number of OHS Staff**	**Number of Worker**	**ROM Coal Production**	**Annual Lost Work Day**
Annual Eff. Work Hour	*0.146*	*0.163*	-947,675	-	-	-	-531	0	-26,566
Annual OHS Education Time	*0.422*	*0.470*	-	-194	-	-	-394	0	-26,789
Annual OHS Expenditure	*0.260*	*0.290*	-	-	-13,790	-	-394	0	-26,789
Number of OHS Staff	*0.070*	*0.078*	-	-	-	0	0	0	0
Weighted Averages :							-386	0	-24,665

OO-AHP.DEA targets of inefficient establishments are also estimated. In this estimation, it can be obtained how maximum desirable output and minimum undesirable output can be reached with the present levels of the inputs. OO-AHP.DEA target values of Armutçuk, Karadon, and Üzülmez are presented in Table 64, Table 65 and Table 66 respectively.

Armutçuk establishment should decrease the number of worker as 459 and also annual OHS education time may be reduced as 46 hours. Annual lost day number, annual accident number, annual accident cost and number of injured workers should be decreased as 1,482, 158, 13,792, and 158 respectively. However, number of workers who died and ROM coal production must be staying same when these reductions applied.

Table 64 Target Values of OO-AHP.DEA for Armutçuk for 2011

Estimation Output Name	***AHP Weight***	***Normalized AHP Weights***	**Annual Death Worker Number**	**Annual Lost Day Number**	**Annual Accident Number**	**Annual Accident Cost**	**Annual Injured Worker Number**	**Annual ROM Coal Production**	**Number of Worker**	**Annual OHS Education Time**
Annual Death Worker Number	0,281	0,295	0	-	-	-	-	0	-524	-56
Annual Lost Day Number	0,247	0,260	-	-1.482	-	-	-	0	-524	-56
Annual Accident Number	0,145	0,152	-	-	-158	-	-	0	-524	-56
Annual Accident Cost	0,143	0,150	-	-	-	-13.792	-	0	-585	-45
Annual Injured Worker Number	0,135	0,142	-	-	-	-	-158	0	-524	-56
Weighted Average :								0	-459	-46

As presented in Table 65, Karadon establishment needs to reduce worker number and annual OHS education time as 513 and 260 respectively while it has to increase its ROM coal production as 140,171 ton. Annual death worker number, annual lost day number, annual accident cost, and annual injured worker number should be also reduced as 1, 15,548, 594, 851,745, and 593 respectively to become relatively efficient establishment.

Table 65 Target Values of OO-AHP.DEA for Karadon for 2011

Estimation Output Name	***AHP Weights***	***Normalized AHP Weights***	**Annual Death Worker Number**	**Annual Lost Day Number**	**Annual Accident Number**	**Annual Accident Cost**	**Annual Injured Worker Number**	**Annual ROM Coal Production**	**Number of Worker**	**Annual OHS Education Time**
Annual Death Worker Number	0,281	0,295	-1	-	-	-	-	474.386	0	-19
Annual Lost Day Number	0,247	0,260	-	-15.548	-	-	-	0	-860	-461
Annual Accident Number	0,145	0,152	-	-	-594	-	-	0	-860	-461
Annual Accident Cost	0,143	0,150	-	-	-	-851.745	-	0	-1.054	-426
Annual Injured Worker Number	0,135	0,142	-	-	-	-	-593	0	-860	-461
Weighted Average :								140.171	-513	-260

When the Table 66 is explored, Üzülmez establishment should reduce number of worker as 74 worker and annual education time as 46 hours but it should increase annual ROM coal production as 133,372 ton. Moreover, annual death number, annual lost work day, annual accident number, annual accident cost, and annual injured worker number need to be decreased as 3, 25,067, 151, 1,330,076, and 149 respectively.

Table 66 Target Values of OO-AHP.DEA for Üzülmez for 2011

Estimation Output Name	***AHP Weights***	***Normalized AHP Weights***	**Annual Death Worker Number**	**Annual Lost Day Number**	**Annual Accident Number**	**Annual Accident Cost**	**Annual Injured Worker Number**	**Annual ROM Coal Production**	**Number of Worker**	**Annual OHS Education Time**
Annual Death Worker Number	0,281	0,295	-3	-	-	-	-	210.408	0	0
Annual Lost Day Number	0,247	0,260	-	-25.067	-	-	-	160.052	0	-63
Annual Accident Number	0,145	0,152	-	-	-151	-	-	0	-394	-194
Annual Accident Cost	0,143	0,150	-	-	-	-1.330.076	-	197.057	-94	0
Annual Injured Worker Number	0,135	0,142	-	-	-	-	-149	0	-394	-194
Weighted Average :								133.372	-74	-46

Finally, when the IO and OO-AHP.DEA targets are analyzed, it can be said that the inefficient establishments employ more worker than the needed amount. This problem reduces the efficiencies of the establishments. Number of workers may be reduced or these workers should be used more effectively to increase the annual production without increasing number of worker who died or injured. The target results also indicate that number of annual education time should be decreased. However, in reality, annual education time should not be decreased to prevent the accidents. The reductions in the targets values indicate that the OHS educations do not reach the aim of awareness and it does not conducted effectively. The education style and program should be revised and updated.

5.3 Validation of the AHP.DEA Method

To test the reliability of the AHP.DEA technique results, scores of IO-AHP.DEA and OO-AHP.DEA should be consistent. In other words, success order of firms or establishments for IO-AHP.DEA and OO-AHP.DEA should be same. As presented in Table 67, success order of TTK establishments is same for IO-AHP.DEA and OO-AHP.DEA scores.

Table 67 Relative Efficiency Order of TTK Establishment based on IO-AHP.DEA and OO-AHP.DEA Scores

Order No	Establishment	Overall IO-AHP.DEA	Overall OO-AHP.DEA
1	KOZLU	0,989	1,000
2	AMASRA	0,948	0,944
3	ARMUTÇUK	0,846	0,904
4	KARADON	0,760	0,739
5	ÜZÜLMEZ	0,743	0,710

The second validation indicator test can be conducted with using deviations between the IO-AHP.DEA and OO-AHP.DEA scores of each establishment. The upper limit of the deviation may be different for using different advanced DEA models. Nevertheless, it can be advised that the deviation should not be more than 5%. As known, 95% confidence level is accepted as accurate in engineering. The deviation for each establishment is stated in Table 68. As stated in this table, only deviation of Armutçuk results is beyond the boundary but the others provide the deviation criterion. The overrun deviation is only 6.416% and this overrun is accepted in this study.

Table 68 The Deviation between Overall IO-AHP.DEA and OO-AHP.DEA Scores

Establishment	Overall IO-AHP.DEA	Overall OO-AHP.DEA	Deviation, %
AMASRA	0.948	0.944	0.424
ARMUTÇUK	0.846	0.904	6.416
KARADON	0.760	0.739	2.842
KOZLU	0.989	1.000	1.100
ÜZÜLMEZ	0.743	0.710	4.648

Results of this study provide the necessary conditions to become a valid model as presented above. Therefore, the newly developed model can be applied for different disciplines with small modifications since in some disciplines some small modifications should be integrated to the model.

This study has been completed by the coordination of TTK. OHS experts of TTK were visited in several times throughout the study. Their suggestions and opinions were taken into consideration and results of this study were also discussed by them. They have indicated that the accurate level of the study is satisfactory.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

In this study, it is focused on the developing a new DEA model to evaluate the OHS efficiency of limited number decision making units. The present research study has three objectives. Firstly, to explore a new model for applying DEA for limited number DMUs cases. The goal is to develop a suitable model with integration of AHP and DEA techniques. The newly developed model is named as AHP.DEA technique and it combines the power of subjective and objective evaluations based on DEA technique. The main advantage of AHP.DEA model is that it creates an opportunity for using more input and output variables in the efficiency estimation procedure than classical DEA techniques. The second objective of this study is testing the newly developed method with real OHS data whether it is suitable for efficiency measurement or not. The last one is that increasing the awareness of DEA usage and its benefits in OHS and mining fields.

6.1 Conclusions

AHP.DEA technique is developed to get rid of the some drawbacks of conventional DEA technique. Two main advancements have been provided with development of AHP.DEA technique. The first one is that DEA, a powerful relative efficiency measurement technique, cannot be applied for limited number DMUs cases but now, it can be applied for these cases with the newly developed technique.

As mentioned in detail in section 2.3.3: DMUs Set and Input/Output Selection, total number of usable input and output variables is determined by number of DMUs. Therefore, there are some constraints in the application of DEA to the limited number DMUs problems or some important variables cannot be included in the estimation procedure. However, with the development of AHP.DEA technique, total number of input and output variables is not determined by number of DMUs directly. Therefore, all aspects of problems in limited number DMUs cases are included in the relative efficiency estimation procedure. For example, only four input and output variables can be used for TTK case in conventional DEA application. However, with the development of IO-AHP.DEA and OO-AHP.DEA models, the number of used variables is determined as seven and eight respectively. Therefore, all important OHS input and output variables are included in the relative efficiency estimation of the establishments and thus accuracy of the estimation is increased.

The second advancement is that subjective expert opinion is integrated to DEA application. Before AHP.DEA technique, DEA can only give objective results but in some critical operations, subjective evaluation is as crucial as objective evaluation. OHS in mining operations can be given as an example for this situation. Therefore, this study contributes to DEA field with developing AHP.DEA method. When the literature of DEA studies are explored, there is not any study related with increasing the number of input and outputs. Also, there is no method which combines powerful aspects of subjective and objective evaluation based on DEA method.

As mentioned in Chapter 1, one of the objectives of this study is increasing the awareness of DEA in mining and OHS fields. There is little study in these fields and conventional DEA method is applied in these studies. Moreover, incorrect applications of DEA are included in some of these studies as mentioned in Topic 2.6. DEA is a powerful application and it can be used as a decision support tool, hence this useful method should be applied intensively in OHS and mining sectors. The developed AHP.DEA technique has all the features and benefits of DEA. Therefore, it can be applied for all cases beside limited number DMUs cases.

After the development of AHP.DEA technique, IO-AHP.DEA and OO-AHP.DEA techniques are introduced. IO-AHP.DEA technique is used to measure the relative efficiency of input usage. In other words, it can be answered that which firm or establishment uses its inputs or sources more efficiently to reduce the undesired outputs and increase desirable outputs. On the other hand, OO-AHP.DEA technique measures which firm use lesser input to reach planned or realized output levels. Objective of these two techniques are different but the deviation between their results should not be more than 5%. Reliability of the AHP.DEA can be measured with comparing the results of them.

After the development of AHP.DEA technique, it has been applied to the Turkish Hard Coal Enterprise (TTK) to test the suitability. The reason of selection of TTK is that it has five establishments so it is suitable for a limited number DMUs case. Some OHS data has been collected from TTK establishments' database and the developed technique was run based on this OHS data.

After the application of newly developed method, the results of the case study are discussed in detail in Chapter 4 and Chapter 5. The results indicate that Kozlu is a relative efficient establishment for 2007-2011 period and its overall IO-AHP.DEA and OO-AHP.DEA scores are 98.9% and 100% respectively while Üzülmez is the relatively worst one with 74.3% IO-AHP.DEA score and 71.0% OO-AHP.DEA score. The inefficient establishments should modify their OHS decisions based on the efficient ones to reduce the accidents and to become relative efficient establishment.

6.2 Recommendations

AHP.DEA method is developed with its mathematical background and its validity is tested. Therefore, a software package can be developed for applying this method to different problems in several disciplines. In this software, all advanced DEA models should be included since type of advanced models can be different for each application.

In this study, OHS relative efficiency measurement case is investigated. In OHS scenarios, inputs and outputs are fixed like number of workers, annual lost day number, and annual number of accidents. These values cannot be fluctuated because they were realized and they had fix values. However, for some cases the inputs and outputs may fluctuate. These fluctuating data can be represented as linguistic variables. In the further studies, fuzzy logic technique can be integrated to AHP.DEA technique for limited number DMUs cases to solve the data fluctuation problems or cases.

REFERENCES

Abbaspour, M., Lotfi, F. H., Karbassi, A. R., Roayaei, E., & Nikoomaram, H. (2010). Development of a Model to Assess Environmental Performance, Concerning HSE-MS Principles. *Environmental Monitoring and Assessment*, *165*(1-4), 517–28.

Allen, R., Athanassopoulos, A., Dyson, R. G., & Thanassoulis, E. (1997). Weights Restrictions and Value Judgements in Data Envelopment Analysis: Evolution, Development and Future Directions. *Annals of Operations Research*, *73*, 13–34.

Aydeğer, M. (2005). Toplam Faktör Verimliliği ve Bileşenleri (in Turkish), *Master Thesis*, *Gazi University.* p.112. Ankara.

Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. *Management Science*, *30*(9), 1078–1092.

Beasley, J. E. (1990). Comparing University Departments. *OMEGA*, *18*(2), 171–183.

Behn, R. (2003). Why Measure Performance? Different Purposes Require Different Measures. *Public Administration Review*, *63*(5), 586–606.

Beriha, G. S., Patnaik, B., & Mahapatra, S. S. (2011a). Safety Performance Evaluation of Indian Organizations using Data Envelopment Analysis. *Benchmarking: An International Journal*, *18*(2), 197–220.

Beriha, G. S., Patnaik, B., & Mahapatra, S. S. (2011b). A Data Envelopment Analysis Approach for Benchmarking of Safety Performance. *3rd International Conference on Information and Financial Engineering* (Vol. 12, pp. 6–12). Sanghai.

Bhushan, N., & Rai, K. (2004). *Strategic Decision Making: Applying the Analytic Hierarchy Process, Decision Engineering.pdf* (p. 172). London: Springer-Verlag.

Biçer, N. (2008). Modular Coal-Processing Plants Applied to Zonguldak Hard Coal. *Turkish-American Clean Energy Technologies Conference*. İstanbul.

Boussofiane, A., Dyson, R. G., & Thanassoulis, E. (1991). Applied Data Envelopment Analysis. *European Journal of Operational Research*, *52*(1), 1–15.

Bowlin, W. F. (1987). Evaluating the Efficiency of US Air Force Real-Property Maintenance Activities. *Journal of the Operational Research Society*, *38*(2), 127–135.

Bowlin, W. F. (1999). An Analysis of the Financial Performance of Defense Business Segments using Data Envelopment Analysis. *Journal of Accounting and Public Policy*, *18*, 287–310.

Brockett, P. L., Charnes, A., Cooper, W. W., Huang, Z. M., & Sun, D. (1997). Data Transformations in DEA Cone Ratio Envelopment Approaches for Monitoring Bank Performances. *European Journal of Operational Research*, *98*(2), 250–268.

Byrnes, P., Färe, R., Grosskopf, S., & Knox Lovell, C. a. (1988). The Effect of Unions on Productivity: U.S. Surface Mining of Coal. *Management Science*, *34*(9), 1037–1053.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the Efficiency of Decision Making Units. *European Journal of Operational Research*, *2*(6), 429–444.

Charnes, A., Cooper, W. W., & Rhodes, E. (1979). Short Communication: Measuring the Efficiency of Decision Making Units. *European Journal of Operational Research*, *3*, 1979.

Charnes, A., Cooper, W. W., & Huang, Z. M. (1990). Polyhedral Cone-Ratio DEA Models with an Illustrative Application to Large Commercial Banks. *Journal of Econometrics*, *46*(1-2), 73–91.

Chen, Y., & Sherman, H. D. (2004). The Benefits of Non-Radial vs. Radial Super-Efficiency DEA: An Application to Burden-Sharing Amongst NATO Member Nations. *Socio-Economic Planning Sciences*, *38*(4), 307–320.

Chung, Y. H., Färe, R., & Grosskopf, S. (1997). Productivity and Undesirable Outputs: A Directional Distance Function Approach. *Journal of Environmental Management*, *51*(3), 229–240.

Coelli, T. J., Rao, D. S. P., O'Donnell, C. J., & Battese, G. E. (2005). *An Introduction to Efficiency and Productivity Analysis*. (p.349). New York: Springer.

Cook, W. D., Roll, Y., & Kazakov, A. (1990). A DEA Model for Measuring the Relative Efficiency of Highway Maintenance Patrols. *INFOR*, *28*, 113–124.

Cook, W. D., & Seiford, L. M. (2009). Data Envelopment Analysis (DEA)-Thirty Years On. *European Journal of Operational Research*, *192*(1), 1–17.

Cooper, W. W., Seiford, L. M., & Tone, K. (2006). *Introduction to Data Envelopment Analysis and its Uses with DEA-Solver Software and References*. *Policy* (p. 354). New York: Springer.

Cristóbal, J. R. S. (2011). A multi criteria data envelopment analysis model to evaluate the efficiency of the Renewable Energy technologies. *Renewable Energy*, *36*(10), 2742–2746.

Çimen, S. (2011). The Analysis of Total Factor Efficiency in the Public Lignite Mining Organizations in Turkey. Ph.D. Thesis, Middle East Technical University. p.212. Ankara

DEA2010. (2010). Performance Management and Measurement with Data Envelopment Analysis. In A. Emrouznejad, I. H. Osman, & A. L. Anouze (Eds.), *Proceeding of the 8th International Conference of DEA* (p. 257). Beirut.

Debreu, G. (1951). The Coefficient of Resource Utilization. *Econometrica*, *19*(3), 273–292.

Dyson, R. G., & Thanassoulis, E. (1988). Reducing Weight Flexibility in Data Envelopment Analysis. *Journal of the Operational Research Society*, *39*(6), 563–576.

El-Mashaleh, M. S., Rababeh, S. M., & Hyari, K. H. (2010). Utilizing Data Envelopment Analysis to Benchmark Safety Performance of Construction Contractors. *International Journal of Project Management*, *28*(1), 61–67.

Eroğlu, E., & Lorcu, F. (2007). Veri Zarflama Analitik Hiyerarşi Prosesi (VZAHP) ile Sayısal Karar Verme (in Turkish). *İ.Ü. İşletme Fakültesi İşletme Dergisi*, *36*(2), 30–53.

Erpolat, S., & Cinemre, N. (2011). Notebook Seçiminde Hibrit Bir Yaklaşım: Analitik Hiyerarşi Yöntemine Dayalı Veri Zarflama Analizi. *Istanbul University Journal of the School of Business Administration*, *40*(2), 207–225.

Ertürk, M. (2009). Efficiency Analysis of Turkish Natural Gas Distribution Companies by Using DEA Method, *Master Thesis, Middle East Technical University*. p.118. Ankara

Fang, H. (2009). Comparative Study on Efficiency Performance of Listed Coal Mining Companies in China and the US. *Energy Policy*, *37*(12), 5140–5148.

Farrell, M. J. (1957). The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society. Series A (General)*, *120*(3), 253–290.

Feroz, E. H., Raab, R., & Haag, S. (2001). An Income Efficiency Model Approach to the Economic Consequences of OSHA Cotton Dust Regulation. *Australian Journal of Management*, *26*(1), 69–89.

Freeman, R. (2008). *Labour Productivity Indicators - Comparison of Two OECD Databases, Productivity Differentials and The Balassa-Samuelson Effect*. *Statistics* (p. 76). Retrieved from http://www.oecd.org/dataoecd/57/15/41354425.pdf (Last Access Date: 27.12.2012)

Fried, H. O., Lovell, C. A. K., & Schmidt, S. S. (2008). *The Measurement of Productive Efficiency and Productivity Growth*. Oxford University Press.

Färe, R., Grosskopf, S., Lovell, C. A. K., & Pasurka, C. (1989). Multilateral Productivity Comparisons when Some Outputs Are Undesirable: A Nonparametric Approach. *The Review of Economics and Statistics*, *71*(1), 90–98.

Gang, C., & Zhenhua, Q. (2011). MaxDEA Manual - Version 5.2. Beijing.

Genç, B., & Hermanus, M. (2011). Towards Benchmarking of Safety Performance in the Mining Sector. *22nd International Mining Congress and Exhibition of Turkey*. Ankara.

Goto, M., & Tsutsui, M. (1998). Comparison of Productive and Cost Efficiencies Among Japanese and US Electric Utilities. *OMEGA, International Journal of Management Science*, *26*(2), 177–194.

Güyagüler, T., Karakaş, A., & Güngör, A. (2005). *Occupational Health and Safety in Mining Industry* (p. 160). Ankara: ODTÜ Matbaası.

Kabnurkar, A. (2001). *Mathematical Modeling for Data Envelopment Analysis with Fuzzy Restrictions on Weights*. Virginia Polytechnic Institute and State University.

Karakoç, İ. D. (2003). Veri Zarflama Analizi'ndeki Ağırlık Kısıtlamalarının Belirlenmesinde Analitik Hiyerarşi Sürecinin Kullanımı (in Turkish). *D.E.Ü.İ.İ.B.F. Dergisi*, *18*(2), 1–12.

Karsak, E. E., & İşcan, F. (2010). Çimento Sektöründe Göreli Faaliyet Performanslarının Ağırlık Kısıtlamaları ve Çapraz Etkinlik Kullanılarak Veri Zarflama Analizi ile Değerlendirilmesi. *Endüstri Mühendisliği Dergisi*, *2*(3), 2–10.

Kasap, Y. (2010). Türkiye Kömür İşletmelerinde Teknik Etkinlik Ve Toplam Faktör Verimlilik Gelişimi (in Turkish). *Dumlupınar Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, (22), 75–86.

Koch, S. (2009). *Measuring the Efficiency of Free and Open Source Software Projects using Data Envelopment Analysis*. (P. F. Tiako, Ed.) *Business* (pp. 2963–2977). Hershey: Langston University, USA.

Koopmans, T. C. (1951). Efficient Allocation of Recources. *Econometrica,*, *19*(4), 455–465.

Kornbluth, J. S. H. (1991). Analysing Policy Effectiveness using Cone Restricted Data Envelopment Analysis. *Journal of the Operational Research Society*, *42*(12), 1097–1104.

Kulshreshtha, M., & Parikh, J. K. (2002). Study of Efficiency and Productivity Growth in Opencast and Underground Coal Mining in India: A DEA Analysis. *Energy Economics*, *24*(5), 439–453.

Liao, H. C., & Chen, Y. K. (2010). Assessing Occupational Safety Strategy of Taipei's Building Industry in Terms of Economic Efficiency. *APOSHO 25 Annual Meeting and Conference* (pp.1–7). Flic en Flac, Mauritus. Retrieved from http://www.aposho.org/conference/img/csiv-c3.doc (Last Access Date: 27.12.2012)

Manzoni, A. (2007). A New Approach to Performance Measurement using Data Envelopment Analysis: Implications for Organisation Behaviour, Corporate Governance and Supply Chain Management. *Ph.D. Thesis, Victoria University*. p.289. Melbourne.

Mohajeri, N., & Amin, G. R. (2010). Railway Station Site Selection using Analytical Hierarchy Process and Data Envelopment Analysis. *Computers & Industrial Engineering*, *59*(1), 107–114.

Mohammadi, A., Rafiee, S., Mohtasebi, S. S., Mousavi Avval, S. H., & Rafiee, H. (2011). Energy Efficiency Improvement and Input Cost Saving in Kiwifruit Production using Data Envelopment Analysis Approach. *Renewable Energy*, *36*(9), 2573–2579.

Mousavi-Avval, S. H., Rafiee, S., Jafari, A., & Mohammadi, A. (2011). Improving Energy Use Efficiency of Canola Production using Data Envelopment Analysis (DEA) Approach. *Energy*, *36*(5), 2765–2772.

Nachiappan, S., & Ramanathan, R. (2008). Robust Decision Making using Data Envelopment Analytic Hierarchy Process. *7th WSEAS Int. Conf. on Artificial Intelligence, Knowledge Engineering and Data Bases (AIKED'08)* (pp.269–275). Cambridge.

Nataraja, N. R., & Johnson, A. L. (2011). Guidelines for using Variable Selection Techniques in Data Envelopment Analysis. *European Journal of Operational Research*, *215(3),* 662-669.

Neely, A. (1999). The Performance Measurement Revolution: Why Now and What Next? *International Journal of Operations & Production Management*, *19*(2), 205–228.

Nissi, E., & Rapposelli, A. (2010). Analysing Industrial Accidents in European Countries using Data Envelopment Analysis. *XXV National Conference of Labour Economics*. Pescara, Italy.

Norman, M., & Stoker, B. (1991). *Data Envelopment Analysis: The Assessment of Performance* (p. 262). John Wiley and Sons.

OFM. (2009). *Performance Measure Guide* (p. 27). Washington.

Pasupathy, K. S. (2002). Modeling Undesirable Outputs in Data Envelopment Analysis : Various Approaches*, Master Thesis, Virginia Polytechnic Institute and State University*. p.119. Blacksburg.

Puig-Junoy, J. (2000). Partitioning Input Cost Efficiency into its Allocative and Technical Components: An Empirical DEA Application to Hospitals. *Socio-Economic Planning Sciences*, *34*(3), 199–218.

Ramanathan, R. (2003). *An Introduction to Data Envelopment Analysis, A Tool for Performance Measurement* (p. 201). New Delhi.

Ramanathan, R. (2006). Data Envelopment Analysis for Weight Derivation and Aggregation in the Analytic Hierarchy Process. *Computers & Operations Research*, *33*(5), 1289–1307.

Ray, S. C. (2004). *Data Envelopment Analysis Theory and Techniques for Economics and Operations Research*. *Management Science* (p. 340). Cambridge.

Roll, Y., & Wade, D. (1991). Controlling Factor Weights in Data Envelopment Analysis. *IIE Transactions*, *23*(1), 2–9.

Saaty, T. L. (1980). *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation* (p. 287). McGraw Hill International.

Saaty, T. L. (1990). How to Make a Decision: The Analytic Hierarchy Process. *European Journal of Operational Research*, *48*(1), 9–26.

Saaty, T. L. (2008). Decision Making with the Analytic Hierarchy Process. *International Journal of Services Sciences*, *1*(1), 83.

Sala-Garrido, R., Hernández-Sancho, F., & Molinos-Senante, M. (2012). Assessing the Efficiency of Wastewater Treatment Plants in an Uncertain Context: A DEA with Tolerances Approach. *Environmental Science & Policy*, *18*, 34–44.

Sarkar, D., Bhattacharjee, A., & Kumar, N. (2003). Performance Evaluation of Underground Coal Mines: A Case Study. *Proceeding of 19th World Mining Congress* (pp. 917–928). New Delhi.

Seiford, L. M., & Zhu, J. (2002). Modeling Undesirable Factors in Efficiency Evaluation. *European Journal of Operational Research*, *142*(1), 16–20.

Sevkli, M., Koh, S. C. L., Zaim, S., Demirbağ, M., & Tatoğlu, E. (2007). An Application of Data Envelopment Analytic Hierarchy Process for Supplier Selection: A Case Study of BEKO in Turkey. *International Journal of Production Research*, *45*(9), 1973–2003.

Sgourou, E., Katsakiori, P., Goutsos, S., & Manatakis, E. (2010). Assessment of Selected Safety Performance Evaluation Methods in Regards to their Conceptual, Methodological and Practical Characteristics. *Safety Science*, *48*(8), 1019–1025.

Sowlati, T. (2001). Establishing the Practical Frontier in Data Envelopment Analysis, *Ph.D. Thesis, University of Toronto*. p.151. Toronto.

Thanassoulis, E., Boussofiane, A., & Dyson, R. G. (1995). Exploring Output Quality Targets in the Provision of Perinatal Care in England using Data Envelopment Analysis. *European Journal of Operational Research*, *80*(3), 588–607.

Thompson, R. G., Singleton, F. D. J., Thrall, R. M., & Smith, B. A. (1986). Comperative Site Evaluations for Locating a High-Energy Physics Lab in Texas. *Interfaces*, *16*(6), 35–49.

Thompson, R. G., Langemeier, L. N., Lee, C., Lee, E., & R.M., T. (1990). The Role of Multiplier Bounds in Efficiency Analysis with Application to Kansas Farming. *Journal of Econometrics*, *46*(1-2), 93–108.

Thompson, R. G., Lee, E., & Thrall, R. M. (1992). DEA/AR-Efficiency of U.S. Independent Oil/Gas Producers Over Time. *Computers & Operations Research*, *19*(5), 377–391.

Thompson, R. G., Dharmapala, P. S., Rothenberg, L. J., & Thrall, R. M. (1994). DEA ARs and CRs Applied to Worldwide Major Oil Companies. *The Journal of Productivity Analysis*, *5*, 181–203.

Tong, L., & Ding, R. (2008). Efficiency Assessment of Coal Mine Safety Input by Data Envelopment Analysis. *Journal of China University of Mining and Technology*, *18*(1), 88–92.

Tsolas, I. (2008). Derivation of Mineral Processing Environmental Sustainability Indicators using a DEA Weight-Restricted Algorithm. *Mineral and Metallurgical Processing*, *25*(4), 199–205.

Tsolas, I. E. (2011). Performance Assessment of Mining Operations using Nonparametric Production Analysis: A Bootstrapping Approach in DEA. *Resources Policy*, *36*(2), 159–167.

TTK (2013). Official Webpage of Turkish Hard Coal Enterprise. http://www.taskomuru.gov.tr/index.php?page=sayfagoster&id=14. (Last Access Date: 13.01.2013)

Vaidya, O. (2006). Analytic Hierarchy Process: An Overview of Applications. *European Journal of Operational Research*, *169*(1), 1–29.

Vassiloglou, M., & Giokas, D. (1990). A Study of the Relative Efficiency of Bank Branches: An Application of Data Envelopment Analysis. *Journal of the Operational Research Society*, *41*(7), 591–597.

Wang, Y.-M., Chin, K.-S., & Poon, G. K. K. (2008). A Data Envelopment Analysis Method with Assurance Region for Weight Generation in the Analytic Hierarchy Process. *Decision Support Systems*, *45*(4), 913–921.

Wong, Y. H. B., & Beasley, J. E. (1990). Restricting Weight Flexibility in Data Envelopment Analysis. *Journal of the Operational Research Society*, *41*(9), 829–835.

Wu, J., An, Q., Ali, S., & Liang, L. (2012). DEA Based Resource Allocation Considering Environmental Factors. *Mathematical and Computer Modelling*, *in Press*(Corrected Proof).

Yang, T., & Kuo, C. (2003). A Hierarchical AHP/DEA Methodology for the Facilities Layout Design Problem. *European Journal of Operational Research*, *147*(1), 128–136.

Zhu, J. (1996). Data Envelopment Analysis with Preference Structure. *Journal of the Operational Research Society*, *47*(1), 136–150.

Zhu, J. (2009). *Quantitative Models for Performance Evaluation and Benchmarking, Data Envelopment Analysis with Spreadsheets*. *Operations Research* (p. 267). New York.

APPENDIX A

TURKISH HARD COAL ENTERPRISE (TTK)
OCCUPATIONAL HEALTH AND SAFETY (OHS) INPUTS EVALUATION

TAKING OHS EXPERTS' OPINION QUESTIONAIRE

Analytical Hierarchy Process (AHP) is frequently used for complex multi-criteria decision making method for solving problems. Despite the use of many different areas of discipline, AHP is not widely used in the field of Occupational Health and Safety (OHS) and mining.

With the increase of the use of AHP method in the field of OHS, management of OHS resources can be distributed better so it can prevent many accidents as a result.

AHP evaluation can be done on the basis of which are given by experts opinion. AHS experts that will arise as a result of the direct impact on responses of experts to questionnaires have an direct impact on the AHP results.

In this academic questionnaire study, importance weights of OHS inputs and ranking order of them are estimated for five establishment of TTK. In this way, a better manipulation of the OHS resources can be allocated.

Use of the method of AHP in an important area as OHS will provide many benefits, both in time and financially. To benefit from the advantages of the method, this questionnaire needs to be filled by people who specialize in this area.

As a result of the meeting, you have been selected an expert on OHS in TTK establishments.

To reach the desired goal of the study and obtain the best results for establishments of TTK, thank you for your interest and time.

Ömer ERDEM
Research Assistant

Advisor: Prof. Dr. Tevfik Güyagüler

EXPERT OPINION SURVEY QUESTIONNAIRE FOR DETERMINING THE IMPORTANCE WEIGHTS OF OHS INPUTS

This survey questionnaire is based on pairwise comparisons of OHS criteria for TTK establishments. As a result of these comparisons, inputs of TTK establishments can be ranked in order of importance.

A sample question is given below. Explanations of the digits are written on the odd numbers. Importance degree of the even numbers represents the intermediate values. Please, select the criteria that you think it is superior to the pairwise comparisons and mark the importance degree of your selection.

SAMPLE ANSWERING

**We think that Criterion A is “much more important” than Criterion B.*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Criterion A	9	8	7	6	[✓ 5]	4	3	2	1	2	3	4	5	6	7	8	9	*Criterion B*

PART 1: Pairwise Comparison of Determined OHS Criterions to Evaluate OHS Inputs

*Please, make a pairwise comparison between the OHS criterions. This comparison must be conducted based on OHS situation of TTK establishments.

Which criterion is more important for TTK establishments?

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Accident Cost*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Lost Day Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Number of Death Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Lost Day Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Death Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Death Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Injured Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

*** THIS IS THE END OF PART 1 ***

*** PLEASE, CONTINUE WITH PART 2 ***

PART 2: Pairwise Comparison of Determined OHS Criterions to Evaluate OHS Inputs

2.1. Please make a pairwise comparison with regarding **Annual Accident Numbers** in TTK establishments.

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Number of OHS Staff*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Expenditures*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Expenditures*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Expenditures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Expenditures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Education Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

*** This is the end of 2.1 ***

2.2. Please make a pairwise comparison with regarding **Annual Accident Costs** in TTK establishments.

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Number of OHS Staff*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Expenditures*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Expenditures*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Expenditures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Expenditures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Education Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

*** This is the end of 2.2 ***

2.3. Please make a pairwise comparison with regarding **Annual Number of Lost Day** in TTK establishments.

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Number of OHS Staff*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Expenditures*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Expenditures*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Expenditures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Expenditures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Education Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

*** This is the end of 2.3 ***

2.4. Please make a pairwise comparison with regarding **Annual Death Worker Number** in TTK establishments.

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Number of OHS Staff*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Expenditures*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Expenditures*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Expenditures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Expenditures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Education Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

*** This is the end of 2.4 ***

2.5. Please make a pairwise comparison with regarding **Annual Injured Worker Number** in TTK establishments.

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Number of OHS Staff*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Expenditures*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Expenditures*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Expenditures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Expenditures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Education Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

*** This is the end of 2.5 ***

2.6. Please make a pairwise comparison with regarding **ROM Coal Production** in TTK establishments.

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Number of OHS Staff*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Expenditures*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Expenditures*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Number of OHS Staff	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Expenditures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Expenditures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Education Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

*** This is the end of 2.6 and Input Evaluation Questionnaire ***

*** Thank you for your time and consideration ***

APPENDIX B

TURKISH HARD COAL ENTERPRISE (TTK) OCCUPATIONAL HEALTH AND SAFETY (OHS) OUTPUTS EVALUATION

TAKING OHS EXPERTS' OPINION QUESTIONAIRE

Analytical Hierarchy Process (AHP) is frequently used for complex multi-criteria decision making method for solving problems. Despite the use of many different areas of discipline, AHP is not widely used in the field of Occupational Health and Safety (OHS) and mining.

With the increase of the use of AHP method in the field of OHS, management of OHS resources can be distributed better so it can prevent many accidents as a result.

AHP evaluation can be done on the basis of which are given by experts opinion. AHS experts that will arise as a result of the direct impact on responses of experts to questionnaires have a direct impact on the AHP results.

In this academic questionnaire study, importance weights of OHS outputs and ranking order of them are estimated for five establishment of TTK. In this way, a better manipulation of the OHS resources can be allocated.

Use of the method of AHP in an important area as OHS will provide many benefits, both in time and financially. To benefit from the advantages of the method, this questionnaire needs to be filled by people who specialize in this area.

As a result of the meeting, you have been selected an expert on OHS in TTK establishments.

To reach the desired goal of the study and obtain the best results for establishments of TTK, thank you for your interest and time.

Ömer ERDEM
Research Assistant

Advisor: Prof. Dr. Tevfik Güyagüler

EXPERT OPINION SURVEY QUESTIONNAIRE FOR DETERMINING THE IMPORTANCE WEIGHTS OF OHS OUTPUTS

This survey questionnaire is based on pairwise comparisons of OHS criteria for TTK establishments. As a result of these comparisons, outputs of TTK establishments can be ranked in order of importance.

A sample question is given below. Explanations of the digits are written on the odd numbers. Importance degree of the even numbers represents the intermediate values. Please, select the criteria that you think it is superior to the pairwise comparisons and mark the importance degree of your selection.

SAMPLE ANSWERING

**We think that Criterion A is "much more important" than Criterion B.*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Criterion A	9	8	7	6	[✓ 5]	4	3	2	1	2	3	4	5	6	7	8	9	*Criterion B*

PART 1: Pairwise Comparison of Determined OHS Criterions to Evaluate OHS Outputs

*Please, make a pairwise comparison between the OHS criterions. This comparison must be conducted based on which criterion is more effective on **Accident Occurrence** at TTK establishments.

Which criterion is more important for TTK establishments with regarding Accident Occurrence?

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*OHS Staff Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Expenditures*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
OHS Staff Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Expenditures*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
OHS Staff Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
OHS Staff Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Expenditures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual OHS Education Time*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Expenditures	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual OHS Education Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Effective Work Hour*

*** THIS IS THE END OF PART 1 ***

*** PLEASE, CONTINUE WITH PART 2 ***

PART 2: Pairwise Comparison of Determined OHS Criterions to Evaluate OHS Inputs

2.1. Please make a pairwise comparison with regarding **Worker Number** in TTK establishments. In other words, which criterion is more affected by **Worker Number**?

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Accident Cost*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Lost Day Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Lost Day Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Death Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Death Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Injured Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

*** This is the end of 2.1 ***

2.2. Please make a pairwise comparison with regarding **Number of OHS Staff** in TTK establishments. In other words, which criterion is more affected by **Number of OHS Staff**?

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Accident Cost*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Lost Day Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Lost Day Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Death Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Death Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Injured Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

*** This is the end of 2.2 ***

2.3. Please make a pairwise comparison with regarding **Annual OHS Expenditures** in TTK establishments. In other words, which criterion is more affected by **Annual OHS Expenditures**?

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Accident Cost*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Lost Day Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Lost Day Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Death Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Death Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Injured Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

*** This is the end of 2.3 ***

2.4. Please make a pairwise comparison with regarding **Annual OHS Education Time** in TTK establishments. In other words, which criterion is more affected by **Annual OHS Education Time**?

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Accident Cost*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Lost Day Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Lost Day Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Death Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Death Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Injured Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

*** This is the end of 2.4 ***

2.5. Please make a pairwise comparison with regarding **Annual Effective Work Hour** in TTK establishments. In other words, which criterion is more affected by **Annual Effective Work Hour**?

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Accident Cost*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Lost Day Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Lost Day Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Accident Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Death Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Lost Day Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Death Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*Annual Injured Worker Number*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Death Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

	Absolutely More Important		Very Much More Important		Much More Important		Somewhat More Important		Equal Importance		Somewhat More Important		Much More Important		Very Much More Important		Absolutely More Important	
Annual Injured Worker Number	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	*ROM Coal Production*

*** This is the end of 2.4 and Output Evaluation Questionnaire. Thank you for your time and consideration ***

APPENDIX C

DEA RESULTS

Results of Data Envelopment Analyses are given in the following tables. In these tables target values for inefficient firms can also be obtained. These target values are named as slack variable in these tables.

1. DEA Results used to Estimate IO-AHP.DEA Scores

1.1 For 2007

Table 69 Estimation Input: Annual Effective Work Hour, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (Effective Work Hour)	Slack Movement (Effective Work Hour)	Projection (Effective Work Hour)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	0,961	ARMUTCUK(0,455); KOZLU(0,071)	0	656	-12,852	643,148	1558942	-81007,422	1477934,578	194739	0	194739	1639	0	1639
2	ARMUTCUK	1	ARMUTCUK(1,000)	2	1172	0	1172	2686725	0	2686725	342149	0	342149	154	0	154
3	KARADON	0,775	KOZLU(1,458)	0	2964	-683,944	2280,056	6804630	-1504177,862	5300452,138	809726	0	809726	33024	-638,167	32385,833
4	KOZLU	1	KOZLU(1,000)	3	1564	0	1564	3635835	0	3635835	555430	0	555430	22215	0	22215
5	ÜZÜLMEZ	0,849	ARMUTCUK(0,354); KOZLU(0,721)	0	1833	-290,292	1542,708	4185435	-612475,155	3572959,845	521675	0	521675	16080	0	16080

Table 70 Estimation Input: Annual OHS Education Time, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	0,493	ARMUTCUK(0,516); KOZLU(0,033)	0	656	0	656	315	-198,262	116,738	194739	0	194739	1639	-833,795	805,205
2	ARMUTCUK	1	ARMUTCUK(1,000)	3	1172	0	1172	192	0	192	342149	0	342149	154	0	154
3	KARADON	0,908	ARMUTCUK(2,367)	0	2964	-190,358	2773,642	504	-49,615	454,385	809726	0	809726	33024	-32659,545	364,455
4	KOZLU	1	KOZLU(1,000)	1	1564	0	1564	540	0	540	555430	0	555430	22215	0	22215
5	ÜZÜLMEZ	0,476	ARMUTCUK(1,525)	0	1833	-46,05	1786,95	823	-530,257	292,743	521675	0	521675	16080	-15845,196	234,804

Table 71 Estimation Input: Annual OHS Expenditure, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Expenditures)	Slack Movement (OHS Expenditures)	Projection (OHS Expenditures)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	0	656	0	656	131505,609857125	0	131505,61	194739	0	194739	1639	0	1639
2	ARMUTCUK	1	ARMUTCUK(1,000)	0	1172	0	1172	315616,255171572	0	315616,255	342149	0	342149	154	0	154
3	KARADON	0,796	ÜZÜLMEZ(1,552)	0	2964	-118,88	2845,12	637821,583317865	-170734,4	467087,184	809726	0	809726	33024	-8065,177	24958,823
4	KOZLU	1	KOZLU(1,000)	0	1564	0	1564	453989,967891073	0	453989,968	555430	0	555430	22215	0	22215
5	ÜZÜLMEZ	1	ÜZÜLMEZ(1,000)	1	1833	0	1833	300926,123762364	0	300926,124	521675	0	521675	16080	0	16080

Table 72 Estimation Input: Number of OHS Staff, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Staff Number)	Slack Movement (OHS Staff Number)	Projection (OHS Staff Number)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	0,786	ARMUTCUK(0,455); KOZLU(0,071)	0	656	-12,852	643,148	46	-22,934	23,066	194739	0	194739	1639	0	1639
2	ARMUTCUK	1	ARMUTCUK(1,000)	1	1172	0	1172	45	0	45	342149	0	342149	154	0	154
3	KARADON	0,585	KOZLU(1,458)	0	2964	-683,944	2280,056	170	-116,06	53,94	809726	0	809726	33024	-638,167	32385,833
4	KOZLU	1	KOZLU(1,000)	2	1564	0	1564	37	0	37	555430	0	555430	22215	0	22215
5	ÜZÜLMEZ	1	ÜZÜLMEZ(1,000)	0	1833	0	1833	39	0	39	521675	0	521675	16080	0	16080

1.2 For 2008

Table 73 Estimation Input: Annual Effective Work Hour, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (Effective Work Hour)	Slack Movement (Effective Work Hour)	Projection (Effective Work Hour)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	0	587	0	587	1415925	0	1415925	203073	0	203073	1607	0	1607
2	ARMUTCUK	0,858	KOZLU(0,642)	0	1062	-157,375	904,625	2445840	-335378,583	2110461,417	332485	0	332485	9758	-1197,424	8560,576
3	KARADON	0,826	KOZLU(1,572)	0	2737	-520,041	2216,959	6178965	-1006869,833	5172095,167	814819	0	814819	34251	-13271,647	20979,353
4	KOZLU	1	KOZLU(1,000)	3	1410	0	1410	3289485	0	3289485	518230	0	518230	13343	0	13343
5	ÜZÜLMEZ	0,773	KOZLU(0,901)	0	1667	-396,795	1270,205	3799815	-836466,54	2963348,46	466850	0	466850	30816	-18795,894	12020,106

Table 74 Estimation Input: Annual OHS Education Time, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	0	587	0	587	327	0	327	203073	0	203073	1607	0	1607
2	ARMUTCUK	1	ARMUTCUK(1,000)	2	1062	0	1062	162	0	162	332485	0	332485	9758	0	9758
3	KARADON	0,767	ARMUTCUK(2,451)	0	2737	-134,363	2602,637	549	-151,988	397,012	814819	0	814819	34251	-10337,128	23913,872
4	KOZLU	1	KOZLU(1,000)	0	1410	0	1410	567	0	567	518230	0	518230	13343	0	13343
5	ÜZÜLMEZ	0,397	ARMUTCUK(1,404)	0	1667	-175,821	1491,179	823	-595,532	227,468	466850	0	466850	30816	-17114,563	13701,437

Table 75 Estimation Input: Annual OHS Expenditure, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Expenditure)	Slack Movement (OHS Expenditure)	Projection (OHS Expenditure)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	0	587	0	587	118070,2166689	0	118070,217	203073	0	203073	1607	0	1607
2	ARMUTCUK	0,854	KOZLU(0,642)	0	1062	-157,375	904,625	213612,555540667	-31133,068	182479,487	332485	0	332485	9758	-1197,424	8560,576
3	KARADON	0,812	KOZLU(1,572)	0	2737	-520,041	2216,959	550525,013667426	-103323,626	447201,387	814819	0	814819	34251	-13271,647	20979,353
4	KOZLU	1	KOZLU(1,000)	3	1410	0	1410	284422,890124615	0	284422,89	518230	0	518230	13343	0	13343
5	ÜZÜLMEZ	0,764	KOZLU(0,901)	0	1667	-396,795	1270,205	335303,323998392	-79079,589	256223,735	466850	0	466850	30816	-18795,894	12020,106

Table 76 Estimation Input: Number of OHS Staff, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Staff Number)	Slack Movement (OHS Staff Number)	Projection (OHS Staff Number)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	0	587	0	587	46	0	46	203073	0	203073	1607	0	1607
2	ARMUTCUK	0,855	KOZLU(0,642)	0	1062	-157,375	904,625	41	-5,713	35,287	332485	0	332485	9758	-1197,424	8560,576
3	KARADON	0,681	KOZLU(1,572)	0	2737	-520,041	2216,959	175	-88,523	86,477	814819	0	814819	34251	-13271,647	20979,353
4	KOZLU	1	KOZLU(1,000)	2	1410	0	1410	55	0	55	518230	0	518230	13343	0	13343
5	ÜZÜLMEZ	1	ÜZÜLMEZ(1,000)	0	1667	0	1667	44	0	44	466850	0	466850	30816	0	30816

1.3 For 2009

Table 77 Estimation Input: Annual Effective Work Hour, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (Effective Work Hour)	Slack Movement (Effective Work Hour)	Projection (Effective Work Hour)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	1	650	0	650	1568047	0	1568047	239598	0	239598	2663	0	2663
2	ARMUTCUK	1	ARMUTCUK(1,000)	0	1110	0	1110	2608267	0	2608267	326820	0	326820	2625	0	2625
3	KARADON	0,87	KOZLU(1,597)	0	3220	-422,27	2797,73	7613512	-978604,62	6634907,38	1043879	0	1043879	52514	-13337,798	39176,202
4	KOZLU	1	KOZLU(1,000)	2	1752	0	1752	4154925	0	4154925	653700	0	653700	24533	0	24533
5	ÜZÜLMEZ	0,836	AMASRA(1,625); KOZLU(0,275)	0	1887	-348,595	1538,405	4341637	-650105,328	3691531,672	569246	0	569246	11077	0	11077

Table 78 Estimation Input: Annual OHS Education Time, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	0	650	0	650	327	0	327	239598	0	239598	2663	0	2663
2	ARMUTCUK	1	ARMUTCUK(1,000)	1	1110	0	1110	315	0	315	326820	0	326820	2625	0	2625
3	KARADON	1	KARADON(1,000)	0	3220	0	3220	828	0	828	1043879	0	1043879	52514	0	52514
4	KOZLU	1	KOZLU(1,000)	1	1752	0	1752	543	0	543	653700	0	653700	24533	0	24533
5	ÜZÜLMEZ	0,748	ARMUTCUK(1,067); KOZLU(0,337)	0	1887	-111,579	1775,421	741	-221,71	519,29	569246	0	569246	11077	0	11077

Table 79 Estimation Input: Annual OHS Expenditure, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Expenditure)	Slack Movement (OHS Expenditure)	Projection (OHS Expenditure)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	2	650	0	650	107903,016591252	0	107903,017	239598	0	239598	2663	0	2663
2	ARMUTCUK	1	ARMUTCUK(1,000)	0	1110	0	1110	184265,151409676	0	184265,151	326820	0	326820	2625	0	2625
3	KARADON	0,879	AMASRA(4,357)	0	3220	-388,084	2831,916	534534,943728971	-64423,786	470111,157	1043879	0	1043879	52514	-40911,859	11602,141
4	KOZLU	1	KOZLU(1,000)	0	1752	0	1752	364997,100873651	0	364997,101	653700	0	653700	24533	0	24533
5	ÜZÜLMEZ	0,818	AMASRA(2,376)	0	1887	-342,705	1544,295	313250,75739645	-56890,685	256360,072	569246	0	569246	11077	-4750,144	6326,856

Table 80 Estimation Input: Number of OHS Staff, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Staff Number)	Slack Movement (OHS Staff Number)	Projection (OHS Staff Number)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	0	650	0	650	42	0	42	239598	0	239598	2663	0	2663
2	ARMUTCUK	1	ARMUTCUK(1,000)	0	1110	0	1110	40	0	40	326820	0	326820	2625	0	2625
3	KARADON	0,743	KOZLU(1,597)	0	3220	-422,27	2797,73	180	-79,397	100,603	1043879	0	1043879	52514	-13337,798	39176,202
4	KOZLU	1	KOZLU(1,000)	1	1752	0	1752	63	0	63	653700	0	653700	24533	0	24533
5	ÜZÜLMEZ	1	ÜZÜLMEZ(1,000)	0	1887	0	1887	45	0	45	569246	0	569246	11077	0	11077

1.4 For 2010

Table 81 Estimation Input: Annual Effective Work Hour, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (Effective Work Hour)	Slack Movement (Effective Work Hour)	Projection (Effective Work Hour)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	4	643	0	643	1454882	0	1454882	287630	0	287630	2619	0	2619
2	ARMUTCUK	0,537	AMASRA(0,923)	0	1110	-516,268	593,732	2496472	-1153067,052	1343404,948	265591	0	265591	4827	-2408,675	2418,325
3	KARADON	0,663	AMASRA(3,148)	0	3065	-1040,984	2024,016	6895462	-2315828,517	4579633,483	905393	0	905393	36795	-28550,991	8244,009
4	KOZLU	0,875	AMASRA(2,375)	0	1752	-224,811	1527,189	3941670	-486179,828	3455490,172	683150	0	683150	17091	-10870,613	6220,387
5	ÜZÜLMEZ	0,736	AMASRA(2,036)	0	1789	-479,773	1309,227	4011585	-1049266,593	2962318,407	585650	0	585650	24937	-19604,394	5332,606

Table 82 Estimation Input: Annual OHS Education Time, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	1	643	0	643	264	0	264	287630	0	287630	2619	0	2619
2	ARMUTCUK	0,813	AMASRA(0,397); KOZLU(0,222)	0	1110	-466,456	643,544	255	-33,17	221,83	265591	0	265591	4827	0	4827
3	KARADON	0,657	KOZLU(1,325)	0	3065	-743,038	2321,962	1107	-407,231	699,769	905393	0	905393	36795	-14143,94	22651,06
4	KOZLU	1	KOZLU(1,000)	3	1752	0	1752	528	0	528	683150	0	683150	17091	0	17091
5	ÜZÜLMEZ	0,762	KOZLU(0,857)	0	1789	-287,048	1501,952	609	-156,357	452,643	585650	0	585650	24937	-10285,248	14651,752

Table 83 Estimation Input: Annual OHS Expenditure, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Expenditure)	Slack Movement (OHS Expenditure)	Projection (OHS Expenditure)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	4	643	0	643	88359,3846153846	0	88359,385	287630	0	287630	2619	0	2619
2	ARMUTCUK	0,535	AMASRA(0,923)	0	1110	-516,268	593,732	152533,307811939	-70944,262	81589,046	265591	0	265591	4827	-2408,675	2418,325
3	KARADON	0,66	AMASRA(3,148)	0	3065	-1040,984	2024,016	421184,313913147	-143049,32	278134,994	905393	0	905393	36795	-28550,991	8244,009
4	KOZLU	0,872	AMASRA(2,375)	0	1752	-224,811	1527,189	240755,275032899	-30892,905	209862,37	683150	0	683150	17091	-10870,613	6220,387
5	ÜZÜLMEZ	0,732	AMASRA(2,036)	0	1789	-479,773	1309,227	245839,71862663	-65929,161	179910,557	585650	0	585650	24937	-19604,394	5332,606

Table 84 Estimation Input: Number of OHS Staff, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Staff Number)	Slack Movement (OHS Staff Number)	Projection (OHS Staff Number)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	2	643	0	643	36	0	36	287630	0	287630	2619	0	2619
2	ARMUTCUK	0,626	AMASRA(0,397); KOZLU(0,222)	0	1110	-466,456	643,544	43	-13,194	29,806	265591	0	265591	4827	0	4827
3	KARADON	0,634	AMASRA(3,148)	0	3065	-1040,984	2024,016	190	-76,68	113,32	905393	0	905393	36795	-28550,991	8244,009
4	KOZLU	1	KOZLU(1,000)	1	1752	0	1752	70	0	70	683150	0	683150	17091	0	17091
5	ÜZÜLMEZ	1	ÜZÜLMEZ(1,000)	0	1789	0	1789	46	0	46	585650	0	585650	24937	0	24937

1.5 For 2011

Table 85 Estimation Input: Annual Effective Work Hour, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (Effective Work Hour)	Slack Movement (Effective Work Hour)	Projection (Effective Work Hour)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	3	644	0	644	1423582	0	1423582	289880	0	289880	3232	0	3232
2	ARMUTCUK	0,489	AMASRA(0,869)	0	1144	-584,632	559,368	2524365	-1287865,09	1236499,91	251785	0	251785	4191	-1383,738	2807,262
3	KARADON	0,598	AMASRA(2,770)	0	2838	-1053,899	1784,101	6835770	-2891959,713	3943810,287	803067	0	803067	24188	-15234,252	8953,748
4	KOZLU	1	KOZLU(1,000)	0	1702	0	1702	3842332	0	3842332	691150	0	691150	7436	0	7436
5	ÜZÜLMEZ	0,73	AMASRA(1,971)	0	1801	-531,795	1269,205	3753292	-947674,515	2805617,485	571300	0	571300	32936	-26566,324	6369,676

Table 86 Estimation Input: Annual OHS Education Time, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	0	644	0	644	249	0	249	289880	0	289880	3232	0	3232
2	ARMUTCUK	0,739	KOZLU(0,364)	0	1144	-523,964	620,036	261	-55,536	205,464	251785	0	251785	4191	-1482,075	2708,925
3	KARADON	0,609	KOZLU(1,162)	0	2838	-860,397	1977,603	1116	-460,672	655,328	803067	0	803067	24188	-15547,898	8640,102
4	KOZLU	1	KOZLU(1,000)	3	1702	0	1702	564	0	564	691150	0	691150	7436	0	7436
5	ÜZÜLMEZ	0,721	KOZLU(0,827)	0	1801	-394,138	1406,862	660	-193,801	466,199	571300	0	571300	32936	-26789,452	6146,548

Table 87 Estimation Input: Annual OHS Expenditure, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Expenditure)	Slack Movement (OHS Expenditure)	Projection (OHS Expenditure)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	1	644	0	644	322004,200516669	0	322004,201	289880	0	289880	3232	0	3232
2	ARMUTCUK	0,553	KOZLU(0,364)	0	1144	-523,964	620,036	480940,374830853	-213200,151	267740,224	251785	0	251785	4191	-1482,075	2708,925
3	KARADON	0,606	AMASRA(2,770)	0	2838	-1053,899	1784,101	1494186,64140731	-602124,591	892062,051	803067	0	803067	24188	-15234,252	8953,748
4	KOZLU	1	KOZLU(1,000)	2	1702	0	1702	734947,101365482	0	734947,101	691150	0	691150	7436	0	7436
5	ÜZÜLMEZ	0,922	KOZLU(0,827)	0	1801	-394,138	1406,862	621292,68187969	-13790,289	607502,393	571300	0	571300	32936	-26789,452	6146,548

Table 88 Estimation Input: Number of OHS Staff, Defined Input: Number of Worker, Defined Outputs: ROM Coal Production and Annual Lost Work Day

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Staff Number)	Slack Movement (OHS Staff Number)	Projection (OHS Staff Number)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	0	644	0	644	47	0	47	289880	0	289880	3232	0	3232
2	ARMUTCUK	0,581	KOZLU(0,319); ÜZÜLMEZ(0,055)	0	1144	-502,159	641,841	49	-19,058	29,942	251785	0	251785	4191	0	4191
3	KARADON	0,625	KOZLU(1,162)	0	2838	-860,397	1977,603	192	-92,074	99,926	803067	0	803067	24188	-15547,898	8640,102
4	KOZLU	1	KOZLU(1,000)	2	1702	0	1702	86	0	86	691150	0	691150	7436	0	7436
5	ÜZÜLMEZ	1	ÜZÜLMEZ(1,000)	1	1801	0	1801	46	0	46	571300	0	571300	32936	0	32936

2. DEA Results used to Estimate OO-AHP.DEA Scores

2.1 For 2007

Table 89 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Death Worker Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Death Worker Number)	Slack Movement (Death Worker Number)	Projection (Death Worker Number)
1	AMASRA	1	AMASRA(1,000)	2	656	0	656	315	0	315	194739	0	194739	0,0000000001	0	0
2	ARMUTCUK	1	ARMUTCUK(1,000)	2	1172	0	1172	192	0	192	342149	0	342149	0,0000000001	0	0
3	KARADON	0,537	AMASRA(0,089); ARMUTCUK(2,479)	0	2964	0	2964	504	0	504	809726	55859,076	865585,076	2	-2	0
4	KOZLU	1	KOZLU(1,000)	0	1564	0	1564	540	0	540	555430	0	555430	2	0	2
5	ÜZÜLMEZ	0,538	AMASRA(2,519); ARMUTCUK(0,154)	0	1833	0	1833	823	0	823	521675	21576,553	543251,553	1	-1	0

Table 90 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Lost Day Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	0,702	ARMUTCUK(0,516); KOZLU(0,033)	0	656	0	656	315	-198,262	116,738	194739	0	194739	1639	-833,795	805,205
2	ARMUTCUK	1	ARMUTCUK(1,000)	3	1172	0	1172	192	0	192	342149	0	342149	154	0	154
3	KARADON	0,545	ARMUTCUK(2,529)	0	2964	0	2964	504	-18,43	485,57	809726	55572,324	865298,324	33024	-32634,532	389,468
4	KOZLU	1	KOZLU(1,000)	1	1564	0	1564	540	0	540	555430	0	555430	22215	0	22215
5	ÜZÜLMEZ	0,548	ARMUTCUK(1,564)	0	1833	0	1833	823	-522,713	300,287	521675	13443,701	535118,701	16080	-15839,145	240,855

Table 91 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Accident Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Accident Number)	Slack Movement (Accident Number)	Projection (Accident Number)
1	AMASRA	0,881	KOZLU(0,073); ÜZÜLMEZ(0,296)	0	656	0	656	315	-32,286	282,714	194739	0	194739	141	-25,37	115,63
2	ARMUTCUK	1	ARMUTCUK(1,000)	1	1172	0	1172	192	0	192	342149	0	342149	249	0	249
3	KARADON	0,775	ARMUTCUK(2,224); ÜZÜLMEZ(0,094)	0	2964	-186,049	2777,951	504	0	504	809726	0	809726	951	-370,201	580,799
4	KOZLU	1	KOZLU(1,000)	1	1564	0	1564	540	0	540	555430	0	555430	414	0	414
5	ÜZÜLMEZ	1	ÜZÜLMEZ(1,000)	2	1833	0	1833	823	0	823	521675	0	521675	289	0	289

Table 92 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Accident Cost, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Accident Cost)	Slack Movement (Accident Cost)	Projection (Accident Cost)
1	AMASRA	0,759	ARMUTCUK(0,516); KOZLU(0,033)	0	656	0	656	315	-198,262	116,738	194739	0	194739	319914,8	-136554,374	183360,426
2	ARMUTCUK	1	ARMUTCUK(1,000)	3	1172	0	1172	192	0	192	342149	0	342149	302636,78	0	302636,78
3	KARADON	0,675	ARMUTCUK(2,367)	0	2964	-190,358	2773,642	504	-49,615	454,385	809726	0	809726	2020616,93	-1304400,108	716216,822
4	KOZLU	1	KOZLU(1,000)	1	1564	0	1564	540	0	540	555430	0	555430	831386,44	0	831386,44
5	ÜZÜLMEZ	0,655	ARMUTCUK(1,564)	0	1833	0	1833	823	-522,713	300,287	521675	13443,701	535118,701	1576788,08	-1103466,222	473321,858

Table 93 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Injured Worker Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Injured Worker Number)	Slack Movement (Injured Worker Number)	Projection (Injured Worker Number)
1	AMASRA	0,882	KOZLU(0,073); ÜZÜLMEZ(0,296)	0	656	0	656	315	-32,286	282,714	194739	0	194739	141	-25,811	115,189
2	ARMUTCUK	1	ARMUTCUK(1,000)	1	1172	0	1172	192	0	192	342149	0	342149	249	0	249
3	KARADON	0,778	ARMUTCUK(2,224); ÜZÜLMEZ(0,094)	0	2964	-186,049	2777,951	504	0	504	809726	0	809726	949	-368,295	580,705
4	KOZLU	1	KOZLU(1,000)	1	1564	0	1564	540	0	540	555430	0	555430	412	0	412
5	ÜZÜLMEZ	1	ÜZÜLMEZ(1,000)	2	1833	0	1833	823	0	823	521675	0	521675	288	0	288

2.2 For 2008

Table 94 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Death Worker Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Death Worker Number)	Slack Movement (Death Worker Number)	Projection (Death Worker Number)
1	AMASRA	1	AMASRA(1,000)	1	587	0	587	327	0	327	203073	0	203073	0,0000000001	0	0
2	ARMUTCUK	1	ARMUTCUK(1,000)	0	1062	0	1062	162	0	162	332485	0	332485	1	0	1
3	KARADON	1	KARADON(1,000)	0	2737	0	2737	549	0	549	814819	0	814819	2	0	2
4	KOZLU	1	KOZLU(1,000)	0	1410	0	1410	567	0	567	518230	0	518230	1	0	1
5	ÜZÜLMEZ	0,536	AMASRA(2,517)	0	1667	-189,627	1477,373	823	0	823	466850	44248,101	511098,101	3	-3	0

Table 95 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Lost Day Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	2	587	0	587	327	0	327	203073	0	203073	1607	0	1607
2	ARMUTCUK	1	ARMUTCUK(1,000)	1	1062	0	1062	162	0	162	332485	0	332485	9758	0	9758
3	KARADON	0,756	AMASRA(0,666); ARMUTCUK(2,044)	0	2737	-175,444	2561,556	549	0	549	814819	0	814819	34251	-13238,146	21012,854
4	KOZLU	1	KOZLU(1,000)	0	1410	0	1410	567	0	567	518230	0	518230	13343	0	13343
5	ÜZÜLMEZ	0,575	AMASRA(2,517)	0	1667	-189,627	1477,373	823	0	823	466850	44248,101	511098,101	30816	-26771,471	4044,529

Table 96 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Accident Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Accident Number)	Slack Movement (Accident Number)	Projection (Accident Number)
1	AMASRA	0,867	KOZLU(0,392)	0	587	-34,479	552,521	327	-104,816	222,184	203073	0	203073	138	-28,28	109,72
2	ARMUTCUK	1	ARMUTCUK(1,000)	1	1062	0	1062	162	0	162	332485	0	332485	187	0	187
3	KARADON	0,721	ARMUTCUK(1,697); KOZLU(0,483)	0	2737	-252,906	2484,094	549	0	549	814819	0	814819	938	-485,263	452,737
4	KOZLU	1	KOZLU(1,000)	3	1410	0	1410	567	0	567	518230	0	518230	280	0	280
5	ÜZÜLMEZ	0,834	KOZLU(0,901)	0	1667	-396,795	1270,205	823	-312,215	510,785	466850	0	466850	344	-91,761	252,239

Table 97 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Accident Cost, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Accident Cost)	Slack Movement (Accident Cost)	Projection (Accident Cost)
1	AMASRA	0,705	ARMUTCUK(0,219); KOZLU(0,251)	0	587	0	587	327	-149,023	177,977	203073	0	203073	652534,9	-367030,626	285504,274
2	ARMUTCUK	1	ARMUTCUK(1,000)	3	1062	0	1062	162	0	162	332485	0	332485	265872,33	0	265872,33
3	KARADON	0,69	ARMUTCUK(2,451)	0	2737	-134,363	2602,637	549	-151,988	397,012	814819	0	814819	1639348,65	-987776,922	651571,728
4	KOZLU	1	KOZLU(1,000)	1	1410	0	1410	567	0	567	518230	0	518230	904329,27	0	904329,27
5	ÜZÜLMEZ	0,653	ARMUTCUK(1,570)	0	1667	0	1667	823	-568,712	254,288	466850	55045,005	521895,005	1274380,8	-857046,361	417334,439

Table 98 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Injured Worker Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Injured Worker Number)	Slack Movement (Injured Worker Number)	Projection (Injured Worker Number)
1	AMASRA	0,868	KOZLU(0,392)	0	587	-34,479	552,521	327	-104,816	222,184	203073	0	203073	138	-28,671	109,329
2	ARMUTCUK	1	ARMUTCUK(1,000)	1	1062	0	1062	162	0	162	332485	0	332485	186	0	186
3	KARADON	0,724	ARMUTCUK(1,697); KOZLU(0,483)	0	2737	-252,906	2484,094	549	0	549	814819	0	814819	936	-485,443	450,557
4	KOZLU	1	KOZLU(1,000)	3	1410	0	1410	567	0	567	518230	0	518230	279	0	279
5	ÜZÜLMEZ	0,836	KOZLU(0,901)	0	1667	-396,795	1270,205	823	-312,215	510,785	466850	0	466850	343	-91,662	251,338

2.3 For 2009

Table 99 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Death Worker Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Death Worker Number)	Slack Movement (Death Worker Number)	Projection (Death Worker Number)
1	AMASRA	1	AMASRA(1,000)	0	650	0	650	327	0	327	239598	0	239598	0,0000000001	0	0
2	ARMUTCUK	1	ARMUTCUK(1,000)	0	1110	0	1110	315	0	315	326820	0	326820	0,0000000001	0	0
3	KARADON	1	KARADON(1,000)	0	3220	0	3220	828	0	828	1043879	0	1043879	4	0	4
4	KOZLU	1	KOZLU(1,000)	0	1752	0	1752	543	0	543	653700	0	653700	1	0	1
5	ÜZÜLMEZ	1	ÜZÜLMEZ(1,000)	0	1887	0	1887	741	0	741	569246	0	569246	0,0000000001	0	0

Table 100 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Lost Day Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	1	650	0	650	327	0	327	239598	0	239598	2663	0	2663
2	ARMUTCUK	1	ARMUTCUK(1,000)	1	1110	0	1110	315	0	315	326820	0	326820	2625	0	2625
3	KARADON	1	KARADON(1,000)	0	3220	0	3220	828	0	828	1043879	0	1043879	52514	0	52514
4	KOZLU	1	KOZLU(1,000)	0	1752	0	1752	543	0	543	653700	0	653700	24533	0	24533
5	ÜZÜLMEZ	0,678	AMASRA(0,283); ARMUTCUK(1,534)	0	1887	0	1887	741	-165,141	575,859	569246	0	569246	11077	-6295,734	4781,266

Table 101 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Accident Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Accident Number)	Slack Movement (Accident Number)	Projection (Accident Number)
1	AMASRA	1	AMASRA(1,000)	1	650	0	650	327	0	327	239598	0	239598	211	0	211
2	ARMUTCUK	1	ARMUTCUK(1,000)	1	1110	0	1110	315	0	315	326820	0	326820	231	0	231
3	KARADON	1	KARADON(1,000)	0	3220	0	3220	828	0	828	1043879	0	1043879	1867	0	1867
4	KOZLU	1	KOZLU(1,000)	0	1752	0	1752	543	0	543	653700	0	653700	624	0	624
5	ÜZÜLMEZ	0,917	AMASRA(0,283); ARMUTCUK(1,534)	0	1887	0	1887	741	-165,141	575,859	569246	0	569246	471	-56,858	414,142

Table 102 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Accident Cost, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Accident Cost)	Slack Movement (Accident Cost)	Projection (Accident Cost)
1	AMASRA	0,675	KOZLU(0,367)	0	650	-7,847	642,153	327	-127,976	199,024	239598	0	239598	726084,82	-468645,052	257439,768
2	ARMUTCUK	0,815	KOZLU(0,500)	0	1110	-234,08	875,92	315	-43,525	271,475	326820	0	326820	504978,95	-153822,159	351156,791
3	KARADON	1	KARADON(1,000)	0	3220	0	3220	828	0	828	1043879	0	1043879	2518731,61	0	2518731,61
4	KOZLU	1	KOZLU(1,000)	3	1752	0	1752	543	0	543	653700	0	653700	702378,05	0	702378,05
5	ÜZÜLMEZ	0,757	KOZLU(0,871)	0	1887	-361,348	1525,652	741	-268,152	472,848	569246	0	569246	1075155,31	-463520,163	611635,147

Table 103 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Injured Worker Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Injured Worker Number)	Slack Movement (Injured Worker Number)	Projection (Injured Worker Number)
1	AMASRA	1	AMASRA(1,000)	1	650	0	650	327	0	327	239598	0	239598	211	0	211
2	ARMUTCUK	1	ARMUTCUK(1,000)	1	1110	0	1110	315	0	315	326820	0	326820	231	0	231
3	KARADON	1	KARADON(1,000)	0	3220	0	3220	828	0	828	1043879	0	1043879	1863	0	1863
4	KOZLU	1	KOZLU(1,000)	0	1752	0	1752	543	0	543	653700	0	653700	623	0	623
5	ÜZÜLMEZ	0,919	AMASRA(0,283); ARMUTCUK(1,534)	0	1887	0	1887	741	-165,141	575,859	569246	0	569246	471	-56,858	414,142

2.4 For 2010

Table 104 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Death Worker Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Death Worker Number)	Slack Movement (Death Worker Number)	Projection (Death Worker Number)
1	AMASRA	1	AMASRA(1,000)	3	643	0	643	264	0	264	287630	0	287630	0,0000000001	0	0
2	ARMUTCUK	0,939	AMASRA(0,923)	0	1110	-516,268	593,732	255	-11,228	243,772	265591	0	265591	0,0000000001	0	0
3	KARADON	0,526	AMASRA(4,193)	0	3065	-368,784	2696,216	1107	0	1107	905393	300691,886	1206084,886	2	-2	0
4	KOZLU	1	KOZLU(1,000)	0	1752	0	1752	528	0	528	683150	0	683150	1	0	1
5	ÜZÜLMEZ	0,534	AMASRA(2,307)	0	1789	-305,716	1483,284	609	0	609	585650	77860,114	663510,114	2	-2	0

Table 105 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Lost Day Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	3	643	0	643	264	0	264	287630	0	287630	2619	0	2619
2	ARMUTCUK	0,706	AMASRA(0,923)	0	1110	-516,268	593,732	255	-11,228	243,772	265591	0	265591	4827	-2408,675	2418,325
3	KARADON	0,607	AMASRA(3,148)	0	3065	-1040,984	2024,016	1107	-275,989	831,011	905393	0	905393	36795	-28550,991	8244,009
4	KOZLU	1	KOZLU(1,000)	0	1752	0	1752	528	0	528	683150	0	683150	17091	0	17091
5	ÜZÜLMEZ	0,604	AMASRA(2,036)	0	1789	-479,773	1309,227	609	-71,464	537,536	585650	0	585650	24937	-19604,394	5332,606

Table 106 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Accident Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Accident Number)	Slack Movement (Accident Number)	Projection (Accident Number)
1	AMASRA	1	AMASRA(1,000)	0	643	0	643	264	0	264	287630	0	287630	267	0	267
2	ARMUTCUK	0,824	KOZLU(0,116); ÜZÜLMEZ(0,318)	0	1110	-337,576	772,424	255	0	255	265591	0	265591	304	-86,638	217,362
3	KARADON	0,696	ÜZÜLMEZ(1,546)	0	3065	-299,273	2765,727	1107	-165,509	941,491	905393	0	905393	1726	-1008,673	717,327
4	KOZLU	1	KOZLU(1,000)	1	1752	0	1752	528	0	528	683150	0	683150	601	0	601
5	ÜZÜLMEZ	1	ÜZÜLMEZ(1,000)	2	1789	0	1789	609	0	609	585650	0	585650	464	0	464

Table 107 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Accident Cost, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Accident Cost)	Slack Movement (Accident Cost)	Projection (Accident Cost)
1	AMASRA	1	AMASRA(1,000)	2	643	0	643	264	0	264	287630	0	287630	95762,82	0	95762,82
2	ARMUTCUK	0,616	KOZLU(0,483)	0	1110	-263,864	846,136	255	0	255	265591	64339,398	329930,398	497572,64	-374796,805	122775,835
3	KARADON	0,661	AMASRA(4,193)	0	3065	-368,784	2696,216	1107	0	1107	905393	300691,886	1206084,886	943979,01	-542428,094	401550,916
4	KOZLU	1	KOZLU(1,000)	2	1752	0	1752	528	0	528	683150	0	683150	254218,2	0	254218,2
5	ÜZÜLMEZ	0,594	AMASRA(0,995); KOZLU(0,656)	0	1789	0	1789	609	0	609	585650	148640,563	734290,563	1531507,25	-1269470,838	262036,412

Table 108 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Injured Worker Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Injured Worker Number)	Slack Movement (Injured Worker Number)	Projection (Injured Worker Number)
1	AMASRA	1	AMASRA(1,000)	0	643	0	643	264	0	264	287630	0	287630	267	0	267
2	ARMUTCUK	0,826	KOZLU(0,116); ÜZÜLMEZ(0,318)	0	1110	-337,576	772,424	255	0	255	265591	0	265591	304	-87,072	216,928
3	KARADON	0,7	ÜZÜLMEZ(1,546)	0	3065	-299,273	2765,727	1107	-165,509	941,491	905393	0	905393	1724	-1008,219	715,781
4	KOZLU	1	KOZLU(1,000)	1	1752	0	1752	528	0	528	683150	0	683150	600	0	600
5	ÜZÜLMEZ	1	ÜZÜLMEZ(1,000)	2	1789	0	1789	609	0	609	585650	0	585650	463	0	463

2.5 For 2011

Table 109 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Death Worker Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Death Worker Number)	Slack Movement (Death Worker Number)	Projection (Death Worker Number)
1	AMASRA	1	AMASRA(1,000)	2	644	0	644	249	0	249	289880	0	289880	0,0000000001	0	0
2	ARMUTCUK	0,649	KOZLU(0,364)	0	1144	-523,964	620,036	261	-55,536	205,464	251785	0	251785	0,0000000001	0	0
3	KARADON	0,516	AMASRA(4,407)	0	2838	0	2838	1116	-18,699	1097,301	803067	474385,547	1277452,547	1	-1	0
4	KOZLU	1	KOZLU(1,000)	2	1702	0	1702	564	0	564	691150	0	691150	0,0000000001	0	0
5	ÜZÜLMEZ	0,525	AMASRA(1,775); KOZLU(0,386)	0	1801	0	1801	660	0	660	571300	210408,488	781708,488	3	-3	0

Table 110 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Lost Day Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Lost Work Day)	Slack Movement (Lost Work Day)	Projection (Lost Work Day)
1	AMASRA	1	AMASRA(1,000)	0	644	0	644	249	0	249	289880	0	289880	3232	0	3232
2	ARMUTCUK	0,772	KOZLU(0,364)	0	1144	-523,964	620,036	261	-55,536	205,464	251785	0	251785	4191	-1482,075	2708,925
3	KARADON	0,651	KOZLU(1,162)	0	2838	-860,397	1977,603	1116	-460,672	655,328	803067	0	803067	24188	-15547,898	8640,102
4	KOZLU	1	KOZLU(1,000)	3	1702	0	1702	564	0	564	691150	0	691150	7436	0	7436
5	ÜZÜLMEZ	0,595	KOZLU(1,058)	0	1801	0	1801	660	-63,194	596,806	571300	160052,027	731352,027	32936	-25067,471	7868,529

Table 111 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Accident Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Accident Number)	Slack Movement (Accident Number)	Projection (Accident Number)
1	AMASRA	1	AMASRA(1,000)	0	644	0	644	249	0	249	289880	0	289880	251	0	251
2	ARMUTCUK	0,74	KOZLU(0,364)	0	1144	-523,964	620,036	261	-55,536	205,464	251785	0	251785	337	-158,129	178,871
3	KARADON	0,724	KOZLU(1,162)	0	2838	-860,397	1977,603	1116	-460,672	655,328	803067	0	803067	1165	-594,493	570,507
4	KOZLU	1	KOZLU(1,000)	3	1702	0	1702	564	0	564	691150	0	691150	491	0	491
5	ÜZÜLMEZ	0,831	KOZLU(0,827)	0	1801	-394,138	1406,862	660	-193,801	466,199	571300	0	571300	557	-151,143	405,857

Table 112 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Accident Cost, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Accident Cost)	Slack Movement (Accident Cost)	Projection (Accident Cost)
1	AMASRA	1	AMASRA(1,000)	3	644	0	644	249	0	249	289880	0	289880	202903,71	0	202903,71
2	ARMUTCUK	0,949	AMASRA(0,869)	0	1144	-584,632	559,368	261	-44,723	216,277	251785	0	251785	190031,08	-13792,255	176238,825
3	KARADON	0,69	AMASRA(2,770)	0	2838	-1053,899	1784,101	1116	-426,185	689,815	803067	0	803067	1413857,41	-851744,558	562112,852
4	KOZLU	1	KOZLU(1,000)	0	1702	0	1702	564	0	564	691150	0	691150	1581464	0	1581464
5	ÜZÜLMEZ	0,618	AMASRA(2,651)	0	1801	-94,012	1706,988	660	0	660	571300	197056,627	768356,627	1867892,98	-1330075,917	537817,063

Table 113 Defined Inputs: Number of Workers and Annual OHS Education Time, Estimation Output: Annual Injured Worker Number, Defined Output: ROM Coal Production

NO	DMU	Score	Benchmark(Lambda)	Times as a benchmark for another DMU	Original (Number of Worker)	Slack Movement (Number of Worker)	Projection (Number of Worker)	Original (OHS Education Time)	Slack Movement (OHS Education Time)	Projection (OHS Education Time)	Original (ROM Coal Production)	Slack Movement (ROM Coal Production)	Projection (ROM Coal Production)	Original (Injured Worker Number)	Slack Movement (Injured Worker Number)	Projection (Injured Worker Number)
1	AMASRA	1	AMASRA(1,000)	0	644	0	644	249	0	249	289880	0	289880	251	0	251
2	ARMUTCUK	0,744	KOZLU(0,364)	0	1144	-523,964	620,036	261	-55,536	205,464	251785	0	251785	337	-158,129	178,871
3	KARADON	0,728	KOZLU(1,162)	0	2838	-860,397	1977,603	1116	-460,672	655,328	803067	0	803067	1164	-593,493	570,507
4	KOZLU	1	KOZLU(1,000)	3	1702	0	1702	564	0	564	691150	0	691150	491	0	491
5	ÜZÜLMEZ	0,835	KOZLU(0,827)	0	1801	-394,138	1406,862	660	-193,801	466,199	571300	0	571300	555	-149,143	405,857

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BOOKS

1. **Erdem, Ö.** (2010). Uncertainty Assessment for the Evaluation of NPV of a Mineral Deposit: Application of Risk Analysis for a Copper Mine. Germany, LAP Lambert Academic Publishing

2. Güyagüler, T. and **Erdem, Ö.** (2008). *Mine Ventilation*. Ankara, ODTÜ Basım İşliği

PUBLICATIONS

1. **Erdem, Ö.**, Güyagüler, T., and Demirel, N. (2012). Uncertainty Assessment for the Evaluation of Net Present Value: Mining Industry Perspective. *The Journal of the Southern African Institute of Mining and Metallurgy.112,* 405-412.

2. **Erdem, Ö.** and Güyagüler, T. (2011). Geological Modeling of Layer Type Deposits in Mine Design Software Environment. *4th Balkan Mining Congress*. Ljubljana-Slovenia.

3. Güyagüler, T., and **Erdem, Ö.** (2011). Economic Analysis of a Small Scale Coal Mine Considering Uncertainty Assessment. *22nd World Mining Congress*, İstanbul.

4. Güyagüler, T., and **Erdem, Ö.** (2010). Kömür Ocaklarında Grizu Patlaması Risk Değerlendirmesi. *İş Sağlığı ve Güvenliği Dergisi*, *47*.

5. **Erdem, Ö.** and Güyagüler, T. (2009). Reserve Estimation of Dereköy Copper Deposit Considering the Feasibility of the Project. *3rd Balkan Mining Congress*, İzmir.

6. **Erdem, Ö.** and Güyagüler, T. (2009). Yüksek Sıcaklığın İnsan Metabolizması ve Çalışma Performansı Üzerindeki Etkisi. *Maden İşletmelerinde İş Sağlığı ve Güvenliği Sempozyumu.* Adana.