An application of data envelopment analytic hierarchy process for supplier selection: a case study of BEKO in Turkey — Source link

Mehmet Sevkli, S.C. Lenny Koh, Selim Zaim, Mehmet Demirbag ...+1 more authors

Institutions: Fatih University, University of Sheffield, Bahçeşehir University

Published on: 16 Jul 2007 - International Journal of Production Research (INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH)

Topics: Analytic hierarchy process and Data envelopment analysis

AN APPLICATION OF DATA ENVELOPMENT ANALYTIC HIERARCHY PROCESS FOR SUPPLIER SELECTION: A CASE STUDY OF BEKO IN TURKEY

Mehmet Sevkli, S C Lenny Koh, Selim Zaim, Mehmet Demirbag, Ekrem Tatoglu

AN APPLICATION OF DATA ENVELOPMENT ANALYTIC HIERARCHY PROCESS FOR SUPPLIER SELECTION: A CASE STUDY OF BEKO IN TURKEY

Journal:	*International Journal of Production Research*
Manuscript ID:	TPRS-2006-IJPR-0304.R1
Manuscript Type:	Original Manuscript
Date Submitted by the Author:	21-Jul-2006
Complete List of Authors:	Sevkli, Mehmet; Fatih University, Industrial Engineering Koh, S C Lenny; University of Sheffield, School of Management Zaim, Selim; Fatih University, Management Demirbag, Mehmet; University of Sheffield, Management School Tatoglu, Ekrem; Bahcesehir University, Business Administration
Keywords:	SUPPLY CHAIN MANAGEMENT, DATA ENVELOPMENT ANALYSIS, SUPPLIER SELECTION
Keywords (user):	analytical hierarchy process, decision making

AN APPLICATION OF DATA ENVELOPMENT ANALYTIC HIERARCHY PROCESS FOR SUPPLIER SELECTION: A CASE STUDY OF BEKO IN TURKEY

by

Mehmet Sevkli[1], S.C. Lenny Koh[2], Selim Zaim[3], Mehmet Demirbag[4] and Ekrem Tatoglu[5]

[1]Assistant Professor, Fatih University, Department of Industrial Engineering, Buyukcekmece, Istanbul, Turkey.

[2]Senior Lecturer, University of Sheffield, Management School, Sheffield, UK.

[3]Associate Professor, Fatih University, Department of Management, Buyukcekmece, Istanbul, Turkey.

[4]Lecturer, University of Sheffield, Management School, Sheffield, UK.

[5]Associate Professor, Bahcesehir University, Faculty of Business Administration, Besiktas, Istanbul, Turkey.

Address for Correspondence:

Dr S.C. Lenny Koh,
Senior Lecturer,
University of Sheffield,
Management School, 9 Mappin Street,
Sheffield, S1 4DT, UK.

Tel: +44 114 222 3395
Fax: +44 114 222 3348
E-mail: S.C.L.Koh@Sheffield.ac.uk

AN APPLICATION OF DATA ENVELOPMENT ANALYTIC HIERARCHY PROCESS FOR SUPPLIER SELECTION: A CASE STUDY OF BEKO IN TURKEY

ABSTRACT

This paper aims to apply a hybrid method of supplier selection to a well-known Turkish company operating in appliance industry. The data envelopment analytic hierarchy process (DEAHP) methodology developed by Ramanathan (2006) was chosen as the survey method. In this method, data envelopment analysis (DEA) approach is embedded into analytic hierarchy process (AHP) methodology. This research concluded that DEAHP method outperforms AHP method for supplier selection despite the findings that AHP model suggested supplier 1 to be the best supplier, contradicting the suggestion made by DEAHP model and the real action taken by BEKO in selecting supplier 2. These findings imply that DEAHP criteria reflect closer to the real optimum of the decision made. Drawing on a real case our study has supported Ramanathan's (2006) work confirming the view that DEAHP method provides better decision than AHP method for supplier selection. Because DEAHP model is relatively more cumbersome to apply, its application will be more appropriate for high value components where stringent purchasing criteria are required. In contrast, AHP would remain to be an appropriate approach for relatively lower value components (C class). The novelty of this research lies in the application of a hybrid approach to a real industry case - DEAHP method for supplier selection, where little has been done on this subject. This study has dealt with one of the most important subjects in supply chain management providing better decision for supplier selection using appropriate quantitative approaches.

Keywords: *Data envelopment analysis, analytical hierarchy process, supply chain, supplier selection, decision making*.

Paper type: Research paper

AN APPLICATION OF DATA ENVELOPMENT ANALYTIC HIERARCHY PROCESS FOR SUPPLIER SELECTION: A CASE STUDY OF BEKO IN TURKEY

INTRODUCTION

A supply chain is an interlinked network of suppliers, manufacturers, distributors and customers whereby materials or services flow from the suppliers through manufacturers and distributors to the customers. In a conventional supply chain, the information flows in the opposite direction, from the customers through the distributors and manufacturers to the suppliers. Conventional supply chains are therefore characterized by the forward flow of material and the backward flow of information (Handfield and Nichols, 2002; Simchi-Levi et al. 2000; Riddalls et al. 2000; Handfield and Nichols, 1999).

A typical supply chain may well be large-scale in nature, having many tiers or echelons of suppliers, where each supplier tier provides goods or services to the next tier in the supply chain. Additionally, each tier may have multiple components creating a network where the linear flow of goods along the supply chain is rare (Riddals et al. 2000). The same is often true for distributors, where there may be several tiers of distribution within the chain that could include finished goods storage, local distributors, regional distributors and national distributors. Exacerbating this situation, each component or member of the supply chain may be a part of a number of other supply chains, each demanding attention and often acting in conflict with each other. Such complexity has resulted in an increasing importance placed on supplier selection.

From a viewpoint of company or a member of a supply chain, there exists competition with other supply chains in order to secure suitable supplies and deliveries. This competition necessitates selecting carefully suitable suppliers for collaboration. Various factors have been used as criteria for supplier selection including price, delivery performance, reputation in the industry, size of enterprise, geographical location, quality (e.g. ISO 9000), environmental compliance (e.g. ISO 14000), capacity, services, lead-time, packaging, transportation storage, and product development. The applicability of these criteria depends on the product or service produced and the market for which these products or services is targeted. To this end, extensive research focuses on developing methods to assist supplier selection, so does the availability of the application evidence of several supplier selection methods in the industry. Nevertheless, little work has been undertaken on rationalizing the real industrial implications of many of the supplier selection methods. This paper evaluates the real industry implications of the existing supplier selection methods and applies a hybrid method of supplier selection to a well-known Turkish company operating in appliance industry.

BACKGROUND LITERATURE

Several supplier selection methods have been identified and widely applied in the industry. Boeing adopts a Preferred Supplier Certification program - a rigorous supplier selection process helping foster long-term relationships with a core group of high-quality, low-cost, on-time suppliers (www.boeing.com). Boeing grades performance quarterly, providing a report card that becomes a tool for improvement and ongoing dialogue in areas of common interest. This program enables Boeing to work closely with its supplier partners by helping them eliminate waste in their own processes. Through the use of Accelerated Improvement Workshops and by implementing a tool known as Value Stream Mapping, Boeing helped an Oklahoma company supplying fuel engine displays for the F/A-18 which in turn reduced the cost of the product by 48%, and cut order-to-delivery time by 40%. Boeing also helped a California based manufacturing company supplying refueling nozzles streamline its processes, resulting in a 16% reduction in assembly time and a reduction in production setup time from 9 hours to 1.5 hours. Value Stream Mapping and Improvement Workshops assisted a South Carolina company producing cables for the Boeing Joint Direct Attack Munition (JDAM) cut assembly time by 44%, and increase productivity by 27%. Also, Boeing helped a British supplier responsible for repairs on a key part for the AV-8B. With the use of Value Stream Mapping, the turnaround time for those repairs was reduced from 8 months to 20 days. The successes in Boeing derived from the Preferred Supplier Certification program and assisted by the Accelerated Improvement Workshops and Value Stream Mapping are self-evidenced, purporting the application of a singular method for supplier selection and supporting supplier partnerships using multiple methods. On the other hand, Diageo, the world leading premium alcoholic beverages, extends its responsibility beyond its own operations to those of its suppliers (www.diageo.com). According to Diageo's policy on corporate citizenship supplier standards – partnering with suppliers, Diageo seeks to collaborate with suppliers that conform to its standards, and select its suppliers based on the following criteria: ethical business practice, human rights and core labor standards, environmental impact, social responsibility and alcohol, and Diageo marketing code. Diageo ensures the entire supplier selection process complies with the company's standard through a framework that encompasses the procurement leadership group, corporate citizenship committee, programme governance group, programme implementation director and network of champions. Feedbacks on changes and improvements are made through this framework back to the board. Diageo is another case illustrating the use of a singular method, i.e. the framework, for supplier selection.

Industrialists and academics differ in their approach to the study of methods for supplier selection in that industrialists take a relatively more practical approach than academics. For instance, Seydel (2006) investigates DEA for decision support in vendor rating and selection despite difficulty in identifying application of DEA for supplier selection. In that study, the multi-criteria decision problem (vendor selection) was described and presented as a hypothetical example. Although the DEA method was modified to incorporate weight constraints and was used to rank the available vendors, which the results were claimed to provide a unique optimum solution, the method still lacks a real application case, in which its implications can be evaluated.

The use of hybrid method for supplier selection is not new. Wang et al. (2005) have developed a decision-based methodology for supply chain design that a plant manager can use to select suppliers. This methodology derived from the techniques of analytical hierarchy process (AHP) and pre-emptive goal programming. AHP is a widely adopted decision support technique in management research. For example, the applications of AHP can be found in evaluating risk factors in Enterprise Resource Planning (ERP) implementation (Huang et al., 2004) and in translating knowledge of supply chain uncertainty (Koh and Tan, 2006). Recently, Haq and Kannan (2006) developed an integrated supplier selection and multi-echelon distribution inventory model for the original equipment manufacturing company in a built-to-order supply chain environment using fuzzy analytical hierarchy process (FAHP) and a genetic algorithm. Following the favourism of a hybrid method, Humphreys et al. (2005) attempted to address the question of paucity of research with real industrial applications through undertaking a survey on supplier evaluation within a multinational telecommunications company. They indicated that the proposed supplier selection methodology would indeed assist in reducing the product development timeframe as it automates the evaluation process and provides the procurement team with a flexible and responsive tool for assessing prospective suppliers. The assessment tool includes four types of indices to measure supplier involvement in design, namely satisfaction index, flexibility index, risk index and confidence index. These indices, nonetheless, measure the extent to which both the customer requirements and the supplier capabilities match or mismatch and therefore reflect the potential or risk of signing a project contract. It may be noted that these indices are limited in measurement nature, and such supplier selection method was not conducted using established quantitative approaches.

The literature review above reveals that previous research on the methods of supplier selection has one or more of the following characteristics:

- The academic-oriented literature has little or no evidence of real applications
- The academic-oriented literature shows minimal use of qualitative approaches
- The academic-oriented literature favours the use of a hybrid method, i.e. with a mix of established quantitative approaches
- The academic-oriented literature has little feedback to industry needs
- The practitioner-oriented literature shows minimal use of established quantitative approaches
- The practitioner-oriented literature prefers the use of a singular and practical method

As such, it is noted that the practical methods used by industry have not been evaluated, while at the same time the theoretical methods developed by academics have not been applied in industry. To rectify this imbalance, a hybrid method - data envelopment analytic hierarchy process (DEAHP) recently developed by Ramanathan (2006) has been employed in this study to solve supplier selection problems of a major TV set manufacturer in Turkey. Due to its relative strengths (to be discussed in the methodology section), the DEAHP method has been applied in this paper as an alternative to the conventional and singular methods of weight derivation in analytic hierarchy process (AHP). This paper attempts to address the shortfalls identified earlier based on a real case application of DEAHP method for supplier selection.

The remainder of the paper is organized as follows. Next section briefly discusses the methodologies of DEA and AHP, and explains the DEAHP methodology. This is then followed by the application of DEAHP method to a real case. Conclusions are presented in the final section.

METHODOLOGY

The Analytic Hierarchy Process (AHP) Methodology

The analytic hierarchy process (AHP) methodology, which was developed by Saaty (1980), is a powerful tool in solving complex decision problems. The AHP helps the analysts to organize the critical aspects of a problem into a hierarchical structure similar to a family tree. By reducing complex decisions to a series of simple comparisons and rankings, then synthesizing the results, the AHP not only helps the analysts to arrive at the best decision, but also provides a clear rationale for the choices made (Chin et al., 1999).

In the AHP approach, the decision problem is structured hierarchically at different levels with each level consisting of a finite number of decision elements. The upper level of the hierarchy represents the overall goal, while the lower level consists of all possible alternatives. One or more intermediate levels embody the decision criteria and sub-criteria (Partovi, 1994).

The weights of the criteria and the scores of the alternatives, which are called local priorities, are considered as decision elements in the second step of the decision process. The decision-maker is required to provide his preferences by pairwise comparisons, with respect to the weights and scores. The values of the weights v_i and scores r_{ij} are elicited from these comparisons and represented in a decision table. The last step of the AHP aggregates all local priorities from the decision table by a weighted sum of the type, as shown below.

$$R_j = \sum_i v_i \times r_{ij}$$

The global priorities R_j thus obtained are finally used for ranking of the alternatives and selection of the best alternative. The first and the last steps of the AHP are relatively simple and straightforward, while the assessment of local priorities, based on pairwise comparisons is the main constituent of this method. The pairwise comparison in the AHP assumes that the decision maker can compare any two elements E_i ,E_j at the same level of the hierarchy and provide a numerical value aij of the ratio of their importance. If the element E_i is preferred to Ej then aij >1. Correspondingly, the reciprocal property $a_{ji} = 1/a_{ij}$, j = 1, 2, 3,…n and i =1, 2, 3,…..n always holds.

Each set of comparisons for a level with n elements requires $[n\times(n-1)]/2$ judgments. The second half of the comparison matrix is the reciprocals of those judgments lying above the diagonals and are usually omitted. Judgments are provided by means of a nine point ratio scale that ranges from two factors being equally important to one of the factors being absolutely more important than the others. After the expert supplies the ratings, local priorities of each element are calculated (Tung and Tang, 1998). A local priority vector w = $(w_1, w_{1,} w_{1,} .. w_n)^T$ may be obtained from the comparison matrix by applying some prioritization techniques, such as the Eigenvalue method or the Logarithmic Least Squares method (Udo, 2000). The set of n relative priorities should be normalized to sum of one.

$\sum_{i=1}^{n} w_i = 1 \quad w_i > 1$ and $i = 1,2,3,...n$ So the number of independent local priorities is (n -1).

When the decision-maker is perfectly consistent in his answers to pairwise comparison questions then all elements a_{ij} have perfect values, $a_{ij} = w_i/w_j$. In this case $a_{ij} = a_{ik}a_{kj}$ for all i, j, k =1, 2, 3, …n.

In most practical situations the decision-maker's evaluations aij are not consistent, since they are only estimations of the exact but unknown ratios w_i/w_j. The Eigenvalue method gives good approximation of the preference vector, but when the inconsistency of the decision-maker preferences is substantial then the solutions are not satisfactory.

Saaty (1980) states that in many practical cases the pairwise judgments of decision-makers will contain some degree of uncertainty. It is frequently the case that the decision-maker is certain about the ranking order of the comparison elements but uncertain about the precise numerical values of his judgments. The classical AHP attempts to overcome this problem by introducing a discrete linguistic set of comparison judgments. Instead of directly assigning numerical values to the comparison rations, the decision-maker chooses an appropriate linguistic phrase, best corresponding to his comparison preferences.

The Data Envelopment Analysis Methodology

The deterministic methods to the measurement of productive efficiency often involve mathematical programming (non-parametric) models, including DEA, where no assumptions are made about the form of the production function. Instead, a best-practice function is empirically built from observed inputs and outputs. DEA is a powerful aggregate comparative method for assessing the productivity of organizations with multiple incomparable inputs and outputs. DEA has been developed by Charnes et al. (1978) as a generalization of the framework of Farrell (1957) on the measurement of productive efficiency. The objective function in that model was to maximize the ratio of weighted outputs to weighted inputs for a particular decision making unit. This is done subject to the constraints that the ratio of weighted outputs to weighted inputs is less than or equal to one. The decision variables are output weights and input weights.

DEA is a linear programming based technique for measuring the relative efficiency of organizational units which has received significant attention in recent years due to its advantages over traditional methods. DEA produces a single score for each unit, which makes the comparison easy. It is based on peer group comparison in which efficient units will form the efficient frontier and inefficient units will be enveloped by this frontier. Unlike ratios, DEA can accommodate multiple inputs and multiple outputs. These inputs and outputs can be expressed in different units of measurement.

In contrast to regression methods, DEA focuses on individual observations and optimizes the performance measure of each unit. A priori knowledge of weights or prices for inputs and outputs is not required in DEA; however, managerial judgment can be accommodated when desired.

Another advantage of DEA that attracts analysts and management is its ability to identify the potential improvement for inefficient units. For the inefficient units enveloped by the frontier, DEA compares the unit with a convex combination of units located on the frontier and enables the analyst to indicate the sources and the level of inefficiency for each of its inputs and outputs. The indicated targets, which are shown to the inefficient units as models, are their actual peer units, therefore the results are more likely to be accepted by the managers of these units. DEA advantages resulted in the widespread application of this technique in various industries.

The value of outputs is forced to be 1 or less by the next set of constraints. In general terms, the efficiency of a particular unit can be defined as:

$$efficiency = \frac{value\ of\ outputs}{value\ of\ inputs}$$

It is not possible for any service unit to be more than 100% efficient; thus, the efficiency of a unit must be less than or equal to 1.

$$\frac{value\ of\ outputs}{value\ of\ inputs} \leq 1$$

Converting this to standard linear form, value of outputs $\leq$ value of inputs.

Z: efficiency score

$$Max\ Z = \sum_{i=1}^{m} b_{ih} y_{ih}$$ for h=1,2,3,…k,

m: number of output variables and k: number of decision making units

Subject to:

$$\sum_{i=1}^{n} a_{ih} x_{ih} = 1$$ for h=1,2,3,…k, n: number of input variables

$$\sum_{h=1}^{k} \left(\sum_{i=1}^{m} b_{ih} y_{ih} - \sum_{i=1}^{n} a_{ih} x_{ih} \right) \leq 0$$

x_{ih} : Observed value of Input i for the Decision Making Unit h

y_{ih} : Observed value of Output i for the Decision Making Unit h

a_{ih}, b_{ih} : Weight attached to inputs and outputs of Decision Making Unit h

The Data Envelopment Analytic Hierarchy Process (DEAHP) Methodology

The data envelopment analytic hierarchy process (DEAHP) methodology was first proposed by Ramanathan (2006). In this method, DEA method is embedded into AHP methodology. It derives local weights from a given judgment matrix and aggregates local weights to get overall weights. Each row and column of the pairwise matrix is assumed as a Decision Making Unit (DMU) and an output, respectively. Since calculations of efficiency of each DMU cannot be made entirely with outputs and require at least one input, a dummy input that has a value of 1 for all the DMUs is employed. In DEAHP method, the efficiency scores are calculated using DEA method and could be interpreted as the local weights of the DMUs. A comparison of crisp AHP view and the DEAHP view of a judgment matrix is shown in Figure 1.

Insert Figure 1 over here

Ramanathan (2006) proves that DEA correctly calculates the true weights for a consistent judgment matrix. Normally, when local weights are aggregated to overall weights, the importance measures of criteria (local weights of criteria in this case) are also used. For example, the aggregation rule is weighted arithmetic aggregation incorporating the local weights of each level. However, DEA does not normally require the local weights of criteria for aggregation. In order to obtain the weights of elements in the pairwise comparison matrix, their previous local weights are used as constraints to calculate new local weights. Detailed information about DEAHP approach can be found in Ramanathan (2006).

APPLICATION OF THE DEAHP MODEL

The objective of this study is to develop a general model, which will help to solve the supplier selection problems of a major Turkish TV set manufacturer, BEKO, which is the second leading company in Europe in terms of TV set manufacturing and the major appliance subsidiary of Turkey's largest conglomerate, Koç Group. In 2005, being the only Turkish group listed in Fortune's Global 500, Koç operates in the automotive, durable goods, food, retailing, energy, financial services, tourism, construction and IT industries. Koç Group has consolidated 118 companies, 87,000 employees and 12,000 dealers as well as agencies and after-sales services, generating $18.2 billion in revenues as of 2005. BEKO has a large portfolio of appliances including nearly 400 product types ranging from white goods, electronics, and vacuum cleaners to mobile phones and air conditioners. BEKO, the first brand in Turkey ever to export its products under its own brand, began this journey with the objective to become a major player in the global white goods industry. Having achieved a great deal in the domestic market first, BEKO has now managed to introduce its brand to millions of consumers in more than 100 countries worldwide reaching consolidated sales volume of €3 billion as of 2005 (www.beko.com.tr). Specifically, the study was undertaken to solve the supplier selection problem of BEKO for TV tube purchasing. Global TV tube manufacturing is a highly concentrated industry where there are only few global suppliers accounting for nearly 90 percent of worldwide sales. This study was undertaken on three major TV tube suppliers of BEKO. The main reasons for selecting TV tube suppliers are twofold. First, TV tube is of high value component (A class) nature and also the most expensive supply item within this category. Second, it has the longest lead time in all supply items for TV set manufacturing. In order to maintain the confidentiality of the supplier companies, they will be numbered as suppliers 1, 2, 3. The model presented in this study utilizes the DEAHP and crisp AHP approaches comparatively. In DEAHP model, judgment matrix data are used as output variables to determine the best supplier for the buyer company. The main steps of the model are listed as follows:

1. Definition of the criteria for supplier selection to design the AHP tree structure.
2. Calculation of the weights of the supplier selection criteria.
3. Computing the overall score of each supplier.
4. Comparing the DEAHP and AHP results.

The forthcoming subsections detail each of the four steps in the model.

Definition of Supplier Selection Criteria

Supplier selection criteria were determined based on the review of prior literature (see for example, Barbarosoglu and Yazgac, 1997; Braglia and Petroni, 2000; Tam and Tummala, 2001; Masella and Rangone, 2000) and semi-structured interviews undertaken with 22 managers from relevant departments including purchasing, manufacturing, quality assurance and R&D. Figure 2 shows the structuring of the hierarchy of supplier selection problem, which includes four levels. The top level of the hierarchy represents the ultimate goal of the problem, while the second level of the hierarchy consists of six main supplier selection criteria, which are namely *performance assessment*, *human resources*, *quality system*, *manufacturing*, *business*, and *information technology*. At the third level, these criteria are decomposed into various sub-criteria that may affect the buyer's choice for a particular supplier. Finally, the bottom level of the hierarchy represents the alternative suppliers. Each selection criterion in the tree diagram is briefly described below.

Insert Figure 2 over here

Performance Assessment

Performance assessment criteria of the supplier selection consist of three criteria, which involve shipment quality, delivery and cost analysis.

Shipment Quality: Shipment quality refers to the vendor's ability to meet quality specifications consistently. Shipment quality can be divided into eight categories, which include product performance, features, reliability, durability, conformance, serviceability, aesthetics and perceived quality.

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

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

Human Resources

Human resources criteria consist of four categories, which are namely number of employees, organizational structure, training and number of technical staff.

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

Organizational Structure: It refers to the organizational structure of the firm and the clarity of employee job definitions.

Training: It refers to the availability of professional educational activities and a scheduled yearly training program. This criterion necessitates that all personnel, whose work may create a significant impact on the supply chain process, have received appropriate training.

Number of Technical Staff: This criterion refers to the technical capability and availability of the staff in more technically oriented departments in the supplier firm.

Quality System Assessment

Quality system assessment consists of four categories, which are management commitment, inspection and control, quality planning and quality assurance.

Management Commitment: Management commitment refers to the preparation of the documentation system regarding the quality assurance system, which encourages work force participation, emphasizing the importance of the role of the quality function in the firm, the establishment and implementation of quality improvement programs, appropriate environmental policy and regular management reviews.

Inspection: The purpose of inspection is to assure the buyer that the supplier has delivered an item, which corresponds to the description furnished. Inspection and the control procedure can involve measurement, testing, touching, weighing or testing of the product. Its goal is to detect the bad process immediately. Inspection and control take place in every stage of manufacturing process ranging from inbound logistics to final production stage.

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

Quality Assurance: The responsibility of the quality assurance group is to implement the method of the purchasing activities with lot certification; to establish quality assurance; and to help in designing, implementing and monitoring the quality improvement program.

Manufacturing

The manufacturing related selection criteria consist of six factors which are namely production capacity, predictive and preventive maintenance, lead-time, transportation storage and packaging, up to date techniques and equipment and product development.

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

Predictive and Preventive Maintenance: In this stage, preventive and breakdown maintenance were considered. Preventive maintenance involves performing routine inspections, servicing and keeping facilities in good repair. These activities are intended to build a system that will detect potential failures to prevent them. Breakdown maintenance, however, occurs when the equipment fails and it must be repaired on an emergency or priority basis.

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

Transportation-Storage and Packaging: This criterion includes the effectiveness of the transportation, storage, and packaging function.

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

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

Business Criteria

Business criteria refer to the supplier selection based on reputation, geographical location, price, patent and technical capability (value engineering and project management).

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

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

Price: The price of the product.

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

Technical Capability: It includes project management skills and value management concepts.

Use of Information Technology

The extent of electronic data interchange (EDI) and internet usage have been identified as the two information technology (IT) related criteria for supplier selection. In addition to these two IT related criteria, RFID (radio frequency identification) has been recently used as a new IT technique, which uses radio waves to identify objects. RFID is projected to rapidly supplant bar code technology as the principal means of identifying items in the supply chain and in a wide variety of applications (Wyld, 2006). A rather more classic form of IT, *Electronic Data Interchange*, refers to the capability of direct electronic transmission of data and standard business forms between a buying firm and its suppliers, while *Internet* includes the supplier's capacity of utilizing internet, comprising both extranet and intranet functions (Leenders and Fearon, 1997).

Calculation of the Weights of the Criteria

First, the hierarchical structure of the supplier selection has been identified based on the evaluations of our responding managers from the buyer company. They also indicated their degree of preference between and within the criteria at each level of the hierarchy in a pairwise form using Saaty's scales ranging from 1 (= 'equally preferred') to 9 (= 'extremely preferred'). Next step involves the weight calculation of each level to obtain the overall score of each supplier with respect to all 25 sub-criteria and pairwise comparisons of the main selection criteria.

Evaluation of the Third Level Decision Alternatives

The third level of the hierarchy, as previously described, has been analyzed using the DEAHP and AHP methodologies. Decision-makers were asked to specify the relative importance of supplier selection criteria. In Table 1 panel A, the following three supplier selection criteria related to performance assessment, which include shipment, delivery and cost, are compared with each other in pairwise form. Panels B to D in Table 1 show pairwise comparisons of suppliers with respect to shipment, delivery and cost and indicate the weight of each criterion related to performance assessment using crisp AHP and DEAHP approaches.

Insert Table 1 over here

The calculations of the DEAHP approach are also illustrated using the entries of Table 1. The local weights of alternatives using crisp AHP and DEAHP methods are shown in the last two columns of Table 1. In DEAHP method, in order to ascertain how to derive local weight from pairwise matrix, an instance of s*hipment* criterion is illustrated in the following model:

$$
\begin{aligned}
&Max\ Z = 1y_{11} + 5y_{12} + 6y_{13} \\
&s.t. \\
&x_{11} = 1, \\
&1y_{11} + 5y_{12} + 6y_{13} - x_{11} \leq 0, \\
&\frac{1}{5}y_{11} + 1y_{12} + 2y_{13} - x_{12} \leq 0, \\
&\frac{1}{6}y_{11} + \frac{1}{2}y_{12} + 1y_{13} - x_{13} \leq 0, \\
&y_{11}, y_{12}, y_{13}, x_{11}, x_{12}, x_{13} \geq 0
\end{aligned}
$$

When this optimization model is solved by Excel Solver, the local weight of shipment is obtained (1.000). To obtain the local weight of other categories, similar models are used by changing the objective function. The resulting local weights of Delivery and Cost are given in Table 1A (0.333, 0.167). The local weights of suppliers with respect to Shipment, Delivery and Cost are also shown in the last columns of Tables 1B to 1D, respectively.

Similarly, Tables 2 to 6 show pairwise comparisons and local weight calculations of other supplier selection categories including human resources, quality system assessment, manufacturing, business criteria and information technology.

Insert Table 2 over here

Insert Table 3 over here

Insert Table 4 over here

Insert Table 5 over here

Insert Table 6 over here

Evaluation of the Second Level Decision Alternatives

Once local weights of suppliers are obtained in the third level, then they are aggregated to obtain second level of weights of the decision alternatives. For example, the second level weights of suppliers are calculated using the following aggregation rule in crisp AHP approach.

Second Level of Supplier 1 = $\sum_j$ {(Local weight of Supplier1 with respect of criterion Cj) × (Local weights of criterion Cj)}

The second level of suppliers weights are computed using the given formula above for the illustration of supplier 1 can be calculated as:

$$(0.633 \times 0.723) + (0.082 \times 0.174) + (0.100 \times 0.103) = 0.482$$

Other supplier's second levels of weights are shown in Table 7 panel A.

The aggregations in DEAHP, additional constraints are appended to calculate the second level of the alternatives. For example, following linear programming model is used to obtain the weights of supplier 1 in the second level.

$$
\begin{aligned}
& Max\ Z = 1y_{11} + 0.167y_{12} + 0.167y_{13} \\
& s.t. \\
& x_{11} = 1, \\
& 1y_{11} + 0.167y_{12} + 0.167y_{13} - x_{11} \le 0, \\
& 0.6y_{11} + 0.833y_{12} + 0.5y_{13} - x_{12} \le 0, \\
& 0.2y_{11} + 1y_{12} + 1y_{13} - x_{13} \le 0, \\
& y_{11} = 3y_{12} = 6y_{13} \text{ (additional constraints)} \\
& y_{11}, y_{12}, y_{13}, x_{11}, x_{12}, x_{13} \ge 0
\end{aligned}
$$

When this optimization model is solved, the local weight of supplier 1 is obtained. The local weights of other suppliers using similar model by changing the objective function and the additional constraints are shown in Table 7. In this model, the additional constraints are obtained from Table 1 panel A, which are 1.000, 0.333, and 0.167 denoting that shipment is three times more important than delivery and six times than cost. Hence, this information is added as a constraint in order to calculate the local weights of next level.

Insert Table 7 over here

Similarly, each supplier's local weight is calculated using the same model for the other categories in human resources, quality system assessment, manufacturing, business criteria and information technology. These results are shown in Tables 8 to 12.

Insert Table 8 over here

Insert Table 9 over here

Insert Table 10 over here

Insert Table 11 over here

Insert Table 12 over here

Evaluation of the First Level Decision Alternatives

In the first level, the relative importance or weight of the supplier selection criteria is determined, that is, ranking the criteria from most important to least important. Table 13 shows the weights of supplier selection criteria calculated for both AHP and DEAHP methodologies. Based on the results of both approaches the most important category of selection criteria was found to be business criteria with their weights being 1.0 and 0.42 for DEAHP and AHP, respectively. In contrast, the least important category of selection criteria was related to information technology with their respective weights being 0.111 and 0.033 for DEAHP and AHP. It should also be noted that the ranking of selection criteria for both the most and the least important criteria is equal in both methods.

Insert Table 13 over here

Computing the Overall Score of Suppliers

The overall weights of each supplier are calculated in aggregation of the first level of criteria. Aggregation procedures are same as the calculation of the second level. These values are providing additional constraints restricting the values of multipliers, which estimate the overall weight of alternatives. DEAHP column in Table 13 is forming the $1.29*y_{m1}=4.5*y_{m2}=2.25*y_{m3}=1.8*y_{m4}=y_{m5}=9*y_{m6}$ constraints. The overall weights of all three suppliers using DEAHP approach are shown in Table 14 panel B, while the overall weights of suppliers based on crisp AHP method are shown in Table 14 panel A.

Insert Table 14 over here

Comparing the DEAHP and AHP results

As noted earlier, supplier 1 was identified to be the most important supplier using the crisp AHP approach under no restrictions. Although the buyer company was aware of the fact that supplier 1 brought up the best performance based on AHP, its managers were not willing to purchase the majority of their supplies from the supplier 1. Instead, they prefer to source from supplier 2, which has also been identified as the most suitable supplier using DEAHP approach. This result tends to confirm the views of managers, as DEAHP approach has been implemented under restrictions related to supplier selection criteria.

Table 13 displays the ranking of all six categories of supplier selection criteria based on overall weights using both AHP and DEAHP approaches. It is readily apparent from Table 13 that there exists a consistent pattern in the ranking of selection criteria for both approaches. The first four leading broad categories of selection criteria include *business*, *performance assessment*, *manufacturing* and *quality system assessment*. The remaining two categories of *human resources* and *information technology* were the lowest ranked selection criteria. The ranking of individual criteria comprising each category of the first four broad selection criteria as well as the evaluation of suppliers based on each criterion are discussed below.

Table 5 shows that from full set of *business criteria*, the price featured the most important criterion in both AHP and DEAHP methods. From the buyer's perspective, supplier 3 has been chosen as the most suitable supplier in terms of price since it offered the lowest price among the three suppliers. In contrast, supplier 1 was preferred as the most appropriate supplier with respect to the following two *business criteria*: reputation and location, while supplier 2 was determined to be the most preferred supplier in terms of technical capability. When all five criteria were considered together, supplier 2 emerges as the most appropriate supplier, as shown in Table 11.

Table 1 indicates that from the full set of three criteria constituting *performance assessment*, the shipment criterion was found to have the highest weight, while the cost criterion had the lowest weight in both AHP and DEAHP approaches. Of the three suppliers, supplier 1 had the highest weight in terms of shipment, and was considered as the most suitable supplier in both approaches. In contrast, supplier 3 was identified to be the most preferred supplier by having the highest weight in terms of delivery and cost, though supplier 2 was the second most suitable supplier in all three of the selection criteria. According to overall evaluation of the *performance assessment*, supplier 1, however, arises as the most appropriate supplier as was shown in Table 7.

From the whole set of six criteria comprising *manufacturing*, new product development and up to date technology were found to have the two highest ranking criteria, while predictive and preventive maintenance and transportation-storage and packaging had the lowest ranking criteria based on two methods, as shown in Table 4. Supplier 2 was selected as the most suitable supplier with respect to new product development in both methods. In addition, suppliers 1 and 2 were equally preferred based on the criterion of up to date technology and equipment. Table 10, however, indicates that supplier 2 was selected as the most appropriate supplier with respect to all six manufacturing criteria in both methods.

Finally, Table 3 indicates that the quality assurance criterion comprising *quality system assessment* was noted as the most important individual criterion in both AHP and DEAHP methods. In overall, Table 9 shows that supplier 1 was chosen as the most preferred supplier based on all four criteria of *quality system assessment*.

CONCLUSIONS

This research concluded that DEAHP method outperforms AHP method for supplier selection despite the findings that AHP model suggested supplier 1 to be the best supplier, contradicting the suggestion made by DEAHP model and the real action taken by BEKO in selecting supplier 2. These findings imply that DEAHP criteria reflect closer to the real optimum of the decision made. Drawing on a real case our study has supported Ramanathan's (2006) work confirming the view that DEAHP method provides better decision than AHP method for supplier selection. Since DEAHP model is relatively more cumbersome to apply, its application will be more appropriate for high value components where stringent purchasing criteria are required. In contrast, AHP would remain to be an appropriate approach for relatively lower value components (C class).

The novelty of this research lies in the application of a hybrid approach to a real industry case - DEAHP method for supplier selection, where little has been done on this subject. This study has dealt with one of the most important subjects in supply chain management providing better decision for supplier selection using appropriate quantitative approaches. More research is certainly called for within the context of studying a more complex supply chain with multiple supply network and node as well as investigating other hybrid methods to find the optimum of the optimum supplier selection solution.

REFERENCES

Barbarosoglu, G. and Yazgac, T. (1997) “An application of the analytic hierarchy process to the supplier selection problem”, *Production and Inventory Management Journal*, First quarter, pp. 14-21.

Braglia, M. and Petroni, A. (2000) “A quality assurance-oriented methodology for handling trade-offs in supplier selection”, *International Journal of Physical Distribution and Logistics Management*, Vol. 30 No. 2, pp. 96-111.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978) “Measuring the efficiency of decision making units”, *European Journal of Operational Research*, Vol. 2, pp. 429-44.

Chin, K.S. and Chiu, S. and Tummala, V.M.R. (1999) “An evaluation of success factors using the AHP to implement ISO 14001- based ESM”, *International Journal of Quality and Reliability Management*, Vol. 16 No. 4, pp. 341-361.

Diageo (2004) Policy on Corporate Citizenship Supplier Standards – Partnering with Suppliers, www.diageo.com.

Farrell, M.J. (1957) “The measurement of productive efficiency,” *Journal of the Royal Statistical Society*, *Series A. General*, Vol 120 No. 3, pp. 253-281.

Handfield, R. and Nichols, E. (1999) *Supply Chain Redesign*, Prentice Hall.

Handfield, R. and Nichols, E. (2002) *Introduction to Supply Chain Management*, Prentice Hall.

Haq, A.N. and Kannan, G. (2006) “Design of an integrated supplier selection and multi-echelon distribution inventory model in a built-to-order supply chain environment”, *International Journal of Production Research*, Vol. 44, No. 10, pp. 1963-1985.

Huang, S.M., Chang, I.C., Li, S.H. and Lin, M.T. (2004) “Assessing risk in ERP projects: identify and prioritize the factors”, *Industrial Management and Data Systems*, Vol. 104 No. 8, pp. 681-688.

Humphreys, P., Huang, G. and Cadden, T. (2005) “A web-based supplier evaluation tool for the product development process”, *Industrial Management and Data Systems*, Vol. 105 No. 2, pp. 147-163.

Koh, S.C.L. and Tan, K.H. (2006) “Translating knowledge of supply chain uncertainty into business strategy and actions”, *Journal of Manufacturing Technology Management*, Vol. 17 No. 4, pp. 472-485.

Leenders, M.R. and Fearon, H.E. (1997) *Purchasing and Supply Management*, McGraw-Hill.

Masella, C. and Rangone, A. (2000) “A contingent approach to the design of vendor selection systems for different types of co-operative customer/supplier relationship”, *International Journal of Operations and Production Management*, Vol. 20 No. 1, pp. 70-84.

Partovi, F.Y. (1994) "Determining what to benchmark: An analytic hierarchy process approach", *International Journal of Operations and Production Management*", Vol. 14 No. 6, pp. 25-39.

Ramanathan, R. (2006) "Data envelopment analysis for weight derivation and aggregation in the analytic hierarchy process", *Computers and Operations Research*, Vol. 33, pp. 1289-1307.

Riddalls, C., Bennett, S. and Tipi, N. (2000) "Modelling the dynamics of supply chains", *International Journal of Systems Science,* Vol. 31 No. 8, pp. 969-976.

Saaty, T.L. (1980) *The Analytical Hierarchy Process*, Mc Graw-Hill, New York, NY.

Seydel, J. (2006) "Data envelopment analysis for decision support", *Industrial Management and Data Systems*, Vol. 106 No. 1, pp. 81-95.

Simchi-Levi D., Kaminski, P. and Simchi-Levi, E. (2000) *Designing and Managing the Supply Chain*, Irwin McGraw-Hill.

Tam, M.C.Y. and Tummala, V.M.R. (2001) "An application of the AHP in vendor selection of a telecommunication system", *Omega*, Vol. 29, pp. 171-182.

Tung, S.L. and Tang, S.L. (1998) "A comparison of the Saaty's AHP and modified AHP for right and left eigenvector inconsistency", *European Journal of Operational Research* Vol. 116, pp. 123-128

Udo, G.G. (2000) "Using analytic hierarchy process to analyse the information technology outsourcing decision", *Industrial Management and Data Systems*, Vol. 100 No.9, pp. 421-429.

Wang, G., Huang, S.H. and Dismukes, J.P. (2005) "Manufacturing supply chain design and evaluation", *International Journal of Advanced Manufacturing Technology*, Vol. 25 No. 1-2, pp. 93-100.

Wyld, D.C. (2006) "RFID 101: the next big thing for management", *Management Research News*, Vol. 29 No. 4, pp. 154-173.

Figure 1
Comparison of Crisp AHP View and DEAHP View

Crisp AHP View

	Criteria 1	Criteria 2	Criteria 3	...	Criteria m
Alternative 1	1	a_{12}	a_{13}	...	a_{1m}
Alternative 2	$1/a_{12}$	1	a_{23}	...	a_{2m}
Alternative 3	$1/a_{13}$	$1/a_{23}$	1	...	a_{3m}
...	...	...	...	...	...
Alternative n	$1/a_{n1}$	$1/a_{n2}$	$1/a_{n3}$	...	1

$\Rightarrow$

DEAHP View

	Output 1	Output 2	Output 3	...	Output m	Dummy Input
DMU 1	1	a_{12}	a_{13}	...	a_{1m}	1
DMU 2	$1/a_{12}$	1	a_{23}	...	a_{2m}	1
DMU 3	$1/a_{13}$	$1/a_{23}$	1	...	a_{3m}	1
...	...	...	...	...	...	...
DMU n	$1/a_{n1}$	$1/a_{n2}$	$1/a_{n3}$	...	1	1

Figure 2
Structuring of the Supplier Selection Problem

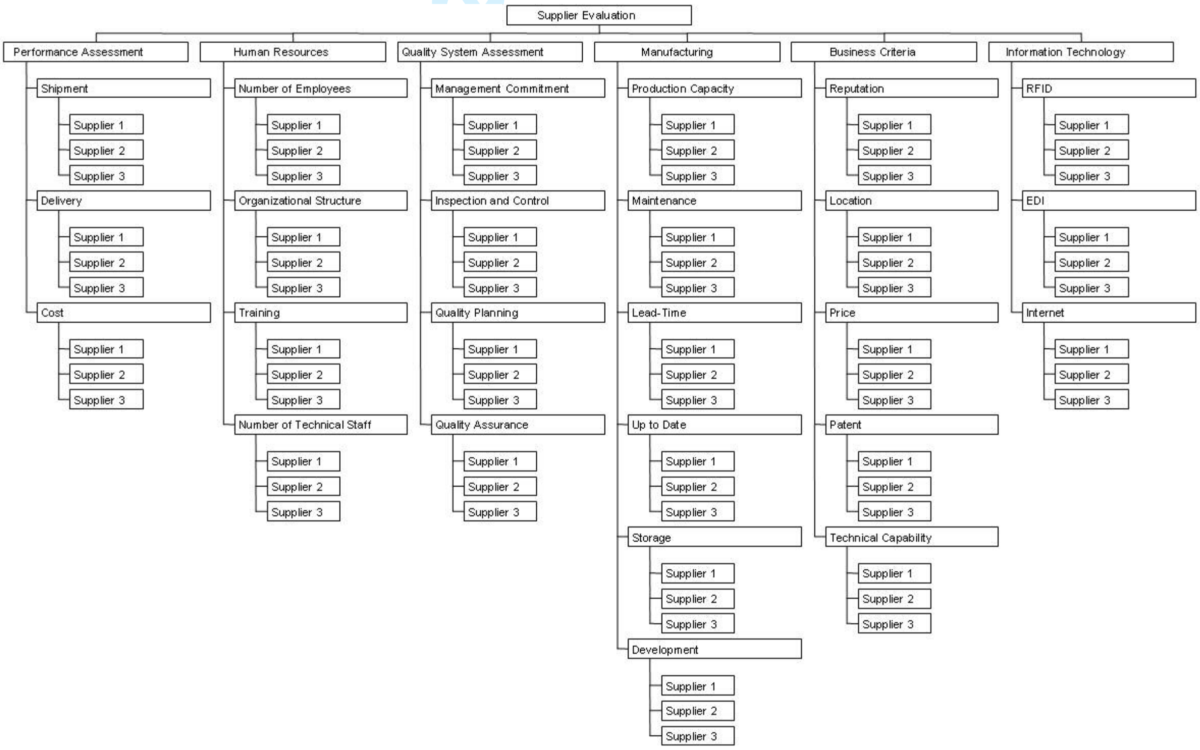

Table 1
Performance Assessment

A. Comparison of Criteria with respect to Performance Assessment

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Shipment	1	5	6	1	0.723	1.000
Delivery	1/5	1	2	1	0.174	0.333
Cost	1/6	1/2	1	1	0.103	0.167

Consistency ratio = 0.0374

B. Comparison of Suppliers with respect to Shipment

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	3	5	1	0.633	1.000
Supplier 2	1/3	1	3	1	0.260	0.600
Supplier 3	1/5	1/3	1	1	0.106	0.200

Consistency ratio = 0.0419

C. Comparison of Suppliers with respect to Delivery

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	1/5	1/6	1	0.082	0.167
Supplier 2	5	1	1/2	1	0.343	0.833
Supplier 3	6	2	1	1	0.575	1.000

Consistency ratio = 0.0299

D. Comparison of Suppliers with respect to Cost

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	1/3	1/6	1	0.100	0.167
Supplier 2	3	1	1/2	1	0.300	0.500
Supplier 3	6	2	1	1	0.600	1.000

Consistency ratio = 0.0000

Table 2
Human Resources

A. Comparison of criteria with respect to Human Resources

DMU	Output 1	Output 2	Output 3	Output 4	Input	AHP	DEAHP
Number of Employees	1	1/5	1/6	1/3	1	0.063	0.167
Organization Structure	5	1	1/2	3	1	0.309	0.833
Training	6	2	1	4	1	0.492	1.000
Number of Tech. Staff	3	1/3	1/4	1	1	0.136	0.500

Consistency ratio =0.0367

B. Comparison of Suppliers with respect to Number of Employees

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	1/3	1/5	1	0.110	0.200
Supplier 2	3	1	1/2	1	0.309	0.600
Supplier 3	5	2	1	1	0.581	1.000

Consistency ratio = 0.0037

C. Comparison of Suppliers with respect to Organization Structure

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	4	6	1	0.685	1.000
Supplier 2	1/4	1	3	1	0.221	0.500
Supplier 3	1/6	1/3	1	1	0.093	0.167

Consistency ratio = 0.0644

D. Comparison of Suppliers with respect to Number of Training

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	4	6	1	0.685	1.000
Supplier 2	1/4	1	3	1	0.221	0.500
Supplier 3	1/6	1/3	1	1	0.093	0.167

Consistency ratio = 0.0644

E. Comparison of Suppliers with respect to Number of Technical Staff

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	1/3	2	1	0.230	0.400
Supplier 2	3	1	5	1	0.648	1.000
Supplier 3	1/2	1/5	1	1	0.122	0.200

Consistency ratio = 0.0041

Table 3
Quality System Assessment

A. Comparison of criteria with respect to Quality System Assessment

DMU	Output 1	Output 2	Output 3	Output 4	Input	AHP	DEAHP
Management Commitment	1	1/4	1/4	1/6	1	0.062	0.167
Inspection and Control	4	1	1/3	1/3	1	0.165	0.667
Quality Planning	4	3	1	1/3	1	0.270	1.000
Quality Assurance	6	3	3	1	1	0.503	1.000

Consistency ratio = 0.0944

B. Comparison of Suppliers with respect to Management Commitment

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	4	5	1	0.665	1.000
Supplier 2	1/4	1	3	1	0.231	0.600
Supplier 3	1/5	1/3	1	1	0.104	0.200

Consistency ratio = 0.0996

C. Comparison of Suppliers with respect to Inspection and Control

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	5	7	1	0.724	1.000
Supplier 2	1/5	1	3	1	0.193	0.429
Supplier 3	1/7	1/3	1	1	0.083	0.143

Consistency ratio = 0.0844

D. Comparison of Suppliers with respect to Quality Planning

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	7	9	1	0.790	1.000
Supplier 2	1/7	1	2	1	0.133	0.222
Supplier 3	1/9	1/2	1	1	0.077	0.111

Consistency ratio = 0.0322

E. Comparison of Suppliers with respect to Quality Assurance

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	5	7	1	0.724	1.000
Supplier 2	1/5	1	3	1	0.193	0.429
Supplier 3	1/7	1/3	1	1	0.083	0.143

Consistency ratio = 0.0844

Table 4
Manufacturing Criteria

A. Comparison of criteria with respect to Manufacturing Criteria

DMU	Output 1	Output 2	Output 3	Output 4	Output 5	Output 6	Input	AHP	DEAHP
Production Capacity	1	2	3	1/2	4	1/3	1	0.151	0.500
Maintenance	1/2	1	1/2	1/4	2	1/7	1	0.062	0.222
Lead Time	1/3	2	1	1/3	2	1/6	1	0.079	0.286
Up to Date Technology	2	4	3	1	6	1/2	1	0.241	0.667
Transportation-Storage	1/4	1/2	1/2	1/6	1	1/9	1	0.039	0.111
New Product Development	3	7	6	2	9	1	1	0.428	1.000

Consistency ratio = 0.0183

B. Comparison of Suppliers with respect to Production Capacity

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	1/5	1/4	1	0.096	0.200
Supplier 2	5	1	3	1	0.619	1.000
Supplier 3	4	1/3	1	1	0.284	0.800

Consistency ratio = 0.0923

C. Comparison of Suppliers with respect to Maintenance

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	3	5	1	0.633	1.000
Supplier 2	1/3	1	3	1	0.260	0.600
Supplier 3	1/5	1/3	1	1	0.106	0.200

Consistency ratio = 0.0419

D. Comparison of Suppliers with respect to Production Planning

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	2	1/4	1	0.201	0.400
Supplier 2	1/2	1	1/5	1	0.118	0.200
Supplier 3	4	5	1	1	0.681	1.000

Consistency ratio = 0.0290

E. Comparison of Suppliers with respect to Up to Date

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	1	4	1	0.444	1.000
Supplier 2	1	1	4	1	0.444	1.000
Supplier 3	1/4	1/4	1	1	0.111	0.250

Consistency ratio = 0.0000

F. Comparison of Suppliers with respect to Storage

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	3	1/3	1	0.272	0.750
Supplier 2	1/3	1	1/4	1	0.120	0.250
Supplier 3	3	4	1	1	0.608	1.000

Consistency ratio = 0.0767

G. Comparison of Suppliers with respect to Development

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	1/3	6	1	0.290	0.750
Supplier 2	3	1	8	1	0.646	1.000
Supplier 3	1/6	1/8	1	1	0.064	0.125

Consistency ratio = 0.0840

Table 5
Business Criteria

A. Comparison of Criteria with respect to Business Criteria

DMU	Output 1	Output 2	Output 3	Output 4	Output 5	Input	AHP	DEAHP
Reputation	1	2	1/8	1/3	1/7	1	0.054	0.222
Location	1/2	1	1/9	1/5	1/8	1	0.036	0.111
Price	8	9	1	5	2	1	0.473	1.000
Patent	3	5	1/5	1	1/3	1	0.131	0.556
Technical Capability	7	8	1/2	3	1	1	0.306	0.889

Consistency ratio = 0.0452

B. Comparison of Suppliers with respect to Reputation

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	3	8	1	0.646	1.000
Supplier 2	1/3	1	6	1	0.290	0.750
Supplier 3	1/8	1/6	1	1	0.064	0.125

Consistency ratio = 0.0840

C. Comparison of Suppliers with respect to Location

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	4	5	1	0.665	1.000
Supplier 2	1/4	1	3	1	0.231	0.600
Supplier 3	1/5	1/3	1	1	0.104	0.200

Consistency ratio = 0.0996

D. Comparison of Suppliers with respect to Price

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	1/3	1/4	1	0.120	0.250
Supplier 2	3	1	1/3	1	0.272	0.750
Supplier 3	4	3	1	1	0.608	1.000

Consistency ratio = 0.0767

E. Comparison of Suppliers with respect to Patent

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	1	1	1	0.333	1.000
Supplier 2	1	1	1	1	0.333	1.000
Supplier 3	1	1	1	1	0.333	1.000

Consistency ratio = 0.0000

F. Comparison of Suppliers with respect to Technical Capability

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	1/4	5	1	0.236	0.556
Supplier 2	4	1	9	1	0.701	1.000
Supplier 3	1/5	1/9	1	1	0.062	0.111

Consistency ratio = 0.0893

Table 6
Information Technology

A. Comparison of criteria with respect to Information Technology

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
RFID	1	1/6	1/7	1	0.070	0.143
EDI	6	1	1/2	1	0.350	0.857
Internet	7	2	1	1	0.580	1.000

Consistency ratio = 0.0374

B. Comparison of Suppliers with respect to RFID

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	1	3	1	0.429	1.000
Supplier 2	1	1	3	1	0.429	1.000
Supplier 3	1/3	1/3	1	1	0.143	0.333

Consistency ratio = 0.0000

C. Comparison of Suppliers with respect to EDI

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	1	3	1	0.429	1.000
Supplier 2	1	1	3	1	0.429	1.000
Supplier 3	1/3	1/3	1	1	0.143	0.333

Consistency ratio = 0.0000

D. Comparison of Suppliers with respect to Internet

DMU	Output 1	Output 2	Output 3	Input	AHP	DEAHP
Supplier 1	1	1	3	1	0.429	1.000
Supplier 2	1	1	3	1	0.429	1.000
Supplier 3	1/3	1/3	1	1	0.143	0.333

Consistency ratio = 0.0000

Table 7
Weights of Suppliers with respect to Performance Assessment using both AHP and DEAHP

A. Weights of Suppliers with respect to Performance Assessment using AHP

	Shipment	Delivery	Cost	AHP
Supplier 1	0.633	0.082	0.100	0.482
Supplier 2	0.260	0.343	0.300	0.279
Supplier 3	0.106	0.575	0.600	0.239
Local Weights of Criteria	0.723	0.174	0.103	

B. Weights of Suppliers with respect to Performance Assessment using DEAHP

DMU	Output 1	Output 2	Output 3	Input	DEAHP
Supplier 1	1.000	0.167	0.167	1	1.000
Supplier 2	0.600	0.833	0.500	1	0.887
Supplier 3	0.200	1.000	1.000	1	0.646
Criteria Efficiency Constraints	vm1	= 3*vm2	= 6*vm3		

Table 8

Weights of Suppliers with respect to Human Resources using both AHP and DEAHP

A. Weights of Suppliers with respect to Human Resources

	Number of Employees	Organization Structure	Training	Number of Tech. Staff	AHP
Supplier 1	0.110	0.685	0.685	0.230	0.587
Supplier 2	0.309	0.221	0.221	0.648	0.285
Supplier 3	0.581	0.093	0.093	0.122	0.128
Local Weights of Criteria	0.063	0.309	0.492	0.136	

B. Weights of Suppliers with respect to Human Resources

DMU	Output 1	Output 2	Output 3	Output 4	Input	DEAHP
Supplier 1	0.200	1.000	1.000	0.400	1	1.000
Supplier 2	0.600	0.500	0.500	1.000	1	0.734
Supplier 3	1.000	0.167	0.167	0.200	1	0.277
Criteria Efficiency Constraints	6*vm1	= 1.2*vm2	= vm3	= 2*vm4		

Table 9

Weights of Suppliers with respect to Quality System Assessment using both AHP and DEAHP

A. Weights of Suppliers with respect to Quality System Assessment

	Management Commitment	Inspection and Control	Quality Planning	Quality Assurance	AHP
Supplier 1	0.665	0.724	0.790	0.724	0.738
Supplier 2	0.231	0.193	0.133	0.193	0.179
Supplier 3	0.104	0.083	0.077	0.083	0.083
Local Weights of Criteria	0.062	0.165	0.270	0.503	

B. Weights of Suppliers with respect to Quality System Assessment

DMU	Output 1	Output 2	Output 3	Output 4	Input	DEAHP
Supplier 1	1.000	1.000	1.000	1.000	1	1.000
Supplier 2	0.600	0.429	0.222	0.429	1	0.366
Supplier 3	0.200	0.143	0.111	0.143	1	0.135
Criteria Efficiency Constraints	6*vm1	= 1.5*vm2	= vm3	= vm4		

Table 10

Weights of Suppliers with respect to manufacturing using both AHP and DEAHP

A. Weights of Suppliers with respect to Manufacturing

	Production Capacity	Maintenance	Lead Time	Up to Date	Transportation-Storage	New Product Development	AHP
Supplier 1	0.096	0.633	0.201	0.444	0.272	0.290	0.311
Supplier 2	0.619	0.260	0.118	0.444	0.120	0.646	0.507
Supplier 3	0.284	0.106	0.681	0.111	0.608	0.064	0.181
Local Weights of Criteria	0.151	0.062	0.079	0.241	0.039	0.428	

B. Weights of Suppliers with respect to Manufacturing

DMU	Output 1	Output 2	Output 3	Output 4	Output 5	Output 6	Input	DEAHP
Supplier 1	0.200	1.000	0.400	1.000	0.750	0.750	1	0.812
Supplier 2	1.000	0.600	0.200	1.000	0.250	1.000	1	1.000
Supplier 3	0.800	0.200	1.000	0.250	1.000	0.125	1	0.475
Criteria Efficiency Constraints	2*vm1	= 4.5*vm2	= 3.5*vm3	= 1.5*vm4	= 9*vm5	= vm6		

Table 11
Weights of Suppliers with respect to Business Criteria using both AHP and DEAHP

A. Weights of Suppliers with respect to Business Criteria

	Reputation	Location	Price	Patent	Technical Capability	AHP
Supplier 1	0.646	0.665	0.120	0.333	0.236	0.231
Supplier 2	0.290	0.231	0.272	0.333	0.701	0.411
Supplier 3	0.064	0.104	0.608	0.333	0.062	0.358
Local Weights of Criteria	0.054	0.036	0.473	0.131	0.306	

B. Weights of Suppliers with respect to Business Criteria

DMU	Output 1	Output 2	Output 3	Output 4	Output 5	Input	DEAHP
Supplier 1	1.000	1.000	0.250	1.000	0.556	1	0.673
Supplier 2	0.750	0.600	0.750	1.000	1.000	1	1.000
Supplier 3	0.125	0.200	1.000	1.000	0.111	1	0.702
Criteria Efficiency Constraints	4.5*vm1	= 9*vm2	= vm3	= 1.8*vm4	= 1.25*vm5		

Table 12
Weights of Suppliers with respect to Information Technology using both AHP and DEAHP

A. Weights of Suppliers with respect to Information Technology

	On Line	EDI	Internet	AHP
Supplier 1	0.429	0.429	0.429	0.429
Supplier 2	0.429	0.429	0.429	0.429
Supplier 3	0.143	0.143	0.143	0.143
Local Weights of Criteria	0.070	0.350	0.580	

B. Weights of Suppliers with respect to Information Technology

DMU	Output 1	Output 2	Output 3	Input	DEAHP
Supplier 1	1.000	1.000	1.000	1	1.000
Supplier 2	1.000	1.000	1.000	1	1.000
Supplier 3	0.333	0.333	0.333	1	0.333
Criteria Efficiency Constraints	7*vm1	= 1.17*vm2	= vm3		

Table 13
Weights of Supplier Selection Criteria

A. Comparison of Criteria with respect to Goal

DMU	Output 1	Output 2	Output 3	Output 4	Output 5	Output 6	Input	AHP	DEAHP
Performance Assessment	1	4	3	2	1/2	7	1	0.244	0.778
Human Resources	1/4	1	1/2	1/3	1/8	2	1	0.055	0.222
Quality System Assessment	1/3	2	1	1/2	1/5	4	1	0.096	0.444
Manufacturing Criteria	1/2	3	2	1	1/3	5	1	0.153	0.556
Business Criteria	2	8	5	3	1	9	1	0.420	1.000
Information Technology	1/7	1/2	1/4	1/5	1/9	1	1	0.033	0.111

Consistency ratio = 0.0169

Table 14
Overall Weights of Suppliers

A. Overall Weights of Suppliers using AHP

	Performance Assessment	Human Resources	Quality System Assessment	Manufacturing Criteria	Business Criteria	Information Technology	AHP
Supplier 1	0.482	0.587	0.738	0.311	0.231	0.429	**0.379**
Supplier 2	0.279	0.285	0.179	0.507	0.411	0.429	**0.365**
Supplier 3	0.239	0.128	0.083	0.181	0.358	0.143	**0.256**
Local Weights of Criteria	0.244	0.055	0.096	0.153	0.420	0.033	

B. Overall Weights of Suppliers using DEAHP

DMU	Output 1	Output 2	Output 3	Output 4	Output 5	Output 6	Input	DEA
Supplier 1	1.000	1.000	1.000	0.812	0.673	1.000	1	**0.999**
Supplier 2	0.887	0.734	0.366	1.000	1.000	1.000	1	**1.000**
Supplier 3	0.646	0.277	0.135	0.475	0.702	0.333	1	**0.607**
Criteria Efficiency Constraints	1.29*vm1	= 4.5*vm2	= 2.25*vm3	= 1.8*vm4	= vm5	= 9*vm6		