AN INTEGRATED MULTI-CRITERIA DECISION MAKING APPROACH FOR THE VENDOR PERFORMANCE EVALUATION IN A RETAIL COMPANY

(BİR PERAKENDE FİRMASINDA ENTEGRE ÇOKLU KARAR VERME YÖNTEMLERİ YAKLAŞIMI İLE TEDARİKÇİ PERFORMANS DEĞERLENDİRMESİ)

by

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Thesis

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

MASTER OF SCIENCE

Date of Submission : Sep 13, 2011
Date of Defense Examination: Sep 15, 2011

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ACKNOWLEDGEMENTS

I am deeply grateful to my supervisor, Doç.Dr.Öncan, for helping and guiding me in completing my thesis. During my study, he did not only lead me about our research, he was also so patient at every step of the study.

I would like to thank to my family, especially to my mother. During my education life, she has always encouraged me.

I also would like to thank to my instructors whose courses I had the chance of attending.

13/09/2011
Neslihan Neşe ALDIKAÇTI

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LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
ANN	Artificial Neural Network
ANP	Analytical Network Process
BCC	Banker - Charnes – Cooper Model
CCR	Charnes – Cooper - Rhodes Model
CI	Consistency Index
CR	Consistency Ratio
CRS	Constant Return to Scale
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
GMROI	Gross Margin Return on Inventory
ISAs	Intelligent Software Agents
RI	Random Indices
SA	Sensitivity Analysis
TCO	Total Cost of Ownership
VRS	Variable Return to Scale
WAC	Weighted Average Clustering Model

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ABSTRACT

Today, in a very rapid development, the competitive structure of the retail world is increasing every passing day. Companies are adopting different strategies to maintain the race ahead. Most of these strategies are shaped around the product features. The product cost, sales price, quality and customer attention are considered as the important factors. The supplier selection process has become critic, because these important elements are based on supplier characteristics.

Because supplier selection has become such an important issue, the number of studies on this subject in academic literature has started to rise. The analysis which contains various models and techniques was used in these studies to make the companies have an ability to choose optimum suppliers.

In this study we address the measurement of supplier efficiencies in a retail company. For that purpose, we suggest a two stage approach which employs both the Data Envelopment Analysis (DEA) and the Analytical Hierarchical Process (AHP) methods. In the first stage, we measure the efficiency of the suppliers with DEA method. Next, in the second stage, we use the AHP method to verify the results obtained with the first stage. As an illustrative example, we have applied the proposed approach in the supplier selection process of a retail company. We have observed that the results obtained by both DEA and AHP methods are consistent.

RÉSUMÉ

Aujourd'hui, dans le monde de commerce de détail qui est en train de s'évoluer avec une vitesse importante, une structure plus concurrentielle augmente avec chaque jour qui passe. Les entreprises adoptent des stratégies visant à maintenir la course à venir. La plupart de ces stratégies s'articulent autour des caractéristiques du produit. Le coût et la qualité du produit, les prix de vente, la perception des consommateurs émergent comme des facteurs importants. Généralement les fournisseurs sont à la source de ces facteurs d'où le processus de sélection des fournisseurs est devenu critique pour les entreprises.

Avec l'importance croissante de la sélection des fournisseurs un certain nombre d'études ont commencé à augmenter dans la littérature. Les études utilisant les différents modèles et techniques ont été effectuées pour former les analyses qui permettront aux entreprises d'acquérir la faculté de choix optimal des fournisseurs.

Cette étude a mesuré l'efficacité du fournisseur dans une entreprise du commerce de détail. Les fournisseurs ont été évalués à deux étapes en utilisant les Analyse D'enveloppement des Données (AED) et Processus de Hiérarchie Analytique (PHA). À la première étape les scores d'efficience des fournisseurs ont été mesurés en utilisant la méthode AED, à la deuxième étape la cohérence avec les résultats du premier tour ont été évalués utilisant la méthode PHA. La méthode a été appliquée aux données de l'entreprise et les résultats ont été en accord avec les uns les autres.

ÖZET

Günümüzde çok hızlı bir gelişim içinde olan perakende dünyasında rekabetçi yapı her geçen gün biraz daha artmaktadır. Firmalar bu yarışı önde sürdürebilmek için farklı stratejiler benimsemektedir. Bu stratejilerin büyük bir kısmı ürün özellikleri etrafında şekillenmektedir. Ürünün maliyet, satış fiyatı, kalitesi ve müşteri algısı önemli unsurlar olarak dikkat çekmektedir. Bu unsurlar çoğunlukla tedarikçi kaynaklı olduğundan firmalarda tedarikçi seçimi kritik bir süreç halini almıştır.

Tedarikçi seçimi konusunun bu kadar önemli hale gelmesi ile birlikte literatürde bu konuda yapılan çalışma sayısı da artmaya başlamıştır. Çalışmalarda çeşitli model ve teknikler kullanılarak tedarikçi seçiminde optimum karar verme yetisini firmaya kazandıracak analizler oluşturulmuştur.

Bu çalışmada bir perakende firmasında tedarikçi etkinliği ölçülmüştür. Veri Zarflama Analizi (VZA) ve Analitik Hiyerarşi Prosesi (AHP) yöntemleri kullanılarak iki aşamalı olarak tedarikçiler değerlendirilmiştir. İlk aşamada VZA yöntemi kullanılarak tedarikçilerin etkinlik skorları ölçülmüş, ikinci aşamada ise AHP yöntemi kullanılarak ilk aşamadaki sonuçlar ile tutarlılığı test edilmiştir. Yöntem firmanın verilerine uygulanmış ve sonuçların birbiri ile tutarlı olduğu gözlenmiştir.

1 INTRODUCTION

The performance of the retail industry is crucial for a growing economy. The retail industry deals with the sale of goods to public in small lots for use or consumption rather than for resale. Customers or buyers may be individuals or businesses. In commerce, a retailer buys goods or products in large quantities from manufacturers or importers, either directly or through a wholesaler, and then sells smaller quantities to the end users.

In the global world economy, the retail industry is highly competitive. New brands were born into this world and existing brands open new branches in other countries. This activity of the retail world makes the competition among the corporation in the global market leave the stage to the competition among the network of corporations. During this competition, increasing productivity, minimizing costs and customer response times are the key objectives. Due to this reason efficient supplier-chain and performance-based supply-chain management are highly important to reach these key objectives. Suppliers are one of the most important actors of the supply-chain, because supplier performance directly affects the quality of products, total costs and customer satisfaction. Hence, supplier evaluation has a strategic importance for corporations [1].

Purchasing materials and supplies represent 40 to 60 percent of the sales of the end products in most organizations. Therefore small cost discounts in purchasing of these items make great impact on the cost, quality, technology, and time-to-market of the products. Consequently, a thorough supplier selection process can reduce or prevent many potential problems which may arise in the future. The problem of a supplier can directly and substantially affect both cost and quality. For these reasons, the supplier selection problem is of vital importance for operation of every firm [2].

It is clear that one of the most important processes performed in the retail industry is the supplier selection. The supplier selection decision is a highly complex process because it requires solving a multi-criteria problem which may include both qualitative and quantitative factors. First, this selection decision involves more than one criterion. Second these criteria in the selection process may frequently contradict with each other, such as low price vs. poor quality. A third complication comes from internal policies and external systems on the buying system. Fourth, as organizational requirements and market conditions change, the importance of the analysis of trade-offs among the selection criteria may be increased [3].

There are several factors that affect the supplier selection decisions of organizational buyers. These factors include the composition and functional specialization of the decision makers, buyer-seller relationships, the role of intermediaries in the decision process, and the impact of environmental factors on the decision. Purchase decisions are also influenced by three dimensions of the buyer behavior. These are: technical, commercial and social. Therefore by only having correct understanding of these factors it is possible to evaluate the decision process of organizational buyers [4].

In the literature there are various approaches for the supplier evaluation problem. These approaches differ in some ways such as ease of use, level of decision subjectivity, required resources to use the technique and implementation costs. Also, there are many criteria that are used in supplier evaluation and selection such as products, services and purchase situations. The most commonly used ones -cost, delivery and product quality focus on the output of the supplier. The relative importance of these selection criteria has been examined over various purchasing performance. When companies have long-term relationships with suppliers, output criteria need to be complemented with criteria related to the process and structure. Therefore, enhanced interaction between buyer and supplier would reduce the problems related to complementary, overlapping and contradictory procedures and outcomes [5].

From a decision support system perspective, the research on the supplier selection problem can be divided into two groups. First group includes giving grades to suppliers on a set of criteria, and then using a weighting scheme to calculate a supplier score. Second group includes Mathematical Programming (MP) techniques that model the constraints and an objective function to select the optimal supplier. Both of the groups have different advantages and disadvantages. The grading method is easy but it remains so simplistic in consideration of constraints. The other group, MP methods accommodate both constraints and supplier selection criteria. However, they must make restrictive assumptions to reduce inordinate complexity [2].

In this work we deal with the measurement of supplier efficiencies in a retail company. For that purpose we have employed a two stage approach which employs both the Data Envelopment Analysis (DEA) and the Analytical Hierarchical Process (AHP) methods. In the first stage, we measure the efficiency of the suppliers with DEA method. Next, in the second stage, we use the AHP method to verify the results obtained with the first stage. We used Analytical Network Process (ANP) for selecting selection criteria. As an illustrative example, we have applied the proposed approach in the supplier selection process of a retail company. The remainder of this study is organized as follows; Chapter 2 reviews previous studies on Supplier Selection, DEA, AHP, AHP and Sensitivity Analysis (SA). In Chapter 3, these methods are applied to the real data of a retail company and finally conclusion and future directions are described in Chapter 4.

2 LITERATURE REVIEW

In this study, we evaluate the suppliers by using DEA and AHP methods. We mention three main subjects at the whole study: Supplier Evaluation, DEA and AHP. The literature reviews of these subjects are mentioned at the following sections.

2.1 SUPPLIER EVALUATION

In today's competitive retail world, the effectiveness of supplier selection process is highly important for the future effects. In this world, supplier selection is as important as developing new products.

In general, the cost of raw materials and component parts constitute the main part of the total product cost [6]. The percentage of sales revenues spent on purchasing form more than 80 percent in petroleum refining industry to 25 percent in the pharmaceutical industry. Mostly, it is between 45 to 65 percent of sales revenues on purchasing. Therefore, the firms have to spend big amount of their sales revenues on purchasing [7]. Due to this reason, the supplier selection process was mentioned as one of the key issues of supply chain management [8].

It is clear that to have good suppliers which support cost reduction and profit maximization is important for corporate competition [9]. Moreover, quality and time-loyalty are the factors which make the selection decision a more complex process. The effect on inventory management, production planning and control, cash flow requirements and product quality makes the supplier selection a more critical process [10].

The supplier selection process has changes during past years. In order to reach the best supplier goal, there have been developed so many approaches in the literature. Boer et al. reviewed the suitable various methods such as DEA, Total Cost Approaches, Linear Programming, Linear Weighting Models, Statistical Methods and Artificial Intelligence [11].

Linear weighting methods are the most utilized approach for supplier selection and supplier evaluation. In Linear Weighting Model weights are given to the criteria due to the importance of them. The highest important criterion gets the biggest weight. Ratings on the criteria are multiplied by their weights and summed in order to obtain a single figure for each supplier. The supplier with the highest overall rating can be selected [12]. Timmerman used a weighted linear method of multiple criteria for the supplier selection problem [13]. Ng and Skitmore developed a weighed linear programming approach for supplier selection [14]. The objective of the model was maximization of supplier score. The method involves the decision makers in determining the relative importance weights of criteria as AHP method.

AHP was used as a technique for supplier selection by Nydick and Hill and Masella and Rangone [15, 16]. AHP was also applied to supplier selection and evaluation in steel manufacturing company by Tahriri et al. [17]. ANP was used for supplier selection by Sarkis and Talluri [18].

MP Model allows the decision-maker to formulate the decision problem in terms of a mathematical objective function that needs to be maximized or minimized by varying the values of the variables in the objective function. Gaballa is the first author who applied MP model to a supplier selection problem in a real case. He formulated a single-objective, mixed-integer programming to minimize the sum of purchasing, transportation and inventory costs by considering multiple items, multiple time periods, vendors' quality, delivery and capacity [19]. Weber and Desai used DEA for supplier evaluation [20]. Weber et al. used hybrid approach of MP and DEA for supplier evaluation [21].

A Mixed Integer Linear Programming (MILP) Model was developed by Rosenthal et al. [22]. This model was focused on a purchasing strategy to minimize total cost. There are a lot of integrated approaches in the literature. AHP and LP model integration are used for supplier selection and order allocation by Ghodsypour et al. [23]. Degraeve et al. developed a MP model that minimizes the total cost of supplier choice and inventory management [24]. Then they extended this study to service sector. Tempemeir and Dahel suggested MILP formulation. Tempmeir used the program for supplier selection and purchase order sizing [25, 26]. Dahel used the program for determining the number of suppliers and order quantities to allocate to these suppliers [26].

Ronen et al. developed a decision system for supplier selection and ordering policy where lead time is rating model as a statistical model sample in the literature [27]. One of the other samples is Soukoup's study [28]. The scope of this study is a simulation solution for unstable demand.

The study of Khoo et al. can be given as the Artificial Intelligence example. It treated the potential use of an Internet-based technology called intelligent software agents (ISAs). These agents are generally used for automating the procurement of goods. The main point of the study is that these agents can be applied to the supplier selection problem [29]. Choy et al. are generated an intelligent generic supplier management tool [30].

Weber et al. and Wu et al. used DEA for selection supplier and their orders quantities allocation in their studies [31, 32].

There are hybrid approaches in the literature. Bhutta et al. developed an AHP and TCO hybrid approach for supplier selection [33]. Ha et al. used a hybrid approach in their study. AHP was used to evaluate the supplier performance. Then DEA and ANN were used to measure the performance efficiency for each supplier. Both results were compiled into one efficiency index using a simple averaging method [34].

Table 2.1 summaries the supplier evaluation approaches literature.

Table 2.1 Supplier Selection and Evaluation Methods

#	Author	Method	Details
1	Zenz, 1981	Linear Weighting Model	In Linear Weighting Model weights are given to the criteria due to the importance of them. The highest important criterion gets the biggest weight. Ratings on the criteria are multiplied by their weights and summed in order to obtain a single figure for each supplier. The supplier with the highest overall rating can be selected.
2	Nydick et al., 1992 Masella et al., 2000 Tahriri, 2008	AHP	AHP is a simple and feasible multi-objective evaluation method widely used for multi-objective evaluation activities. It is designed for subjective evaluation of a set of alternatives based on multiple criteria in a hierarchical structure. At the top level, the criteria are evaluated and at the lower levels the alternatives are evaluated by each criterion. By a pairwise comparison matrix, the decision makers assess their evaluation separately for all levels.
3	Rosenthal et al., 1995	Mixed Integer Linear Program	A mixed integer linear program was developed by Rosenthal et al.. This program was focus on a purchasing strategy to minimize total cost.
4	Weber et al., 1996	DEA	DEA is a technique to measure the Decision Making Units (DMUs) efficiency. DMUs are the units which are considered as the enterprises which transform inputs to outputs.
5	Weber et al., 1998	DEA - MP Hybrid	MP allows the decision-maker to formulate the decision problem in terms of a mathematical objective function that needs to be maximized or minimized by varying the values of the variables in the objective function. Weber et al. used hybrid approach of MP and DEA for supplier evaluation.
6	Ghodsypour et al., 1998	AHP - LP Hybrid	There are a lot of integrated approaches in the literature. AHP and LP model integration are used for supplier selection and order allocation by Ghodsypour et al .
7	Ronen et al., 1998 Soukoup, 1987	Statistical Model	- Ronen et al. developed a decision system for supplier selection and ordering policy where lead time is rating model as a statistical model sample in the literature. - One of the other samples is Soukoup's study. The scope of this study is a simulation solution for unstable demand.
8	Khoo et al., 1998 Choy et al., 2003	Artificial Intelligence	- As the Artificial Intelligence example, a study by Khoo et al. can be given. It treated the potential use of an Internet-based technology called intelligent software agents (ISAs). These agents are generally used for automating the procurement of goods. The main point of the study is that these agents can be applied to the supplier selection problem. - Choy et al. are generated an intelligent generic supplier management tool.

#	Author	Method	Details
9	Sarkis et al., 2000	ANP	The ANP is built on the AHP. The ANP provides a general framework to deal with decisions without making assumptions about the independence of higher level elements from lower level elements and about the independence of the elements within a level.
10	Degraeve et al., 2000	MP Model	Degraeve et al. developed a MP model that minimizes the total cost of supplier choice and inventory management. Then they extended this study to service sector.
11	Weber et al., 2000 Wu et al., 2007	DEA	- Weber et al. used DEA for selection supplier and their order quantities allocation in their studies. - Wu et al. used DEA for selection supplier and their order quantities allocation in their studies.
12	Tempemeir, 2002 Dahel, 2003	Mixed İnteger Linear Programming	Tempmeir used the program for supplier selection and purchase order sizing. Dahel used the program for determining the number of suppliers and order quantities to allocate to these suppliers.
13	Bhutta et al., 2002	AHP-TCO Hybrid	Bhutta et al. developed an AHP and TCO hybrid approach for supplier selection.
14	Ng, 2008	Weighed linear programming	Ng developed a weighed linear programming for supplier selection. The objective of the program was maximization of supplier score. The method involves the decision makers in determining the relative importance weights of criteria as AHP method.
15	Ha et al, 2008	AHP-DEA-ANN Hybrid	Ha et al. used a hybrid approach in their study. AHP was used to evaluate the supplier performance. Then DEA and ANN were used to measure the performance efficiency for each supplier. Both results were compiled into one efficiency index using a simple averaging method.

This selection process is a multi-criteria problem, which includes both qualitative and quantitative factors. Moreover, it is needed a selection criteria and factor analysis in this selection process. The analysis of criteria for supplier selection and supplier performance measuring has been an important focus since 1960s [35].

In the literature, there are many researches which address the supplier selection and evaluation criteria. These researches are generally grouped according to what they are related to: the supplier, the product or the purchasing organization. According to Wagner et al., there is a hierarchy of effect dominated by selling history, mark-up and delivery. Product quality and fashionability are less important, while the reputation, service and country of origin have insignificant importance [36].

Weber et al. classified criteria based on Dickson's 23 criteria [37]. According to this study; net price, delivery, quality, production facilities, technical capabilities, reputation, financial position, performance history, repair and attitude are the most frequently mentioned criteria. The quality was classified as the most important criterion. Delivery performance and the cost criteria are also classified as the follower of the quality [38]. Table 2.2 shows Dickson's 23 Criteria.

Table 2.2 Dickson's 23 Criteria

#	**Criteria**
1	Price/cost
2	Customer service
3	Delivery
4	Repair service
5	Warranties and claims
6	Training aids
7	Financial position
8	Geographical location
9	Operating controls
10	Performance history
11	Production facilities
12	Reputation and position
13	Technical capability
14	Amount of past business
15	Packaging capability
16	Labor relations record
17	Procedural compliance
18	Attitude
19	Management and organization
20	Impression
21	Communication system
22	Reciprocal arrangement
23	Desire for business

Choi et al. had a supplier selection study for auto industry. They studied on criteria based on studies of Dickson and Weber et al. [39]. They determined 26 criteria and classified them into 8 main groups as finance, consistency, relationship, flexibility, technological capacity, services, reliability and price. Table 2.3 shows this classification.

Table 2.3 Classification by Choi et al.

#	Group	Details
1	Finances	Financial condition, profitability of supplier, financial record disclosures and performance awards
2	Consistency	Conformance quality, consistent delivery, quality philosophy and prompt response
3	Relationship	Long term relationship, relation closeness, communication openness and reputation
4	Flexibility	Product volume changes, short setup time, short delivery lead time and conflict resolutions
5	Technological capability	Design capability and technical capability
6	Services	After sale support and sale representative competences
7	Reliability	Incremental improvement and product reliability
8	Price	Low initial price

Bhutta et al. found that quality, service, delivery and price are dominant criteria [33]. Ghodsypour and O'Brien agreed that cost, quality and service are the three main categories at supplier selection process [6]. Tracey et al. mentioned that quality, delivery-loyalty and product performance are the key criteria in the basis of enhancing for firm performance and dimension of customer satisfaction such as price, quality, variety and delivery [40]. However, in a different perspective, Briggs broached some determining criteria apart from optimum cost such as development, culture, forward engineering, trust, supply chain management, quality and communication [41]. Kotabe found competency, service quality control, transaction-cost drivers, supplier’s brand image and supplier’s country characteristics are the most important criteria [42].

At these researches, it is not possible to build up a common selection criteria list. Factors have a wide variety based on the type of purchase and product. To sum up, cost is not the only criterion at the supplier selection process. Quality, organization and culture are the effective factors at supplier selection process. Table 2.4 shows the important supplier selection criteria list used by various studies.

Table 2.4 Important Supplier Selection Criteria Used by Various Researchers

#	Author	Criteria	Details
1	Wagner et al., 1989	Selling history, mark-up, delivery, product quality and fashionabilty, reputation, service, and country of origin.	There is a hierarchy of effect dominated by selling history, mark-up and delivery. Product quality and fashionability are less important, while the reputation, service and country of origin have insignificant importance.
2	Weber et al., 1991	Net price, delivery, quality, production facilities, technical capabilities, reputation, financial position, performance history, repair, attitude, quality, delivery performance, and cost.	In this study, criteria were based on Dickson's 23 criteria. Net price, delivery, quality, production facilities, technical capabilities, reputation, financial position, performance history, repair and attitude are the most frequently mentioned criteria. The quality was classified as the most important criterion. Delivery performance and the cost criteria are also classified as the follower of the quality.
3	Choi et al., 1996	Finance, consistency, relationship, flexibility, technological capacity, services, reliability and price.	They studied on criteria based on studies of Dickson and Weber et al.. They determined 26 criteria and classified them into 8 main groups as finance, consistency, relationship, flexibility, technological capacity, services, reliability and price.
4	Bhutta et al., 2002	Quality, service, delivery and price.	Bhutta et al. found that quality, service, delivery and price are dominant criteria.
5	Ghodsypour et al., 1998	Cost, quality and service.	Ghodsypour and O'Brien agreed that cost, quality and service are the three main categories at supplier selection process.
6	Tracey et al., 2001	Quality, delivery-loyalty, product performance.	Tracey et al. mentioned that quality, delivery-loyalty and product performance are the key criteria in the basis of enhancing for firm performance and dimension of customer satisfaction such as price, quality, variety and delivery.
7	Briggs, 1994	Optimum cost, development, culture, forward engineering, trust, supply chain management, quality and communication.	Briggs broached some determining criteria apart from optimum cost such as development, culture, forward engineering, trust, supply chain management, quality and communication.
8	Kotabe, 2001	Competency, service quality control, transaction-cost drivers, supplier's brand image and supplier's country.	Kotabe found competency, service quality control, transaction-cost drivers, supplier's brand image and supplier's country characteristics are the most important criteria.

2.2 DATA ENVELOPMENT ANALYSIS

DEA is a technique to measure the Decision Making Units (DMUs) efficiency DEA uses MP models. DMUs are the units which are considered as the enterprises which transform inputs to outputs. In these models, there are multiple inputs and outputs.

The DEA approach has been first proposed by Debreu, but awareness to the method was raised by Farrell [43, 44]. However, the DEA approach became popular by well-known work by Charnes et al.. In this study, DEA has been applied to the efficiency of homogenous units [45].

DEA approach can be used at different evaluations at different sectors. There are numerous studies in literature to improve the approach: Banking [46], retail stores [47], educational institutions [48], manufacturing [49], hospitals [50], police force [51], steel industry productivity [52], highway maintenance efficiency [53], software development [54], and logistics systems [55].

Dyson et al. concentrates on some problematic issues and possible traps during the DEA application [56]. Barros et al. focused on retail store efficiency by using DEA [57]. In this study, the Variable Return to Scale (VRS) hypothesis was chosen to evaluate a supermarket chain group of 47 retail outlets of Portugal. Also output oriented model is selected in this study. There are 9 inputs (full-time employees, part-time employees, cost of labor, absenteeism, area of outlets, number of points of sale (POS), age of the outlets, inventory, and other costs.) and 2 outputs (sales and operational results as profit). When Constant Return to Scale (CRS) assumption was used to compare the results instead of VRS assumption, there are less efficient DMUs. According to this result, economies of scale are determinant factors of efficiency in retail sector.

Keh et al. used DEA to assess performance level of each member of a grocery retailer chain [58]. On the other hand, Donthu et al. is one of the most important articles related DEA in retail sector which 24 stores of a fast food restaurant chain were evaluated in. The authors introduce a model of 4 inputs (store size, store manager experience with the chain, store location, promotion/give-away expenses) and 2 outputs (sales, customer satisfaction) [59].

Mukherjee et al. used DEA at a study on Indian banks. The aim of this study is to obtain a connection between performance benchmarking and strategic homogeneity. 68 Indian banks which could be classified as publicly owned, privately owned and foreign capital were chosen for the study and Charnes, Rhodes, Cooper (CCR) output oriented model was used. It was found that, publicly owned banks have higher efficiency scores and more stable performance during the observed periods [60]. As another literature for DEA in banking sector, Cook et al. evaluates sales and service efficiency of a major Canadian Bank. 20 branches were evaluated in this study [61].

DEA is a very effective tool when it is used correctly but it has both advantages and disadvantages. There are so many advantages of DEA method over other decision making methods. DEA is able to process more than one input and output. DEA is not needed a functional form associating input and output except linear form. Inputs and outputs could have different units. On the other hand DEA has disadvantages too. DEA is very sensitive to measurement errors. It is able to measure the performance of decision points but it does not give hint about the explanation based absolute efficiency of analyze. It is difficult to apply statistical hypothesis tests to its results, because DEA is a non-parametric method. Calculation of the large sized problems may take a long time because of the necessity for one programming model solution for each decision point.

In order to apply the DEA approach, first of all we have to choose decision points. Then for evaluating decision points, input and output factors are needed. Next, we have to choose a model which is suitable for the problem. Finally, we have to solve the model and analyze the results.

The selection of decision points is a very important step for the legality of the DEA results. In case there is any wrong decision point in the analysis, all of the analysis results will be negatively affected. Decision points have to be similar in terms of inputs and outputs. In the other words decision points could be able to rate the same input and output combinations. There must be similar source group for each decision point. All decision points have to work with similar environmental conditions. Environment has an important role on the efficiency of a company.

The second step is to choose input and output factors. The group of input and output items has to include some characteristics. There must be some common factors for all decision points. These factors must also enclose all of the activity levels and performance indicators and must include all measurable, physical and economic sources.

Furthermore there is a rule for the number of DMUs connected to the numbers of inputs and outputs. Minimum DMU number must be equal to 2 times input number multiples output numbers. Beside this general rule the necessity for there to be a correlation between inputs and outputs should not be forgotten. Analyzing normal measurement and the index number all together will cause mistakes in inputs and outputs.

There two different models of DEA analysis: CCR method and Banker, Charnes, Cooper (BCC) method. In DEA-CCR model all observed production combinations can be scaled up or down proportionally, and in DEA-BCC model the variables allow return to scale and is graphically represented by a piecewise linear convex frontier.

1. ***CCR (Charnes – Cooper - Rhodes) Model:*** The objective of the CCR models is the maximization of the efficiency of DMU. After applying the CCR model, the results show the efficiency of the DMUs. In case the efficiency score is equal to 1, we consider the DMU is efficient. Otherwise the DMU is not efficient. CCR model provides an objective evaluation of the efficiency of the set of organizational units.

   The CCR model focuses on the reduction of inputs (input-focused model), on the increase of outputs (output-focused model), or on both objectives at the same time, to provide maximum efficiency. It is designed with the assumption of constant returns to scale. This means that there is no assumption that any positive or negative economies of scale exist.

The decision variables of the CCR model are as follows: Given s outputs, m inputs and j DMUs; let u_r denotes that r^{th} output weight, v_i states that i^{th} input weight, y_{rj} denotes the amount of r^{th} output produced by DMU j and x_{ij} denotes the amount of i^{th} input value utilized by DMU j.

$$Max \quad z = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \qquad j = 1, \ldots, n. \qquad (2.1)$$

Subject to

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1 \qquad j = 1, \ldots, n. \qquad (2.2)$$

$$u_r \ge 0 \qquad r = 1, \ldots, s; \qquad (2.3)$$

$$v_i \ge 0 \qquad i = 1, \ldots, m. \qquad (2.4)$$

The objective function (2.1) states that the ratio weighted outputs to weighted inputs must be maximized. The constraints (2.2) ensure that the ratio should be less than or equal to 1. Constraints (2.3) and (2.4) stand for the nonnegativity restrictions [45].

2. ***<u>BCC (Banker - Charnes – Cooper) Model:</u>*** Banker, Charnes, and Cooper developed another DEA model [62]. It takes for granted that inputs can be reduced to increase efficiency. For a given decision-making unit *j*, DMU_j *(j=1,.., n)* , to be evaluated on any trial generally designated as DMU_o (where o ranges over *1, 2 …, n*), the BCC-Input model may be represented as following:

$$Max \quad z = \sum_{r=1}^{s} u_r y_{r0} - u_0 \qquad (2.5)$$

Subject to

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} - u_0 \le 0 \qquad j = 1, ..., n. \qquad (2.6)$$

$$\sum_{i=1}^{m} v_i x_{i0} = 1 \qquad (2.7)$$

$$u_r \ge 0 \qquad r = 1, ..., s; \qquad (2.8)$$

$$v_i \ge 0 \qquad i = 1, ..., m. \qquad (2.9)$$

$$u_0 \qquad \textit{Free in sign} \qquad (2.10)$$

The two models, described previously, the first is called CCR model (constant return to scale) which is a scale efficiency and technical efficiency, and the second is called BCC model (variable return to scale) which is a pure technical and scale efficiency.

2.3 THE ANALYTICAL NETWORK PROCESS

The basic ANP structure consists of a single network. On the other hand, benefit, cost, opportunity and risks of each alternative are analyzed at the most complex structure. Values of alternatives for each model are turned to one value by using various formulas.

ANP has a wide application area like market, health, politics, and social areas. It should be considered that benefits, costs, opportunities and risks can have different severity due to the problem structure. For example, in the case of delivering ammunition or drug to the front during a war, delivery cost is less important than lives can be recovered [63].

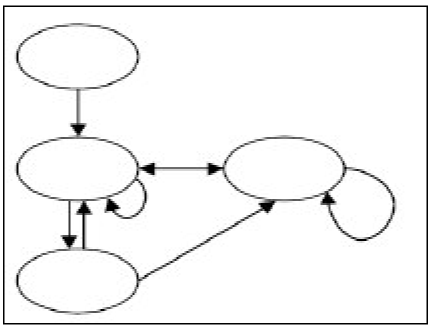

Figure 2.1 The Network Structure

In network structure, relationships are shown with arrow and the directions of the arrows represent the dependency [64]. The dependency between two nodes is called "External Dependency" and it is shown double arrow. The dependencies in a node are called "Internal Dependency" and they are shown with an arrow in a loop shape [65]. Figure 2.1 illustrates a network structure.

ANP structure is generally built up in 7 steps.

Step 1: Factor priorities are determined regardless of dependencies between factors.
Step 2: Units are evaluated regardless of dependencies between factors and unit priorities are determined in the basis of factors.
Step 3: The degrees of the relationships between factors by taking into account the dependencies. At this point, opinions are gotten from experts.
Step 4: Relationships between units for each factor are investigated by evaluating unit dependencies in the basis of factors and related matrices are generated.
Step 5: Depended priorities are achieved by multiplying the matrices which are generated in the 1^{st} and 3^{rd} steps.
Step 6: Depended priorities are calculated for all factors by multiplying the matrices which are generated in the 2^{nd} and 4^{th} steps.
Step 7: Orders of precedence are determined by multiplying matrices which are generated in the 5^{th} and 6^{th} steps [66].

2.3.1 Dependencies

External Dependency: the dependency between clusters is called “External Dependency”. In other words, External Dependency is the interaction between the members of the cluster and the members of the other clusters [64].

The priority vectors which are gotten from the pairwise comparison matrices in ANP are not joined linearly like in AHP method. The vectors are put on the columns of a matrix to show dependencies. There is no obligation to have an interaction between all clusters. The values of the members which have no effect are illustrated by “0”.

2.3.2 Effect Matrix

A special attention must be paid on the concept of “Combining Priorities” between members at a feedback model. Members in a model can have interactions more than one way.

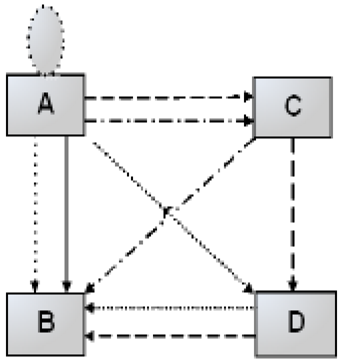

Figure 2.2 The effects of the member A over member B in different ways

Whole possible ways must be considered for the significant measurements of priorities. The priority of any element of the model to another one can be measured by more than one way like the paths and loops which connect these elements to each other. The primary impact of any element A on element B is shown in Figure 2.2 with straight arrow. The impact of element A on element B can be directed on element C. In Figure 2.2 dashed arrow shows this impact. This impact can be obtained by multiplying the impact of element A on element C and the impact of element C over element B. Total secondary impact of element A on element B impact matrices square. There is also tertiary indirect impact of element A on element B as we can see from Figure 2.2. The contribution of this impact to total impact can be obtained by multiplying of impact of element A on element C, impact of element C on element D and impact of element D on element B. This procedure can be go on by calculating fourth, fifth and sixth indirect impacts [67].

2.3.2.1 Super Matrix

All the sensible limits of final priorities can be obtained from zero vectors and priority vectors which are obtained from pairwise comparison matrices. For this reason, super matrix must be a stochastic matrix (The sum of the elements of each column must be equal to 1.). The elements are shown at left sight vertically and up sight horizontally at big matrix. It is needed to compare each cluster which is left sight and up sight with respect to their impacts to ensure that the super matrix is stochastic. The priorities of clusters which are obtained from these comparisons are used to weight the column vectors. Each block which consists of column vectors (up sight and left sight element combinations) is one of the elements of super matrix. All of the column vectors in the block are multiplied by the priority of left sight cluster in terms of up sight cluster. This procedure is performed for all left sight and up sight combinations. Thus the sum of each column which shows the impact of up sight cluster of super matrix equals 1 [64]. Figure 2.3 illustrates the general structure of super matrix.

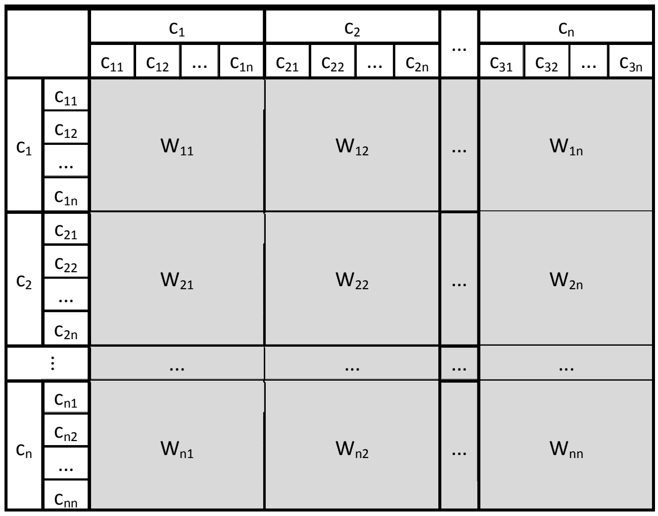

Figure 2.3 The General Structure of Super Matrix

2.3.2.2 Limit Priorities

The aim of the method is to find the limit priorities of each element on other elements. After weighted super matrix is obtained, convergent priorities are found by calculating the powers of matrices. Power calculations go on until all the numbers at a row are equal to each other. In this manner, we have “Limit Super Matrix”. Limit Super Matrix can be calculated via Commercial Software Packages such as Mathematical, Matlab, Excel, Ecnet, and Super Decisions.

2.3.2.3 Control Hierarchy

The critical subject for ANP, control hierarchy, is very important to compare the relationship types on the network. There are two different types of control criteria. If the structure is hierarchy, the control criterion can be connected to the structure as the purpose of the hierarchy. In this case, the control criterion is considered as connection criterion. Otherwise, the control criterion cannot be connected to the structure directly. But it caused comparisons in the network. In this case, the control criterion is considered as "causation criterion". The examples of each situation are shown at Figure 2.4.

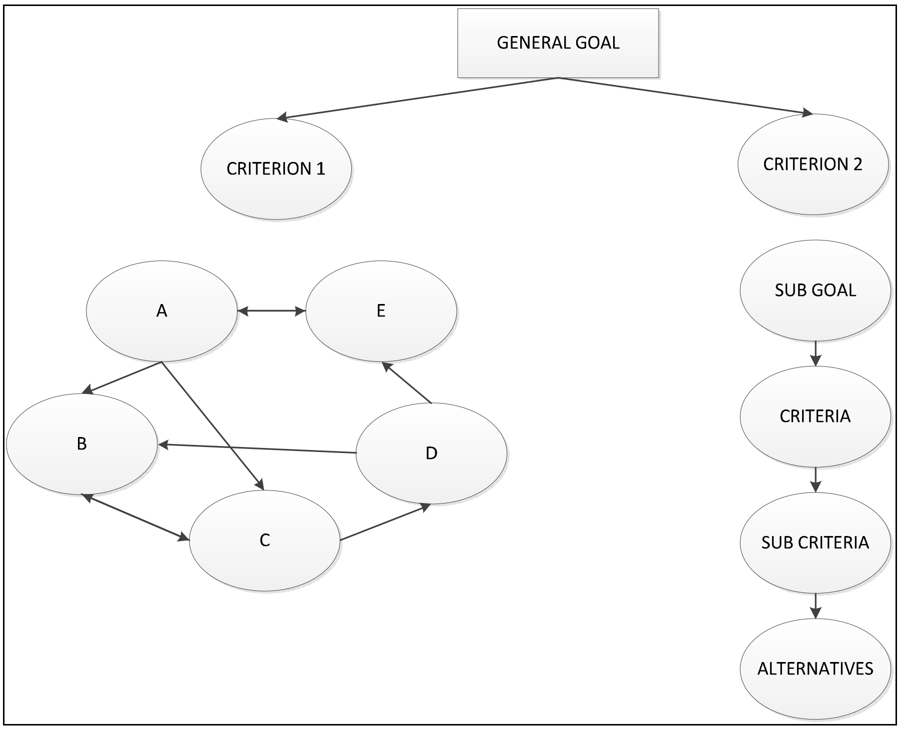

Figure 2.4 Causation and Connection Criteria at Control Hierarchy

The weighting process is one of the encountered problems at control hierarchy. The group weights are used to calculate the weights of effected groups at the super matrix blocks. The convergent priorities at each super matrix are weighted by multiplying with the priorities of themselves sub criteria. If there is no input of any element or group, the value of corresponding priority vector is entered as zero [68].

2.4 THE ANALYTICAL HIERARCHICAL PROCESS

AHP is a simplified version of ANP. While AHP allows the one-way relationships of units, ANP allows complex relationships for decision levels.

AHP is a simple and feasible multi-objective evaluation method widely used for multi-objective evaluation activities. It is designed for subjective evaluation of a set of alternatives based on multiple criteria in a hierarchical structure by Saaty [69]. At the top level, the criteria are evaluated and at the lower levels the alternatives are evaluated by each criterion. By a pairwise comparison matrix, the decision makers assess their evaluation separately for all levels [70].

Saaty and Vargas defined the AHP as a theory for dealing with complex problems [71]. Saaty explained the details of the technique as ranking and the differences between absolute and relative measurement [72]. Vargas reviewed the mechanisms of AHP and divided AHP into two stages, design and evaluation of the hierarchy. The author also introduced a forward planning process [73]. Saaty discussed the comparability of alternatives, clustering and relative versus absolute measurements in AHP [74].

AHP has applied to different areas since it has been developed. AHP was applied in a variety of areas including education [69], economics [75], politics [76], engineering [77], and so on.

Babic et al. used AHP to rank firms due to their business efficiency level in a hybrid model. They used AHP to determine the importance of criteria. Then they used Promethee to make the final rating [78]. Gnanasekaran et al. used the technique to supplier selection process of an automobile component manufacturing company. They found the technique reduces the time and effort in decision-making at the end of the study [79]. Chan et al. used the method in the capital budgeting area [80].

Kendrick et al. can be given as an application example of AHP in project selection area [81]. Lin et al. analyzed Radio Frequency Identification (RFID) adoption decision process by using AHP. In this study, AHP helped to predict possible risks and challenges during adoption [82].

IT is another area that AHP technique used. Sureshchandar et al. developed a framework using AHP for evaluating the criticality of software metrics [83].

There are steps of implementing the AHP method. These steps are given below:

Step 1: The overall goal (objective) is identified, and the issue is clearly defined.
Step 2: The criteria used to satisfy the overall goal are identified. Then the sub criteria under each criterion must be identified. The hierarchical structure is constructed. Figure 2.5 illustrates the hierarchy of AHP.

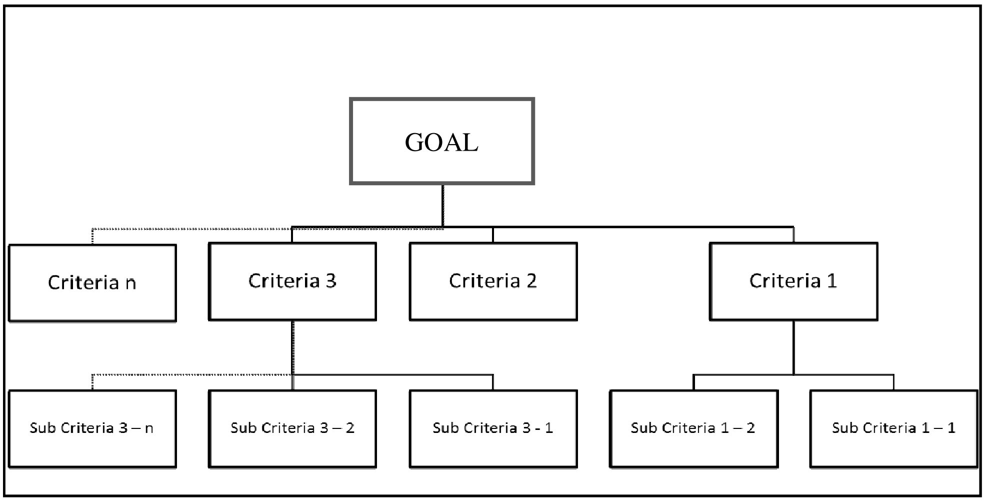

Figure 2.5 The AHP Tree of the Example

Step 3: Pairwise comparisons are constructed. For this step, elements of the problem are paired with respect to their common relative impact on a property and then compared.

The comparisons are made in the following form: How important is element 1 when compared to element 2 with respect to a specific element in the level immediately higher? The hierarchy determines the pairwise comparisons. Therefore, special attention must be given to the form of the hierarchy [84].

The pairwise comparisons are reduced in the square matrix form, A give in equation (2.11).

$$A = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix} \qquad (2.11)$$

A is an *nxn* matrix which n is the number of elements being compared. a_{ij} are the relative scale of alternative I to alternative j with respect to a common element. These judgments have the following characteristic:

$$a_{ij} = 1/a_{ji} \qquad \forall i, j \qquad (2.12)$$

In AHP method, the decision makers assess the relative importance of the elements of each level of hierarchy. To fill the matrix of *A*, the use of a one-to-nine scale to express the decision maker's preferences and intensity of that preference for one element over another was proposed by [69]. The relative importance values are given in Table 2.5. For example, if $a_{12} = 5$, this means that the first alternative is strongly favored over the second alternative based on experience and judgment.

Table 2.5 Scale of Relative Importance

Relative Importance	**Definition**
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extremely important
2,4,6,8	Intermediate values between the two adjacent judgments
Reciprocals of the above non-zero numbers	

A consistent matrix can be based on exact measurements. At this case, the weights w_1, w_2, w_3, …, w_n are already known and a_{ij} can be written as follows where w_i is the relative weight of alternative i:

$$a_{ij} = w_i / w_j \qquad \forall i, j \tag{2.13}$$

Step 4: Weights of the decision elements are estimated by using the eigenvalue method. Consistency of judgments is checked. The procedure is called an eigenvector approach, which takes advantage of characteristics of a special type of matrix called a reciprocal matrix.

The entries a_{ij} are defined by equation 2.12 and according to 2.13 the consistent pairwise comparison matrix A in 2.11, can be represented in the form shown in 2.14.

$$A = \begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{pmatrix} \qquad (2.14)$$

The goal is to find eigenvector w corresponding to maximum eigenvalue λ_{max} which is the relative weights of the objects.

$$w = (w_1, w_2, w_3, ..., w_n) \qquad (2.15)$$

If the pairwise comparison matrix is not consistent, the weights of the objects may not be valid. For this reason, the consistency of the matrix A should be checked. It is critical to know how good the consistency is in decision making process. Consistency means that the decision procedure is producing coherent judgments in specifying the pairwise comparison of the criteria or alternatives. The main consistency rule is:

$$a_{ij} * a_{jk} = a_{ik} \qquad i, j, k = 1, \ldots, n \qquad (2.16)$$

When A is consistent, and

$$a_{ij} = \frac{w_i}{w_j} \Rightarrow w_i = a_{ij} w_j \qquad i, j = 1, \ldots, n \qquad (2.17)$$

$$Aw = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & \cdots & \cdots & a_{nn} \end{pmatrix} \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} = \begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{pmatrix} \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix}$$

$$Aw = \begin{pmatrix} w_1 + w_1 + \ldots + w_1 \\ w_2 + w_2 + \ldots + w_2 \\ \vdots \\ w_n + w_n + \ldots + w_n \end{pmatrix} = \begin{pmatrix} nw_1 \\ nw_2 \\ \vdots \\ nw_n \end{pmatrix}$$

$$Aw = nw \qquad (2.18)$$

Equation (2.18) is satisfied only if w is an eigenvector of A with eigenvalue of *n*. All the rows in the represented matrix are constant multiplies of the first row. From linear algebra all the eigenvalues λ_i for $i = 1, ..., n$ are zero except one. Since A is a reciprocal matrix and all the entries are positive, all the eigenvalues of A are non-negative. Therefore λ_i which is greater than zero can be called λ_{max}.

$$\sum_{i=1}^{n} \lambda_i = Trace\ (A) = n \qquad (2.19)$$

The trace of a matrix is a summation of the diagonal entries. Since all the diagonal elements of A are one, the trace of A is n. Since the all eigenvalues λ_i are zero except λ_{max}.

$$\sum_{i=1}^{n} \lambda_i = \lambda_{\max} \qquad (2.20)$$

An index is needed to measure the consistency of weights. This index is:

$$Consistency\ \ Index = CI = \frac{\lambda_{\max} - n}{n-1} \qquad (2.21)$$

This index shows us how much the consistency of pairwise comparisons differs from the perfect consistency. The consistency check of pairwise comparison is done by comparing the computed consistency index with the average consistency index of randomly generated reciprocal matrices using on-to-nine scale. Table 2.6 shows the random indices (RI) for matrices of order 1 through 15.

Table 2.6 Random Indices

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0,52	0,89	1,11	1,25	1,35	1,4	1,45	1,49	1,51	1,48	1,56	1,57	1,59

AHP measures the overall consistency of rankings by means of a consistency ratio (CR). A CR of 0,10 or less can be considered as acceptable; otherwise the judgments should be improved. It calculates as follows:

$$CR = \frac{CI}{RI} \tag{2.22}$$

Step 5: Hierarchical composition is used to combine the weight vectors and arrive at global and local relative contributions of each element.

AHP has both advantages and disadvantages like DEA technique. The advantages of the method can be listed like:

- ✓ It helps capture both subjective and objective evaluation measures,
- ✓ It allows organizations to minimize common pitfalls of decision making process,
- ✓ It is very useful at complex decisions.

There are also disadvantages of the method. These can be listed like:

- ✓ Correlation between independent factors,
- ✓ Difficulty on consistency ratio control, arbitrariness of rankings, subjective result risk, lengthiness of the comparing process,
- ✓ Limitations of the AHP like having no theoretical basis for constructing hierarchies.

2.5 SENSITIVITY ANALYSIS

The decisions which we achieve at the end of this decision making process will affect the future of our company. This means that sensitivity of the decisions is as important as achieving them. Because of this reason, we need to be confident in the results after we complete the decision making process. Therefore we should find the answers to the following questions:

- How confident are we in the results?
- How much will the results change if our basic data is slightly wrong?
- Will this probability has a minor effect on our results or completely different outcome?

These kinds of questions can be answered by Sensitivity Analysis. The summary of these questions is the optimum solution is the sensitive to a small change in one of the original problem coefficients. For example in our study, we may achieve a sensitivity examination of our results like: “If S1 raised its costs 10%, it will be an inefficient supplier.”

This sort of examination of the impact of input data on the output results is crucial. Some criteria can be subjective or approximate value in the data set. Sensitivity Analysis can show which data has a significant impact on the results. This can also help the decision maker to spend much more attention on having accurate data.

There are several approaches in Sensitivity Analysis. If the model is small enough to solve it quickly, a *brute force* approach can be used. In this approach, the initial data is changed and then the model is run again. These steps can be done as many times as the decision maker wants. However in case the data is large, *classical sensitivity analysis* can be used. This method relies on the relationship between the initial tableau and any later tableau. *Computer-Based Ranging* is between these two extremes. This is simple information about how much certain coefficients can change before the current optimum solution is fundamentally changed [85].

Most solver software return at least following information:

- The *Reduced Costs*: The objective function coefficients for the original variables at the optimum.
- *The Shadow Prices* or *Dual Prices*: The objective function coefficients for the slack and surplus variables at the optimum.
- The ranges of the original objective function coefficient of the original variables for which the current basis remains optimal.
- The ranges of the right-hand-side constants for the constraints for which the current basis remains optimal [86].

3 AN ILLUSTRATIVE EXAMPLE

The aim of our study is to evaluate the supplier efficiency of a shoe retail company. The product range can be clustered according to the end users and it covers women, men, children, sports, textiles and accessories. In this study we have only concentrated on a product cluster consisting of only women, 2010, domestic production, and casual products. We have considered suppliers as DMUs. We have 15 suppliers within the sample cluster. These DMUs are evaluated. We call them from S1 to S15, instead of using their commercial name.

3.1 INPUTS and OUTPUTS

We set a brain storming session to determine criteria. Before the session, we asked for all Production and Planning Department (P&P) managers to list the criteria which are affected them during supplier selection. We tried to reach a consensus and at the end of the session managers agreed with the list at Table 3.1.

Table 3.1 The criteria which are the P&P Managers run in with

#	Criterion
1	Cost
2	Rejection Ratio
3	Inventory Turnover
4	Gross Margin Return on Inventory (GMROI)
5	Sales Quantity
6	Sales Performance
7	Location
8	Delivery Date Loyalty
9	Partnership Life

We had a criteria list which showed us expert opinions after the brain storming session. We applied ANP method to these criteria to achieve the relative importance of them. We applied ANP due to how these criteria affected the supplier selection. These effect areas are Financial, Logistics, Performance, Quality, and Reliability.

We used Super Decision Software for evaluation. We set the dependencies on the software and then made comparisons. Figure 3.1 shows the model.

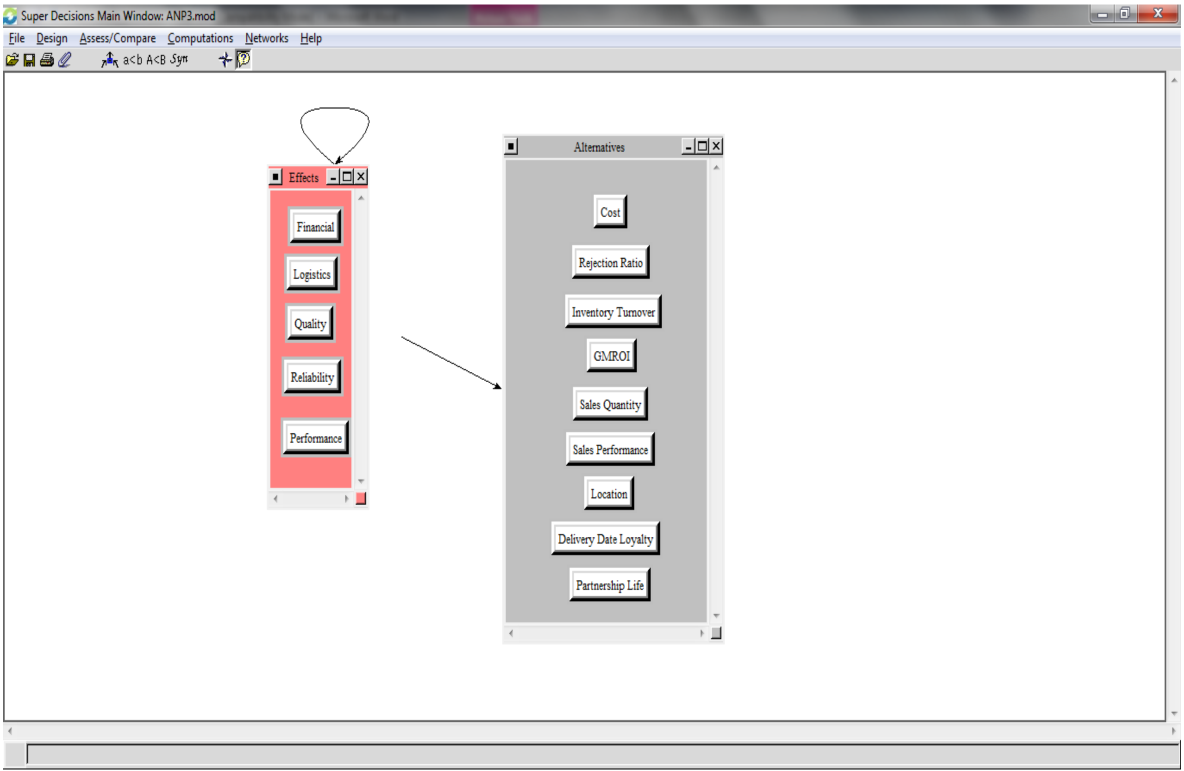

Figure 3.1 Super Decision Software Screen

After solving the model via Super Decision Software, we achieved the criteria priorities. Table 3.2 shows the all criteria priorities.

Table 3.2 Criteria Priorities

#	Criteria	Ideals	Normal	Raw
1	Sales Quantity	1,00000	0,25782	0,12891
2	GMROI	0,74451	0,19195	0,09597
3	Rejection Ratio	0,61833	0,15942	0,07971
4	Inventory Turnover	0,58510	0,15085	0,07542
5	Cost	0,56990	0,14693	0,07347
6	Sales Performance	0,17236	0,04444	0,02222
7	Partnership Life	0,10544	0,02718	0,01359
8	Delivery Date Loyalty	0,06297	0,01623	0,00812
9	Location	0,02013	0,00519	0,00260

We would need some criteria for cluster structure in the next steps of the whole analysis. So we needed to divide these criteria into two groups. We used the enough number of the most meaningful ones for AHP and DEA analysis. At this step, we used the Weighted Average Clustering Method (WAC) to divide these criteria into two groups. We used SAS software for clustering. Figure 3.2 shows the genogram.

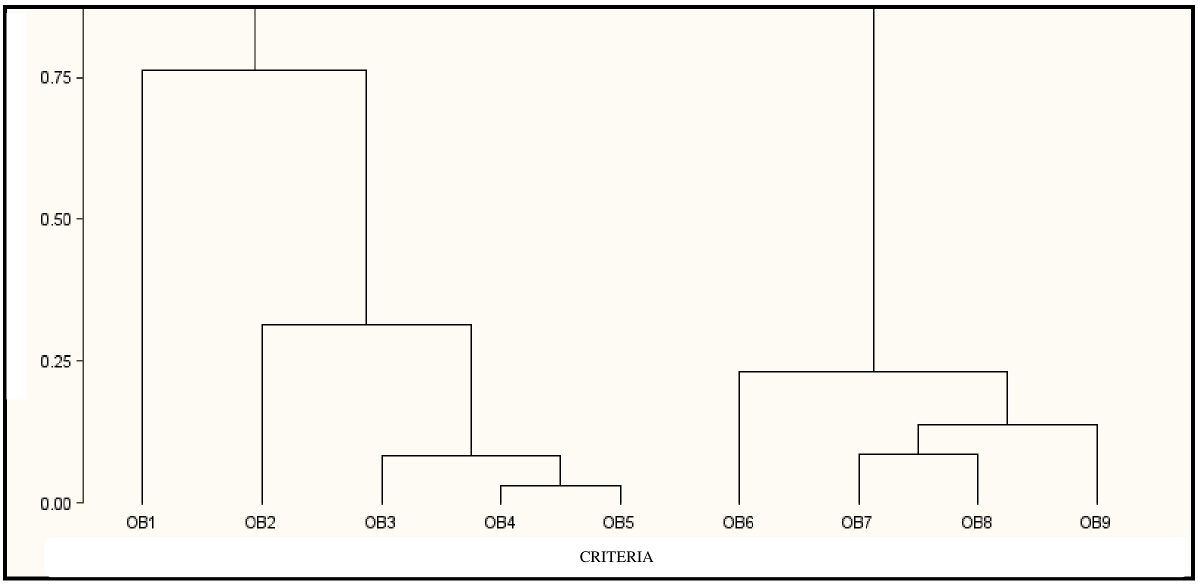

Figure 3.2 Dendrogram for Criteria

As we see from Figure 3.2, the criteria are separated into 2 groups. First group members are the most effective ones. Second group members have less effect on the supplier selection and evaluation due to ANP results.

As a result, we have considered five evaluation criteria at the end of the method: Cost, Rejection Ratio, Inventory Turnover, GMROI, and Sales Quantity. Among them, Cost and Rejection Ratio are considered as inputs and Inventory Turnover, GMROI and Sales Quantity are taken in account as outputs. The explanations of these criteria are given as follows. As we mentioned before, other 4 criteria which experts are agreed with are used at the clustering structure at the following sections.

Cost: The biggest part of the sales cost comes from the first price of products. The minimization of unit cost probably will have great effect on total cost [70, 87, and 88]. Its related attributes include appropriateness of the materials price to the market price, competitiveness of cost, cost reduction capability, cost reduction effort, cost reduction performance, direct cost, fluctuation on costs, indirect-coordination cost, logistics cost, manufacturing cost, unit cost, ordering cost, parts price, product price, and total cost of shipments.

Rejection Ratio: This criterion shows both product quality and product ability to meet the customer expectations. If the customer is not satisfied with the product, he/she probably gives back the product. So if the rejection ratio is so high for a supplier, this means customers are not satisfied with any feature of products of this supplier [87].

Inventory Turnover: The inventory turnover is a measure of the number of times inventory is sold or used in a time period such as a year. The equation for inventory turnover equals the cost of goods sold divided by the average inventory. This criterion is important, because it gives the performance of the product. Accordingly, this criterion shows the performance of the supplier in one way.

GMROI: Gross Margin Return on Inventory (GMROI) is a "turn and earn" metric that measures inventory performance based on both margin and inventory turnover. It is one way to determine how valuable the seller's inventory is. Furthermore it describes the relationship between total sales, total profit from total sales, and the amount of resources invested in the inventory sold. GMROI is particularly important in the retail industry where stock turn and Gross Margin Percent (simply called margin) can vary heavily by item, location, and week. GMROI can act as the main driver for retailers to analyze their product and store offering.

Sales Quantity: This criterion is very important to show the performance of the supplier. The importance of it can be raised by the policy of the firm. If the firm policy is to sell more quantity than to sell more expensive products, then the quantity becomes more important criteria. Even the firm policy is not linked to the sales quantity; it is also important criteria because it sets the total cost of goods sold and revenue.

Table 3.3 presents the values of 5 criteria values for 15 suppliers.

Table 3.3 Input and Output Values of DMUs

DMUs	INPUT		OUTPUT		
Supplier	Cost	Rejection	Sales	Inventory Turnover	GMROI
S1	42.19	0.07	4.309	1.69	3.18
S2	28.94	0.10	1.878	6.24	2.11
S3	25.05	0.07	3.653	6.26	8.79
S4	46.81	0.06	889	12.35	10.51
S5	23.83	0.07	13.067	3.24	3.34
S6	46.21	0.09	2.641	3.59	2.53
S7	44.36	0.05	17.645	3.48	2.95
S8	54.37	0.06	2.026	1.47	1.45
S9	16.34	0.04	9.232	4.96	3.23
S10	60.64	0.02	235	0.08	1.08
S11	56.65	0.08	6.859	1.77	2.56
S12	56.54	0.07	2.381	0.89	2.04
S13	69.30	0.03	197	0.10	1.27
S14	56.91	0.06	3.921	1.18	2.60
S15	62.37	0.09	5.197	3.42	1.40

Also Table 3.4 shows the analysis of the data set values as minimum, maximum, mean and standard division.

Table 3.4 Analysis of the Data Set

Name	Minimum	Maximum	Mean	Standard Derivation
Cost	16.34	69.3	46.034	15.401
Rejection Ratio	0.02	0.1	0.064	0.0215
Sales	197	17645	4942	4785.204
Inventory Turnover	0.08	12.35	3.3813	3.0691
GMROI	1.08	10.51	3.2693	2.62

3.1.1 Input Data Analysis

We have included 2 of the 5 criteria as inputs. We took cost and rejection ratio as inputs because we need to minimize these values. Figure 3.3 illustrates input values.

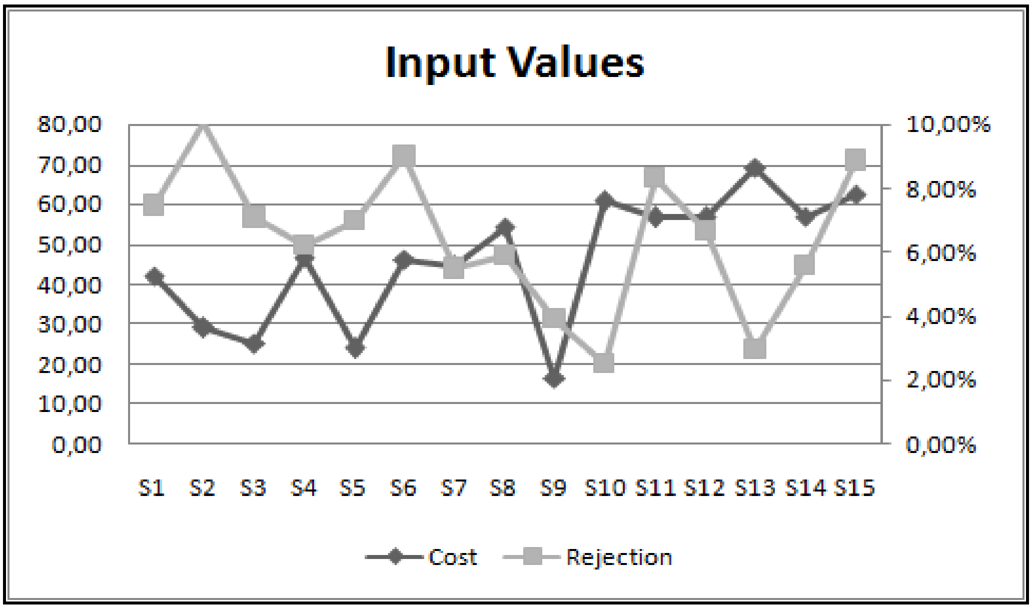

Figure 3.3 Input Values

There is an insignificant correlation between input parameters. In practice, we can say that if a product is cheap then the quality is poor. According to this generalization, we can say there is a strict correlation between cost and rejection ratio. But when we analyze the values of cost and rejection ratio, we can see that the correlation values are -0,21272874 which states as a bad correlation. This can say us that customers estimate the product quality depending on cost during shopping. So rejection ratio is not so correlated to the cost.

3.1.2 Output Data Analysis

We have included 3 of 5 criteria as outputs. We took sales, inventory turnover and GMROI as outputs because we need to maximize these values. In Figure 3.4 output values are illustrated.

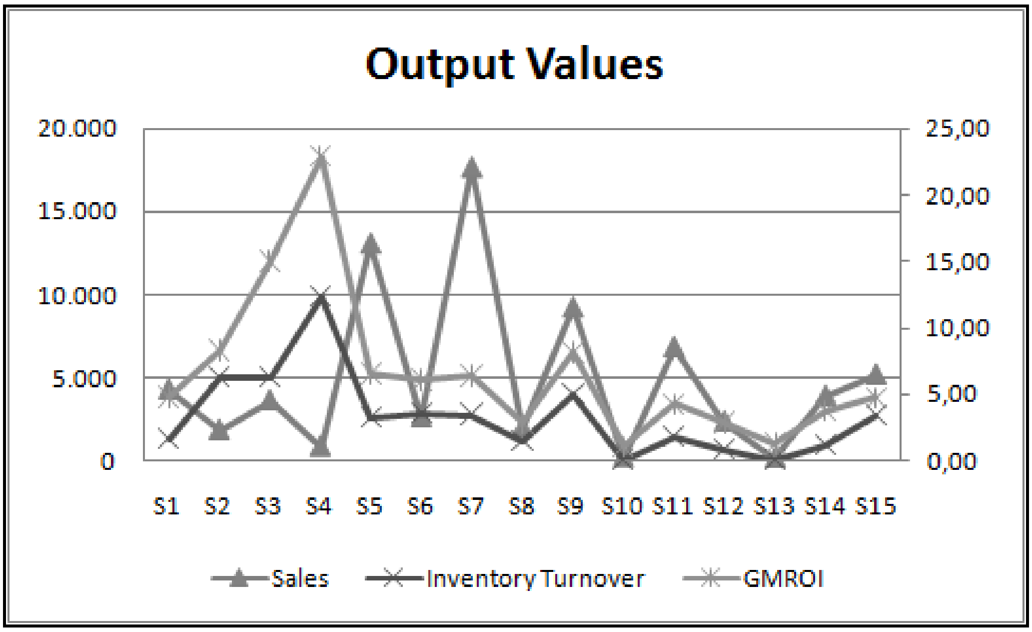

Figure 3.4 Output Values

There is only one significant correlation between outputs. Table 3.5 shows the correlation values between outputs.

Table 3.5 Correlation Between Outputs

#	1. Variable	2. Variable	Correlation
1	Sales	Inventory Turnover	0,00399414
2	Sales	GMROI	- 0,04115070
3	Inventory Turnover	GMROI	0,83095339

As we can see from Table 3.5, there is only one significant correlation which is between inventory turnover and GMROI. This is an expected result for Inventory Turnover and GMROI.

3.2 DETAILS OF THE MODEL

We performed our analysis in two stages. In the first stage, we have evaluated all suppliers by means of the DEA method. Recall that, we have employed output oriented constant returns-to-scale *CCR model* where we assume that the company is trying to *maximize* outputs while having *same* input. Since inputs are linked to the suppliers, outputs can be modified by the firm. We have evaluated the suppliers according to the 2010 values of the evaluation factors.

We can set a linear programming model for each supplier by using DEA CCR formulation that mentioned at the previous sections. Then by solving these models, efficiency for each supplier can be calculated. These models for each supplier are listed in Appendix.

In order to find out relative efficiency of sample suppliers, DEAOS Software is used. The software has options to use a model which optimizes inputs and outputs. The Radial Model attempts a radial improvement. It is logical to use output maximization since the suppliers are trying to do their best. The cross efficiency scores of the suppliers by DEA method are shown in Table 3.6 where S3, S9, S4, and S7 are the most efficient.

Table 3.6 Cross Efficiency Scores

	Efficiency	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
S1	39.2	39.2	17.6	89.6	100.0	71.5	23.0	100.0	19.5	100.0	20.5	35.4	22.7	17.8	35.5	20.5
S2	71.0	13.2	71.0	82.3	86.9	44.8	25.6	25.8	8.9	100.0	0.4	10.3	5.2	0.5	6.8	18.1
S3	100.0	38.4	19.7	100.0	100.0	71.9	23.5	82.9	17.6	100.0	14.7	32.3	21.2	13.7	31.5	18.4
S4	100.0	11.7	30.3	43.4	100.0	22.5	19.4	33.8	11.9	60.2	1.9	10.7	6.2	1.6	9.6	18.5
S5	97.1	18.1	11.5	25.8	3.4	97.1	10.1	70.4	6.6	100.0	0.7	21.4	7.5	0.5	12.2	14.7
S6	27.1	14.5	63.8	79.2	100.0	42.5	27.1	30.3	10.5	100.0	0.6	11.6	6.0	0.6	8.1	20.4
S7	100.0	17.4	5.3	14.8	4.2	52.9	8.3	100.0	9.6	65.4	3.3	24.3	9.6	1.9	18.5	16.4
S8	19.8	36.9	15.3	79.6	100.0	62.1	21.2	100.0	19.8	88.8	32.2	34.1	22.7	24.7	36.5	19.6
S9	100.0	13.2	71.0	82.3	86.9	44.8	25.6	25.8	8.9	100.0	0.4	10.3	5.2	0.5	6.8	18.1
S10	32.2	36.9	15.3	79.6	100.0	62.1	21.2	100.0	19.8	88.8	32.2	34.1	22.7	24.7	36.5	19.6
S11	35.4	39.2	17.6	89.6	100.0	71.5	23.0	100.0	19.5	100.0	20.5	35.4	22.7	17.8	35.5	20.5
S12	22.7	39.2	17.6	89.6	100.0	71.5	23.0	100.0	19.5	100.0	20.5	35.4	22.7	17.8	35.5	20.5
S13	24.7	36.9	15.3	79.6	100.0	62.1	21.2	100.0	19.8	88.8	32.2	34.1	22.7	24.7	36.5	19.6
S14	36.5	36.9	15.3	79.6	100.0	62.1	21.2	100.0	19.8	88.8	32.2	34.1	22.7	24.7	36.5	19.6
S15	28.3	22.4	32.9	51.6	100.0	55.3	24.1	96.2	17.6	100.0	4.0	25.8	12.1	2.8	21.0	28.3

One unique part of the DEA approach is that each supplier is allowed to choose the weights of its inputs and outputs in such a fashion that maximizes the ratio of their weighted output to weighted input, i.e., its efficiency. It is similar to an individual rating himself or herself and trying to project strengths and hiding weaknesses so that the overall image is enhanced. This, in DEA terms, is called self-appraisal. Suppliers which are stronger in some of the outputs, or use less of some of the inputs compared to their competitors may allocate higher weight to these to maximize their output-to-input ratio. Thus, in effect, they are focusing on their strengths and hiding their weaknesses to project themselves as more efficient or ``self-efficient". So, there is an inherent tendency for the suppliers to over-rate themselves. To remove this inbuilt deficiency in the traditional DEA-based efficiency measurement method we performed a second stage with AHP method to cross-check the DEA results.

At the second stage, we have applied the AHP method. The Production Planning (P&P) Department evaluated the suppliers in brain storming sessions. There are steps of implementing the AHP method. These steps are given below:

Step 1: The overall goal (objective) is identified as finding the best supplier.
Step 2: The criteria which are mentioned at previous sections used to satisfy the overall goal are identified as Cost, Rejection Ratio, GMROI, Inventory Turnover, and Sales Quantity. Figure 3.5 illustrates the AHP tree.

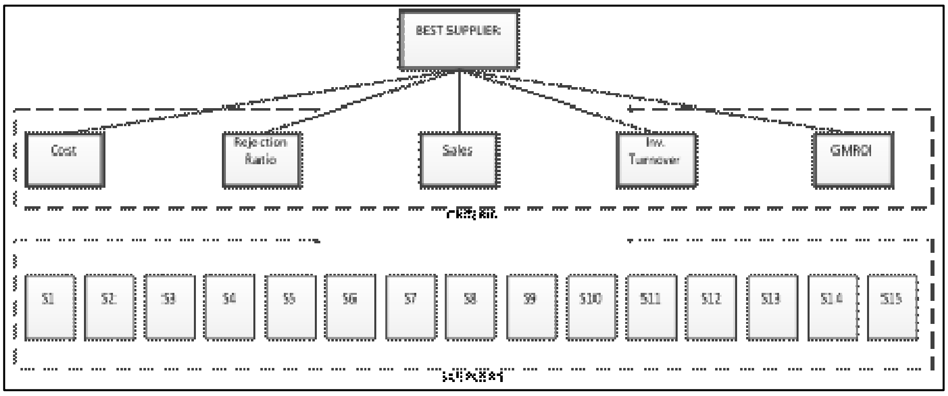

Figure 3.5 AHP Tree of the Example

Step 3: Pairwise comparisons are constructed. For this step, elements of the problem are paired with respect to their common relative impact on a property and then compared due to the relative importance scale in Table 2.5. First the P&P Department evaluated the factors in order to obtain an importance scale of the factors in the brain storming sessions. Next, after evaluating these factors, the participants evaluated the suppliers according to these factors. Table 3.7 shows the ranking results.

Table 3.7 Factor Rankings

	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	
Cost												x								Rejection Ratio
Cost													x							Sales
Cost													x							Inv. Turnover
Cost													x							GMROI
Rejection Ratio													x							Sales
Rejection Ratio													x							Inv. Turnover
Rejection Ratio													x							GMROI
Sales												x								Inv. Turnover
Sales												x								GMROI
Inv. Turnover												x								GMROI

The participants had different views, but all of them closely know the company, suppliers, products and sales. An important consideration in terms of the quality of the ultimate decision relates to consistency of judgments that the decision maker demonstrated during the sessions for pairwise comparison matrix establishment. Therefore during the sessions the participants tried to reach a consensus. The participants made their evaluation by using both qualitative and quantitative data such as location, date loyalty, order number loyalty, partnership life and sales performance.

Step 4: Weights of the decision elements are estimated by using the eigenvalue method. Consistency of judgments is checked. Consistency Ratio (CR) values must be less than or equal to 0,10. Table 3.8 shows consistencies of judgments for each criterion and all of them are less than 0,10. Also overall CR is equal to 0,07493 and it is again less than 0,10.

Table 3.8 Consistencies of Judgments

Criteria	CR
Cost	0,08285
Rejection Ratio	0,09776
Sales	0,09919
Inv. Turnover	0,09800
GMROI	0,09761

Step 5: Hierarchical composition is used to combine the weight vectors and arrive at global and local relative contributions of each element. Table 3.9 shows the adjusted weights of the suppliers based on criteria.

Table 3.9 Adjusted Weights

S Matrix	**Cost**	**Rejection Ratio**	**Sales Quantity**	**Inv. Turnover**	**GMROI**
Adjusted Weighted (W)	***0,079***	***0,105***	***0,204***	***0,263***	***0,349***
S1	0,053	0,062	0,059	0,033	0,068
S2	0,040	0,081	0,033	0,100	0,065
S3	0,026	0,062	0,042	0,093	0,160
S4	0,039	0,057	0,030	0,153	0,145
S5	0,029	0,072	0,145	0,059	0,046
S6	0,027	0,058	0,039	0,079	0,044
S7	0,052	0,050	0,170	0,117	0,094
S8	0,060	0,052	0,029	0,038	0,039
S9	0,040	0,040	0,117	0,130	0,088
S10	0,146	0,087	0,073	0,027	0,033
S11	0,078	0,100	0,085	0,038	0,045
S12	0,087	0,078	0,040	0,030	0,045
S13	0,132	0,035	0,025	0,016	0,038
S14	0,093	0,063	0,059	0,037	0,067
S15	0,098	0,103	0,055	0,050	0,023

We calculated the importance of the suppliers based on the department feedbacks. According to expert evaluations with AHP method, the new ranking is S7, S4, S3 and S9. Table 3.10 shows the results of the AHP method.

Table 3.10 Composite Weights

Supplier	S7	S4	S3	S9	S5	S2	S11	S14	S1	S10	S6	S15	S12	S8	S13
Composite Weight	0,108	0,106	0,098	0,096	0,071	0,067	0,060	0,059	0,055	0,054	0,052	0,051	0,047	0,040	0,037

3.3 EVALUATION RESULTS

After applying models, to achieve a final result we need to check the consistency of the results. For this purpose, we calculated correlation between two result sets. The correlation is so significant with the value of 0,93019. So we could say that the results of these two methods are consistent. Figure 3.6 illustrates a comparison of the model results.

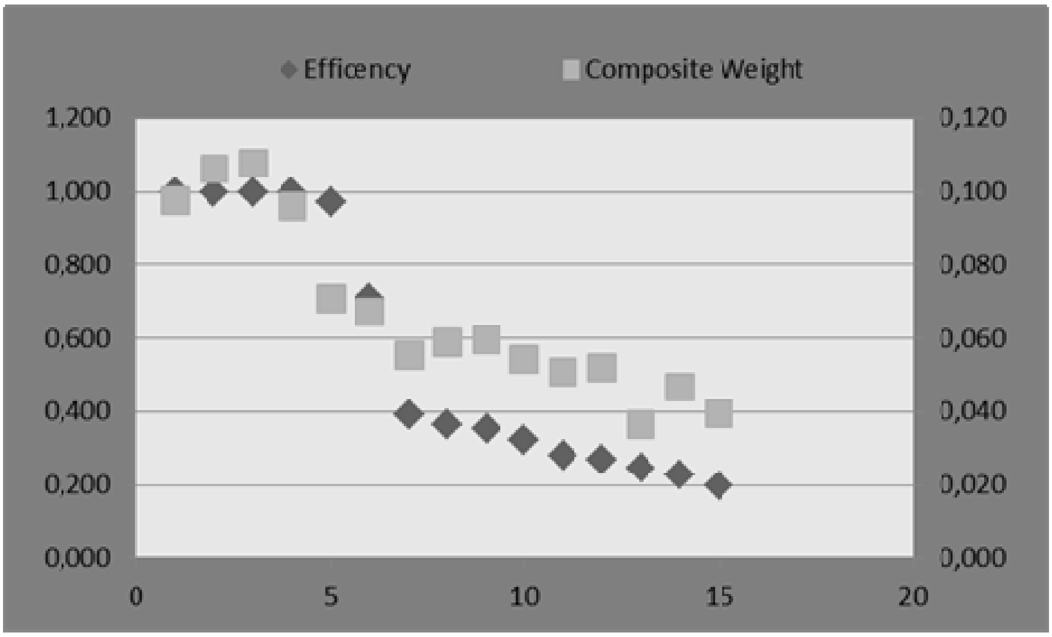

Figure 3.6 Comparison of the results of two models

3.3.1 Sensitivity Analysis

We applied the Sensitivity Analysis to the AHP results. We checked the sensitiveness due to criteria rankings. We used Excel Solver for this analysis and the result is shown at Table 3.11.

Table 3.11 Sensitivity Analysis Results

Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
Weight Cost	0,00051	0	0	0,6697	5,8336
Weight Rejection	13,12965	0	0	0,0103	0,0012
Weight Sales	0,00003	0	4308,9997	7578,7244	648,5311
Weight Inventory Turnover	0,00000	-2,5147	1,6925	2,5147	1E+30
Weight GMROI	0,07757	0	3,1783	0,5631	1,9960

From the Sensitivity Analysis Results, it can be seen that the efficiency is sensitive to the changes on rejection and GMROI than the other criteria. Minimal changes on these criteria can make big effects on the efficiency of the DMUs.

3.3.2 Clustering

Even the results of the two methods are consistent, sort of the results are different like:

- DEA sort is S3, S9, S4, and S7,
- AHP sort is S7, S4, S3 and S9.

Therefore after confirming the reliability of the results by Sensitivity Analysis, a cluster structure is needed for explaining the results. For this structure, we wanted the P&P Department to rank the suppliers due to Location, Delivery Date Loyalty and Partnership Life as worst, average and best. They ranked all suppliers. Beside rakings, we have achieved the past season sales performance of each supplier and we also used this data for clustering. The rankings and the sales performance values are showed at Table 3.12.

Table 3.12 Rankings for Clustering

ID	Sales Performance	Location	Delivery Date Loyalty	Partnership Life
S1	76%	Best	Average	Best
S2	71%	Average	Average	Average
S3	79%	Worst	Average	Average
S4	78%	Worst	Average	Average
S5	90%	Best	Best	Average
S6	72%	Average	Average	Average
S7	72%	Best	Worst	Best
S8	70%	Average	Worst	Average
S9	69%	Best	Best	Average
S10	63%	Best	Best	Worst
S11	69%	Best	Average	Best
S12	73%	Best	Best	Best
S13	68%	Best	Best	Worst
S14	69%	Average	Worst	Average
S15	73%	Best	Worst	Best

After ranking, we used SAS Software again for clustering. We applied WAC Method to the results of both DEA and AHP methods. Figure 3.7 shows the clustering result.

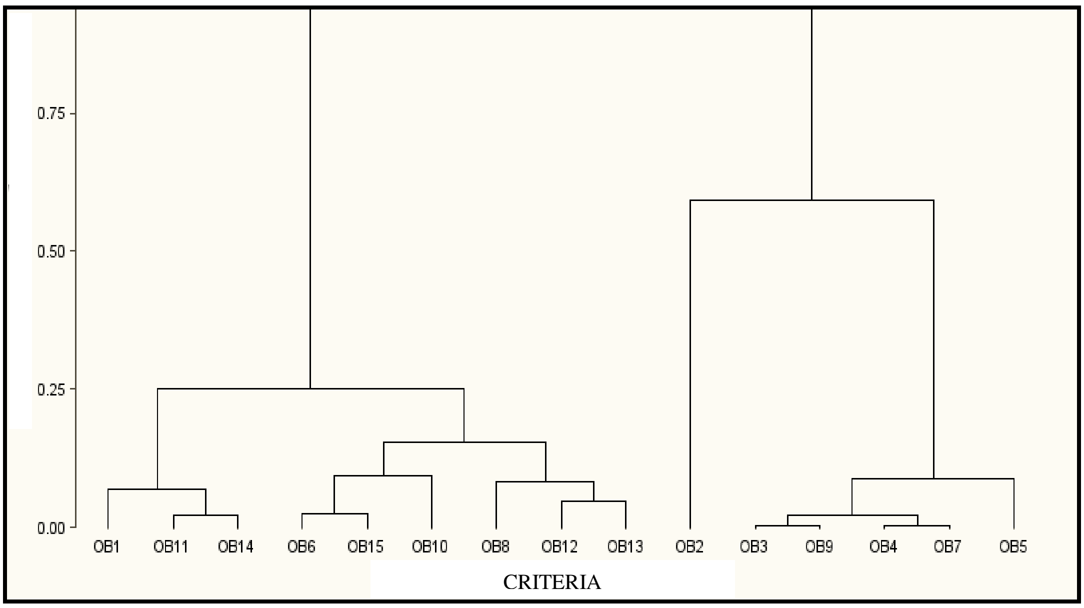

Figure 3.7 Dendrogram for Results

As we see from Figure 3.7, there are 4 obvious clusters. We assumed that two levels as a cluster. Results are listed in Table 3.13 where common characteristics of the cluster members are also summarized.

According to Table 3.13, it is obvious that suppliers S3, S4, S7, S9 and S5 in Cluster 1 are the most preferred ones among all 15 suppliers. At this point, the retail company should consider the production capacity and stock capacity of suppliers S3, S4, S7, S9 and S5. In case the suppliers have enough capacities, the firm should direct all product orders to the suppliers in Cluster 1.

Table 3.13 Classifications of Suppliers

Cluster	Supplier	Efficiency	Composite Weight	Cluster Characteristics
1	S3	1,000	0,098	- Costs are below the average, - Rejection Ratio is close to average, - Inventory Turnover is close to or over the average, - GMROI is close to or over the average, - Sales Performance is around the average, - Partnership Life is average or best.
	S4	1,000	0,106	
	S7	1,000	0,108	
	S9	1,000	0,096	
	S5	0,971	0,071	
2	S2	0,710	0,067	- Cost and Rejection Ratio are below the average.
3	S1	0,392	0,055	- Costs are around the average, - Rejection Ratio is around the average, - Sales are close to average, - Inventory Turnover is less than average, - GMROI is less than the average, - Sales Performance is around the average, - Location is best or average, - Delivery Date Loyalty is average or worst, - Partnership Life is best or average.
	S14	0,365	0,059	
	S11	0,354	0,060	
4	S10	0,322	0,054	- Costs are over the average and close to the max, - GMRIO is close to minimum, - Sales Performance is between minimum and average, - Location is best or average.
	S15	0,283	0,051	
	S6	0,271	0,052	
5	S13	0,247	0,037	- Costs are close to maximum, - Inventory Turnover is less than the average, - GMROI is less than the average, - Sales Performance is less than or equal to the average, - Location is best or average.
	S12	0,227	0,047	
	S8	0,198	0,040	

4 CONCLUSION

Supplier selection and supplier evaluation became a very important step in retail sector during the fast growing of this industry. There are many shoe manufacturers which in the market. Retailers have to choose the best ones for them.

There are many criteria to evaluate the suppliers in practice. This means supplier performance affects retailer sales directly. The criteria such as cost, quality, and reputation are closely linked to supplier performance.

In this work we have considered the measurement of supplier efficiencies in a retail company. We determine the criteria for evaluation with ANP method and WAC method. Then we have applied a two stage approach which employs both the DEA and AHP methods.

In the first stage, we measure the efficiency of the suppliers with DEA method by using criteria which we determine with ANP method. In the second stage, we use the AHP method by using same criteria to verify the results obtained with the first stage. We have observed that the results obtained by both DEA and AHP methods are consistent. To check the reliability of these results, we applied Sensitivity Analysis. We realized that the results are so sensitive to the cost and rejection ratio at the end of the analysis.

After all applications, we need to have a cluster structure to explain the results clearly. Expert rates the suppliers according to location, delivery date loyalty and partnership life as worst, average and best. Also we used the reel sales performance data of the suppliers. We clustered the suppliers according to the DEA and AHP application results by using WAC method. After clustering, we defined the cluster characteristics based on the expert rates at location, delivery date loyalty and partnership life and also the sales performance data.

Consequently one can establish five supplier clusters. The members of the first cluster are the most efficient suppliers for this company. When we look at the characteristics of the first cluster, it can be seen that partnership life and product quality are the most important characteristic for a supplier to be an efficient supplier. Also if we compare first and second clusters, it can be said that rejection ratio has a significant effect on efficiency. Because the difference between these two clusters is only rejection ration of the second cluster is higher than the average. GMROI and SDH are the important at reducing the efficiency of the supplier.

In case the suppliers had infinite capacity for production and storage, the company would direct all product orders to the first cluster members. However, in real world, infinite capacity is not possible. Therefore, the company should send production orders to its suppliers from the most efficient to the least efficient. By using a two stage approach we were able to determine the most preferred suppliers of the retail company.

We believe that the approach used in this work can be applied to other efficiency measurement problems. For further research, one can also apply other multi-criteria decision making methods in addition to the AHP method.

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APPENDIX

<u>For Supplier S1:</u>

Max $4309u_1 + 1{,}69u_2 + 3{,}18u_3$

<u>Constraints:</u>

$4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \leq 0$
$1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \leq 0$
$3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \leq 0$
$889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \leq 0$
$13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \leq 0$
$2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \leq 0$
$17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \leq 0$
$2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \leq 0$
$9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \leq 0$
$235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \leq 0$
$6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \leq 0$
$2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \leq 0$
$197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \leq 0$
$3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \leq 0$
$5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \leq 0$
$42{,}19v_1 + 0{,}07v_2 = 1$
$u_1, u_1, u_3, v_1, v_1 \geq 0$

<u>For Supplier S2:</u>

$\text{Max}\, 1878u_1 + 6{,}24u_2 + 2{,}11u_3$

<u>Constraints:</u>

$4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \leq 0$
$1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \leq 0$
$3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \leq 0$
$889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \leq 0$
$13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \leq 0$
$2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \leq 0$
$17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \leq 0$
$2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \leq 0$
$9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \leq 0$
$235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \leq 0$
$6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \leq 0$
$2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \leq 0$
$197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \leq 0$
$3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \leq 0$
$5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \leq 0$
$28{,}94v_1 + 0{,}10v_2 = 1$
$u_1, u_1, u_3, v_1, v_1 \geq 0$

For Supplier S3:

Max $3653u_1 + 6{,}26u_2 + 8{,}79u_3$

Constraints:

$4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \leq 0$
$1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \leq 0$
$3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \leq 0$
$889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \leq 0$
$13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \leq 0$
$2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \leq 0$
$17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \leq 0$
$2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \leq 0$
$9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \leq 0$
$235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \leq 0$
$6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \leq 0$
$2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \leq 0$
$197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \leq 0$
$3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \leq 0$
$5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \leq 0$
$25{,}05v_1 + 0{,}07v_2 = 1$
$u_1, u_1, u_3, v_1, v_1 \geq 0$

For Supplier S4:

$\text{Max}\,889u_1 + 12{,}35u_2 + 10{,}61u_3$

Constraints:

$4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \le 0$
$1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \le 0$
$3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \le 0$
$889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \le 0$
$13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \le 0$
$2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \le 0$
$17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \le 0$
$2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \le 0$
$9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \le 0$
$235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \le 0$
$6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \le 0$
$2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \le 0$
$197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \le 0$
$3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \le 0$
$5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \le 0$
$46{,}81v_1 + 0{,}06v_2 = 1$
$u_1, u_1, u_3, v_1, v_1 \ge 0$

For Supplier S5:

$\text{Max}\,13067u_1 + 3{,}24u_2 + 3{,}34u_3$

Constraints:

$4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \leq 0$
$1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \leq 0$
$3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \leq 0$
$889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \leq 0$
$13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \leq 0$
$2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \leq 0$
$17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \leq 0$
$2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \leq 0$
$9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \leq 0$
$235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \leq 0$
$6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \leq 0$
$2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \leq 0$
$197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \leq 0$
$3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \leq 0$
$5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \leq 0$
$23{,}83v_1 + 0{,}07v_2 = 1$
$u_1, u_1, u_3, v_1, v_1 \geq 0$

<u>For Supplier S6:</u>

Max $2641u_1 + 3{,}59u_2 + 2{,}53u_3$

<u>Constraints:</u>

$$
\begin{aligned}
&4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \le 0 \\
&1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \le 0 \\
&3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \le 0 \\
&889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \le 0 \\
&13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \le 0 \\
&2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \le 0 \\
&17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \le 0 \\
&2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \le 0 \\
&9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \le 0 \\
&235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \le 0 \\
&6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \le 0 \\
&2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \le 0 \\
&197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \le 0 \\
&3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \le 0 \\
&5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \le 0 \\
&6{,}21v_1 + 0{,}09v_2 = 1 \\
&u_1, u_1, u_3, v_1, v_1 \ge 0
\end{aligned}
$$

<u>For Supplier S7:</u>

$$\text{Max}\, 17645u_1 + 3{,}48u_2 + 2{,}95u_3$$

<u>Constraints:</u>

$$4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \le 0$$
$$1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \le 0$$
$$3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \le 0$$
$$889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \le 0$$
$$13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \le 0$$
$$2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \le 0$$
$$17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \le 0$$
$$2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \le 0$$
$$9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \le 0$$
$$235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \le 0$$
$$6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \le 0$$
$$2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \le 0$$
$$197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \le 0$$
$$3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \le 0$$
$$5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \le 0$$
$$44{,}36v_1 + 0{,}05v_2 = 1$$
$$u_1, u_1, u_3, v_1, v_1 \ge 0$$

<u>For Supplier S8:</u>

Max $2026u_1 + 1{,}47u_2 + 1{,}45u$

<u>Constraints:</u>

$4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \leq 0$
$1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \leq 0$
$3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \leq 0$
$889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \leq 0$
$13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \leq 0$
$2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \leq 0$
$17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \leq 0$
$2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \leq 0$
$9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \leq 0$
$235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \leq 0$
$6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \leq 0$
$2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \leq 0$
$197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \leq 0$
$3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \leq 0$
$5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \leq 0$
$4{,}37v_1 + 0{,}06v_2 = 1$
$u_1, u_1, u_3, v_1, v_1 \geq 0$

For Supplier S9:

$\text{Max}\,9232u_1 + 4{,}96u_2 + 3{,}23u_3$

Constraints:

$4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \leq 0$
$1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \leq 0$
$3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \leq 0$
$889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \leq 0$
$13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \leq 0$
$2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \leq 0$
$17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \leq 0$
$2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \leq 0$
$9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \leq 0$
$235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \leq 0$
$6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \leq 0$
$2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \leq 0$
$197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \leq 0$
$3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \leq 0$
$5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \leq 0$
$6{,}34v_1 + 0{,}04v_2 = 1$
$u_1, u_1, u_3, v_1, v_1 \geq 0$

<u>For Supplier S10:</u>

Max $235u_1 + 0{,}08u_2 + 1{,}08u_3$

<u>Constraints:</u>

$$4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \le 0$$
$$1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \le 0$$
$$3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \le 0$$
$$889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \le 0$$
$$13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \le 0$$
$$2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \le 0$$
$$17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \le 0$$
$$2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \le 0$$
$$9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \le 0$$
$$235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \le 0$$
$$6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \le 0$$
$$2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \le 0$$
$$197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \le 0$$
$$3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \le 0$$
$$5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \le 0$$
$$60{,}64v_1 + 0{,}02v_2 = 1$$
$$u_1, u_1, u_3, v_1, v_1 \ge 0$$

For Supplier S11:

Max $6859u_1 + 1{,}77u_2 + 2{,}56u_3$

Constraints:

$4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \leq 0$
$1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \leq 0$
$3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \leq 0$
$889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \leq 0$
$13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \leq 0$
$2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \leq 0$
$17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \leq 0$
$2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \leq 0$
$9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \leq 0$
$235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \leq 0$
$6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \leq 0$
$2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \leq 0$
$197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \leq 0$
$3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \leq 0$
$5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \leq 0$
$56{,}65v_1 + 0{,}08v_2 = 1$
$u_1, u_1, u_3, v_1, v_1 \geq 0$

For Supplier S12:

Max $2381u_1 + 0{,}89u_2 + 2{,}04u_3$

Constraints:

$$
\begin{aligned}
&4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \le 0\\
&1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \le 0\\
&3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \le 0\\
&889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \le 0\\
&13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \le 0\\
&2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \le 0\\
&17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \le 0\\
&2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \le 0\\
&9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \le 0\\
&235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \le 0\\
&6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \le 0\\
&2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \le 0\\
&197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \le 0\\
&3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \le 0\\
&5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \le 0\\
&56{,}54v_1 + 0{,}07v_2 = 1\\
&u_1, u_1, u_3, v_1, v_1 \ge 0
\end{aligned}
$$

For Supplier S13:

$\text{Max}\,197u_1 + 0{,}10u_2 + 1{,}27u_3$

Constraints:

$4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \leq 0$
$1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \leq 0$
$3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \leq 0$
$889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \leq 0$
$13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \leq 0$
$2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \leq 0$
$17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \leq 0$
$2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \leq 0$
$9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \leq 0$
$235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \leq 0$
$6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \leq 0$
$2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \leq 0$
$197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \leq 0$
$3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \leq 0$
$5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \leq 0$
$69{,}30v_1 + 0{,}03v_2 = 1$
$u_1, u_1, u_3, v_1, v_1 \geq 0$

<u>For Supplier S14:</u>

Max $3921u_1 + 1{,}18u_2 + 2{,}60u_3$

<u>Constraints:</u>

$4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \leq 0$
$1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \leq 0$
$3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \leq 0$
$889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \leq 0$
$13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \leq 0$
$2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \leq 0$
$17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \leq 0$
$2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \leq 0$
$9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \leq 0$
$235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \leq 0$
$6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \leq 0$
$2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \leq 0$
$197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \leq 0$
$3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \leq 0$
$5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \leq 0$
$56{,}91v_1 + 0{,}06v_2 = 1$
$u_1, u_1, u_3, v_1, v_1 \geq 0$

For Supplier S15:

Max $5197u_1 + 3{,}42u_2 + 1{,}40u_3$

Constraints:

$$4309u_1 + 1{,}69u_2 + 3{,}18u_3 - 42{,}19v_1 - 0{,}07v_2 \le 0$$
$$1878u_1 + 6{,}24u_2 + 2{,}11u_3 - 28{,}94v_1 - 0{,}10v_2 \le 0$$
$$3653u_1 + 6{,}26u_2 + 8{,}79u_3 - 25{,}05v_1 - 0{,}07v_2 \le 0$$
$$889u_1 + 12{,}35u_2 + 10{,}61u_3 - 46{,}81v_1 - 0{,}06v_2 \le 0$$
$$13067u_1 + 3{,}24u_2 + 3{,}34u_3 - 23{,}83v_1 - 0{,}07v_2 \le 0$$
$$2641u_1 + 3{,}59u_2 + 2{,}53u_3 - 6{,}21v_1 - 0{,}09v_2 \le 0$$
$$17645u_1 + 3{,}48u_2 + 2{,}95u_3 - 44{,}36v_1 - 0{,}05v_2 \le 0$$
$$2026u_1 + 1{,}47u_2 + 1{,}45u_3 - 4{,}37v_1 - 0{,}06v_2 \le 0$$
$$9232u_1 + 4{,}96u_2 + 3{,}23u_3 - 6{,}34v_1 - 0{,}04v_2 \le 0$$
$$235u_1 + 0{,}08u_2 + 1{,}08u_3 - 60{,}64v_1 - 0{,}02v_2 \le 0$$
$$6859u_1 + 1{,}77u_2 + 2{,}56u_3 - 56{,}65v_1 - 0{,}08v_2 \le 0$$
$$2381u_1 + 0{,}89u_2 + 2{,}04u_3 - 56{,}54v_1 - 0{,}07v_2 \le 0$$
$$197u_1 + 0{,}10u_2 + 1{,}27u_3 - 69{,}30v_1 - 0{,}03v_2 \le 0$$
$$3921u_1 + 1{,}18u_2 + 2{,}60u_3 - 56{,}91v_1 - 0{,}06v_2 \le 0$$
$$5197u_1 + 3{,}42u_2 + 1{,}40u_3 - 62{,}37v_1 - 0{,}09v_2 \le 0$$
$$62{,}37v_1 + 0{,}09v_2 = 1$$
$$u_1, u_1, u_3, v_1, v_1 \ge 0$$

BIOGRAPHICAL SKETCH

Neslihan Neşe Aldıkaçtı, the candidate of Master of Science in Industrial Engineering Department in Galatasaray University, was born in 1983 in İstanbul. She graduated from Hasan Polatkan High School in 2001. In the same year, she started her bachelor education in Industrial Engineering in İstanbul University. She started her double major, Computer Engineering, in 2003. In 2005, she completed her education in Industrial Engineering major with the fourth highest GPA and graduated from İstanbul University. She completed 50% credits of double major. She started to work for Finansbank A.Ş. as Process Management Supervisor in 2005. In 2007, she started to work for HSBC A.Ş. as Service Quality Management Specialist. Then, in 2010 she started to work for FLO A.Ş. in retail sector.