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MULTIPLE CRITERIA METHODS APPLIED TO SELECT SUPPLIERS OF A CAPITAL GOODS COMPANY

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Abstract: *The supplier selection has a significant impact in the supply chain and is usually a multi-criteria decision making process which includes both quantitative and qualitative factors. Organizations use a variety of methodologies to evaluate and select suppliers, because there is no single "best" methodology. In this work an integrated approach of Data Envelopment Analysis (DEA) improved by Analytic Hierarchy Process (AHP) is proposed. Initially, the DEA method is employed to study the efficiency of the alternatives (suppliers) and select the most efficient among them. Later on, when the decision makers´ experiences and preferences are considered in the rating calculation for each supplier, the AHP method is used.*
The proposed methodology provides agility to structure the decision problem, flexibility to change decisions or to evaluate other alternatives and clearness of the results. An application of the proposed methodology is used in a capital goods company.

1. Introduction

Supplier selection decisions are an important component of production and logistics management for many firms. Selecting the right suppliers significantly reduces the material purchasing cost and improves corporate competitiveness (XIA & WU, 2007). This paper analyzes the supplier selection problem (SSP) using mathematical methods. It is important to point out that applying these tools separately is not enough. It is important for any company to have reliable data, so that decisions are not made by a single person, rather by a group of persons. The present tool can be applied in any company, and by respecting the characteristics of each one and associated to other management strategies, can make the difference to win this hard battle called competitiveness.
In most industries, raw material and components costs have a significant portion of the product main cost, representing 40% to 60% of the sales (Ballou, 2005). This means that the results of the decisions made on the supply chain — as an example, small cost reductions in the raw materials and components' acquisition — may have a great impact in the profits for the industry.
The activities associated with the materials acquisition include selecting qualified suppliers, negotiating contracts, comparing price, quality, etc. Maybe the most important process of the materials acquisition is the efficient selection of suppliers, because this can bring significant savings for the organization. An efficient supplier will offer good service level and great savings in the future for the company. That's why many experts believe that the supplier selection is the most important activity of a purchasing department. (Xia et al, 2005).
Most of the published papers on supply chain focus on high level strategic issues. The results are usually generic guidelines for business executives rather than specific tools for plant managers. (WANG et al., 2005).
The supplier selection problem is not new. One of the first publications about this subject was released in 1960. Since then, several authors are studying this theme, like Weber et al. (1991 apud

BELLO, 2003), Nydick and Hill (1992 apud BHUTTA, 2003), Weber and Ellram (1993), Weber (1996), Ghodsypour and O'Brien (1998), etc. Recently, this subject has had great attention by Korpela et al. (2001), Bello (2003), Wang et al. (2004) and Bayazit (2006).
Supplier selection is an essential step in the supply chain, and this selection usually needs multiple criteria, being quite difficult to find a good solution. Traditional techniques in Operations Research use only quantitative measures, while the uncertainties described through qualitative measures exist in all places inside of the supply chain (WANG et al. 2004). A technique that can work with quantitative and qualitative measures is necessary for a better problem modeling. It doesn't exist a better way to evaluate and to select suppliers, and for this reason, the organizations use different kinds of methodologies.
The objective of this paper is to study an integrated approach using Data Envelopment Analysis (DEA) improved by Analytic Hierarchy Process (AHP) for the supplier selection problem for a capital goods company. Initially, the literature review approaches relevant aspects and the methods used in the supplier selection. In the following sections, the methods used in this paper, DEA and AHP, will be described. Finally, the practical application of both methods to solve a supplier selection problem of a Capital Goods Company is described.

2. Background review

2.1 Methods used for SSP - Supplier Selection Problem

Several methods have been used for the supplier selection problem. Nydick and Hill (1992 apud BHUTTA, 2003), Akarte et al. (2001), Bhutta et al. (2002), used Analytic Hierarchy Process (AHP). Timmerman (1986 apud BELLO, 2003) used the Weighted Point Method, Ellram (1995) and Bhutta et al. (2002) used Total Cost of Ownership, Monckza (1988 apud Bello, 2003) and Harding (1998 apud BHUTTA, 2003) used Total Cost Approach.
Other techniques have also been used, such as Mathematical Programming models, Principal Component Analysis (PETRONI and BRAGLIA, 2000), Neural Networks (WEI, 1997 apud BELLO, 2003), Fuzzy Methods (ZAIM, et al., 2003), and Dynamic Programming (MASELLA, et al. 2000).
Wang et al. (2005) proposed an integration between two methodologies: Analytic Hierarchy Process (AHP) and Preemptive Goal Programming (PGP), having qualitative and quantitative measures, respectively. Ghodsypour and O'Brien (1998) report an integration of AHP and Linear Programming models to select the best supplier. Recently Weber (1996) and Sarkis et al (2002) used Data Envelopment Analysis (DEA) to identify the most efficient supplier.
This article proposes an integrated approach of Data Envelopment Analysis (DEA) improved by Analytic Hierarchy Process. DEA was used to study the suppliers' efficiency and to select the most efficient suppliers. Later on, the AHP method was applied to make the alternatives priority. These two methods will be better described in the following sections.

2.2 Criteria used for suppliers' selection

Several criteria affect the supplier selection. According to Weber et al. (1991 *apud* BELLO, 2003) in their research with 74 articles about criteria for supplier selection, it was shown that the criteria of quality, delivery and price received more attention in most of the works, while production facility, geographical location, financial healthy and capacity produced an intermediate attention.
Recent works like Karpak *et al.* (2001) considered cost, quality and delivery reliability as criteria of seller selection. Bhutta *et al.* (2002) used four criteria to evaluate the suppliers: industrial costs, quality, technology, and service.
It should be noted that an important issue for criteria selection is their properties for classification and measurement of the suppliers' performance. In this study, the criteria are described in the methodology.

3. The DEA Method

The DEA (Data Envelopment Analysis) method is a non-parametric statistic tool which aims to measure the relative efficiency of different entities of a common class, and to establish efficiency goals (through benchmarks' identification) for entities considered on this side of the efficiency border (AVELLAR *et al*., 2006). In other words, DEA determines how efficient a business unit is to convert inputs in outputs, when compared with other units (RAGSDALE, 2006). According to Guedes *et al*. (2006), only companies which accomplish similar tasks are compared and they are distinguished by the amount involved of inputs and outputs. And for this study, DEA has three pillars: decision variables, the objective function and the constraints. These pillars establish the three stages of a DEA's modeling problem. In applying this methodology, the first step is to define the decision's variables which are the criteria related to the inputs and the criteria related to the outputs. During this stage, the decision maker has to be careful in his/her selection, because the criteria should express importance to the efficiency model. The expression below links multiple outputs (y) with multiple inputs (x) to obtain the certain unit (j) efficiency. These units are named DMU's (Decision Making Units).

$$\text{Efficiency Measure } j = \frac{u_1 \cdot y_{1j} + u_2 \cdot y_{2j} + \ldots}{v_1 \cdot x_{1j} + v_2 \cdot x_{2j} + \ldots} \quad (1)$$

The efficiency measure (j) depends on a group of weights of v and u which are attributed to each input and each output, respectively. Each appraised DMU will have different weights. These weights u and v are obtained from the Fractional Programming Problem, later on transformed in Linear Programming Problem (LPP) which attributes to each DMU the weights that maximize their efficiency (AVELLAR *et al.*, 2006).
The second stage is the objective's definition. In this stage, the base is the Linear Programming, and a LLP attributed for each DMU, but with a same objective for all DMU's. It has two kinds of objective for DEA's application. The first objective is DEA application oriented by the output, whose objective function consists in maximizing the weighed sum of outputs. The other one is DEA application oriented by the input, whose objective function consists in minimize the weighed sum of inputs. The last stage of DEA modeling is the restrictions definition, where the efficiency measure (j) must be smaller than or equal to 1.
In this study, the CCR model orientated by the input was used. According to Avellar *et al*. (2006), "the DEA method advantage, against other production models, is the capability to incorporate multiple inputs (resources, production factors) and multiple outputs (profits or products) for the measure's calculation of a unique efficiency".

4. Multicriteria Decision Support – The Classical AHP Method

4.1 Concepts

Complex processes of decision making were always, and still are, approached by the man looking forward to find the best solution or the most satisfactory to the problem. Decisions are present in the organizations' life in different degrees of complexity, where sometimes the best choice is the key to obtain success or failure.
Among situations of complex decisions, useful methods to solve problems have evolved and, during the 70', multicriteria methods of decision support, according to Nascimento *et al.* (2005), "call for the appreciation of multiple criteria to determinate an appropriate solution." Multicriteria Methods of Decision Support are designed to explain the decision making process, in such a way to support and to lead the decision maker(s) in evaluating and selecting alternatives to certain problems. It is important to emphasize that Multicriteria Methods of Decision Support assist the decision process according to decision maker preferences in regard to the alternatives; it does not present the decision maker with just one optimum solution for his/her problem.
AHP, which belongs to American School of Multicriteria Decision Support, is one of the discrete multicriteria methods (that has a finite number of alternatives) most applied in the world and in several knowledge areas. Developed by Thomas L. Saaty, the method is characterized by framing the problem to a descendant hierarchical structure, which starts with the global objective (or synthesis criterion), criteria, sub-criteria and alternatives in successive levels (SAATY, 1990). After this stage of hierarchical structuring, the pair-wise comparisons and decision maker judgment is conducted, and the alternatives will be classified by order of importance.

4.2 Hierarchical Structuring and the Modeling Method

Gomes *et al.* (2004) say that, "the beginning of the hierarchy represents a synthesis criterion or global objective, while in the successively lower levels it puts the criteria which present some impact in the criterion of the top level. In the lowest level of the hierarchy, there should be the considered alternatives". Figure 1 represents an example of a hierarchical structure.

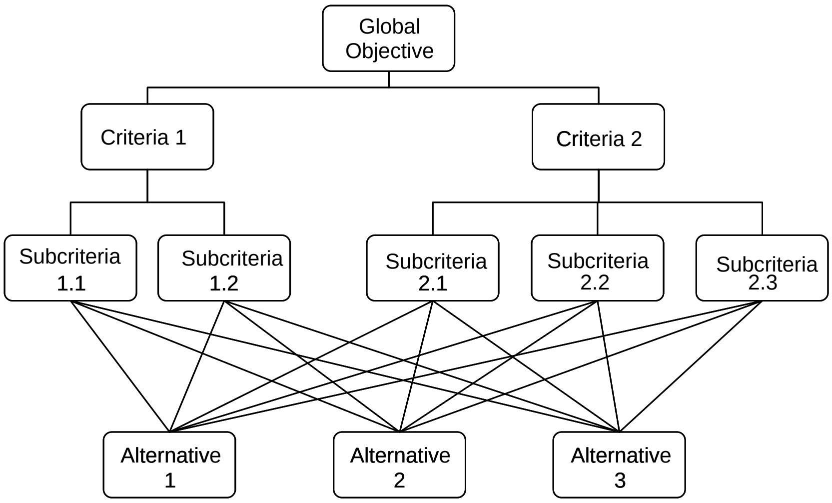

Figure 1: Hierarchical structure (NASCIMENTO *et al.*, 2005)

It is important to point out that, in agreement with Vargas (1990), Gomes *et al.* (2004) and Gomes *et al.* (2006), the decision problem's hierarchy must be complete; in other words, it must contain all of criteria and relative alternatives to the problem. The elements of a given hierarchical level must have the same degree of importance, must be mutually excluding amongst themselves, and when compared pair to pair must satisfy the reciprocity condition.

According to Gomes *et al.* (2004), "after building the hierarchy, each decision maker should make a comparison, pair to pair, of each element in a certain hierarchical level, building a square decision matrix. In that matrix, the decision maker will represent, beginning from a scale previously determined, his preference among the compared elements. "

After comparing the sub-criteria A_i and A_j in relation to the criterion C_k, with $i, j, k = 1, 2, ..., n$, the weights supplied by the decision makers will be, respectively, w_i and w_j, and the sub-criteria's preference *i over j* is the same as w_i/w_j.

It is worth to emphasize that the decision maker must make $n(n-1)/2$ comparisons, where n = number of elements in each analyzed level, and the paired comparisons are accomplished in the whole hierarchical levels through a predefined measures' scale and the results will compose the comparison matrix pair to pair (GOMES *et al.*, 2004).

The decision maker will then translate his/her preferences in relation to the available information in the hierarchy through paired comparisons, answering the following questions: *given a certain criterion C_k and two subcriteria A_i and A_j, which one of the subcriteria is the most satisfactory when compared with each other? And how much more?* (VARGAS, 1990).

The matrix formed by the paired comparison between alternatives or criteria related to a criterion of a hierarchical level immediately superior will have a vector of weights $W = (w_1, w_2, ..., w_n)$. The multiplication of the comparison matrix pair to pair A by the weights' vector W is equal to the product nW, where n is the eigenvalue of A, and W is his eigenvector. Since the mentioned matrix A ($A = (a_{ij})$, $a_{ij} = w_i/w_j$) is positive and reciprocal, in other words, with $a_{ji} = 1/a_{ij}$, assuming all judgments are perfect, and if A satisfies the condition $a_{ij} \times a_{jk} = a_{ik}$ ($i, j, k = 1, 2, ..., n$) in all comparisons, the matrix A is consistent.

Though, as the decision maker's judgments are susceptible to mistake, which makes them inconsistent, the matrix A will also be inconsistent. It is worth to point out, however, that the AHP method allows a certain inconsistency level.

In case the matrix be inconsistent (but reciprocal), the eigenvalue *n* will be denominated λ_{max}. The closer is the eigenvalue λ_{max} to *n*, the more consistent the decision maker's judgments will be and, consequently, the matrix *A*. According to Gomes *et al.* (2004), "therefore $\lambda_{max} - n$ is a consistence's indicator". Or still, in agreement with Saaty (1990), "the inconsistency of the matrix can be measured by the simple number $\lambda_{max} - n$ ", which measures the coherence degree of the decision maker's judgments.
In that way, from the equation $AW = \lambda_{max}W$, and after the normalization of the matrix *A* values, it is possible to obtain the priorities vector and a consistent main right eigenvector *W*. From the eigenvalue calculation λ_{max} , one proceeds to the calculation of the Consistency Index (*CI*) of the matrix. It is important to observe that, to be consistent, a matrix should have $\lambda_{max} \geq n$. After CI calculation, the Consistency Ratio is calculated by the function: (*CR = IC/RI*), where *RI* is a Random Index, previously calculated for a square matrix of order *n*. The *CR* also presents a specific number for the order (*n*) of the matrix that should be greater than the value found through the formula above. The greater the CR is, the greater is the inconsistency.

4.3 The Fundamental Scale of the AHP

After the problem is structured, it follows by paired comparison of the hierarchy's elements in agreement with a predefined scale of measures, denominated Fundamental Scale (Table 1). In that way the verbal preferences of the decision maker will be translated into numbers that represent the importance of a criterion (or alternative) over another.

Table 1: The fundamental scale of the AHP (Gomes *et al*, 2004)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderately more important, likely or preferred	Experience and judgment slightly favor one activity over another
5	Strongly more important, likely or preferred	Experience and judgment strongly favor one activity over another
7	Very strongly more important, likely or preferred	An activity is strongly favored and its dominance demonstrated in practice
9	Extremely more important, likely or preferred	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values to reflect compromise	When compromise is needed

An important aspect of AHP is that the number of elements in each hierarchical level must be seven plus or minus two (7 ± 2). This happens because of two reasons: first, the psychologist George Miller (1956) showed that this is the upper limit of the human capacity to process information and to compare elements. Saaty and Ozdemir (2003) say that through the IR of a great number of compared elements, the inconsistency reduces so slowly that it is insufficient to improve the consistence.
It is important to emphasize that the scale's application is possible as much for subjective (qualitative) as for quantitative judgments. In fact, the permissiveness of the subjectivism and objectivism is one of the main characteristics of the AHP classic method (Birth *et al.*, 2005).

5. The DEA and AHP Method Application

5.1 Scenario Description

The company in study is 100% Brazilian which is specialized in the production of equipment for all kinds of industry segments. The Company head-office is in Sorocaba. In the last two years, it is accomplishing an expansions succession, starting to offer services to the oil segment. Today, the company has as main customer's oil and natural gas, petrochemical and chemical sectors. It is also recognized by its differential in price and quality in sectors that include railroads, ports, fertilizers, metallurgy, mining and petroleum.

This case study requires, through the tools DEA and AHP, that a person responsible for a real project provide a plan to select its suppliers.

The company has Petrobrás as one of its main customers. This relationship of equipments and services supply began on the sixties, which has made the company to be awarded the "Petrobrás" prize of quality control class of products, for two subsequent editions. Participating on the Program of Warranty of Quality of Materials and Services and Associates, which is accomplished annually by Petrobrás, the company has reached an "A" degree of all products in its services class for Petrobrás.

The project on the company agenda is a petroleum refinery oven. It is necessary approximately 200 systems and components and thousands of small components to build this oven, which will be acquired from several suppliers and manufactured by the company. A Pareto Diagram indicates that 20% of all pieces are responsible for 80% of the supply cost. Further applying this methodology, it results that five components are responsible for 70% of the total components cost, which are:

- Heat Exchanger
- Petrochemical Fired Heater
- Asme Code Vessels
- Fired Heater Coils
- Plant Pipe-Rack

5.2 Structuring of the work

After the key elements for the supplier selection process were identified, a second interview with the project manager (decision maker) was accomplished. In this interview, it was identified the current process for suppliers selection, including the criteria and how this selection process is accomplished. Usually, the decision maker gives scores to the suppliers one by one, and then makes the global sum of the points. The supplier that presents the highest score is the chosen one. The actual company method for supplier selection is not accomplished for the size of problem, since it could possibly present an undesired supplier as the best one. Thus a scientific method is required for more reliability and clearness.

The methodology used by the company to collect information about the alternatives was obtained in technical visits, detailed budget and opinion research with other customers. In this context of confused methodology and strong dependence on the experience and perception of the project manager, the methods DEA and AHP were presented to the project leader as well as their respective benefits and restrictions. The methodology applied to support the decision of this case was: (1) Pareto diagram for identification of the main components of the oven; (2) potential suppliers' identification; (3) application of the DEA method for identification of the most efficient suppliers; (4) evaluation of results by the project manager; (5) application of the AHP method to select the best supplier; and (6) evaluation of the results.

5.3 DEA application

DEA was chosen because of the perception that there were some inefficient suppliers that would be considered by the leader, leading to a waste of time and money. With the accomplishment of technical visits, some suppliers were ignored due to their strong financial inefficiency, which could cause the non-supply of the components classified as having high importance to the project. Therefore, DEA was applied to validate the supplier efficiency. For that matter, 2 inputs and 1 output were identified. The inputs identified were Number of Employees (I1) and Build Area (I2). The output was the Revenue (O), as shown in Table 2.

For potential suppliers evaluation, it was applied the DEA model with constant return of scale (CCR) oriented by inputs and without weights' restrictions. Because the selected companies operate in scale less differentiated, the CCR model was chosen. The efficiency indexes can be visualized in Table 3.

Table 2 – The suppliers' inputs and outputs

Company	Inputs		Output
	Total Number of Employees	Build Area (m^2)	Revenue ($R)
A	180	15.000	20.000.000
B	150	5.000	5.000.000
C	30	8.000	2.000.000
D	80	8.000	6.000.000
E	120	6.000	4.000.000
F	40	5.000	1.500.000
G	120	9.000	8.000.000
H	130	12.000	12.000.000
I	105	6.000	13.000.000
J	1.700	70.000	200.000.000

From the above data, the SEM software for DEA application was used, giving the following results (Table 3).

Table 3 – Relative efficiency of potential suppliers

DMU	Efficiency Score
A*	89,74%
B	35,00%
C	53,85%
D*	60,58%
E	27,54%
F	30,29%
G	53,85%
H*	74,56%
I*	100,00%
J*	100,00%

Looking at Table 3, the best performance companies are I and J with both relative efficiency 100% (they are in the efficiency border), followed by companies A, H, D, C, and G. The less efficient companies are B, F and E. Five suppliers were chosen providing more reliance and facility to the project leader during the AHP process. The chosen alternatives are A, D, H, I and J.

5.4 The AHP Application and Results

The purpose to use AHP is that, besides providing a vector of weights expressing the relative importance of the alternatives as a function of each criterion, it provides the best alternative. According with Yang *et al.* (2003), AHP requests four stages: (1) structuring the criteria and alternatives hierarchy for evaluation; (2) assessing the decision maker evaluation by pairwise comparisons; (3) using the eigenvector method to yield priorities for criteria and alternatives by criteria; and (4) synthesizing the alternatives priorities by criteria into composite measures to arrive at a set of ratings for the alternatives.
Through bibliography researches, interviews and contracts analysis of other projects, the range of criteria could be defined. Some of criteria were already in use by the company and others were suggested and accepted by the decision maker. The criteria and sub-criteria selected were: price *, quality * (as subcriteria process and product), delivery (subcriteria lead time and delivery conditions), technical support, supplying exclusion (this happens when a supplier can not manufacture all the products required by the company) and general conditions * (subcriteria access, organization and stability). Those words that appear with (*) represent that the criteria or sub-criteria are already in use by the company. Through the criteria selection, it was possible to structure the hierarchy, containing the principal objective on the top, the criteria and sub-criteria in the intermediate level and the

alternatives in the lowest level. The applied comparison method was the down-up, in other words, the pairwise comparison process begins with the alternatives and it finishes with the criteria.

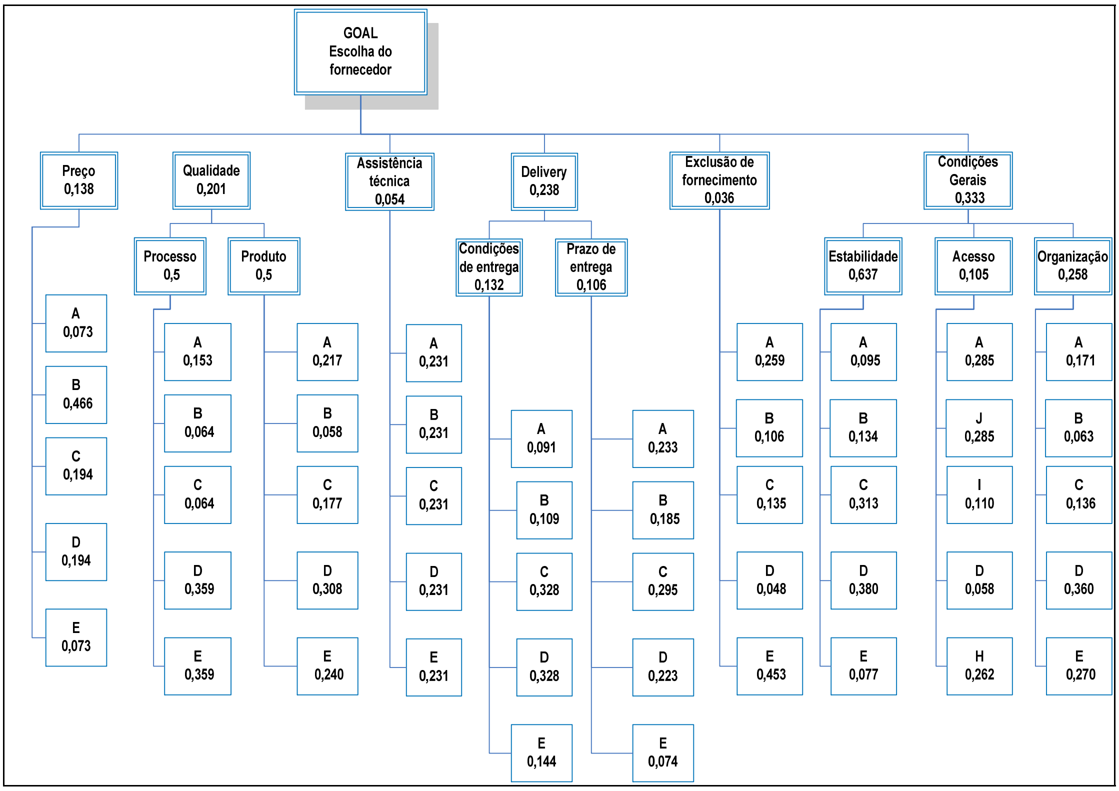

Figure 2: Decision problem hierarchical structure with weights

Once the problem is assembled and the hierarchy made and validated, the evaluation phase begins, where the project leader expresses his/her judgments. The matrix of criteria and alternatives' pairwise comparison are fulfilled by the decision maker in harmony with the Fundamental Scale of AHP. Therefore, the relative importance of criteria, sub-criteria and alternatives are fixed by expert leaders. In the following, the results are shown. All the originated results were considered acceptable, that means, they had consistency ratio below 10 percent.
Unlike the most frequent results about the companies' preference criteria for price and quality, the company in study gave more importance to general conditions of its supplier. While its customer, Petrobrás, gives more importance to price and quality during the auction process.
Supported by the weights in Figure 2, it was possible to solve the problem of supplier selection. For this case, the supplier who presents the better evaluation in the rank (Figure 3) is company D. If other supply restrictions do not exist and the company needs are satisfied, supplier D is indicated as the best supplier by the AHP method to be selected.

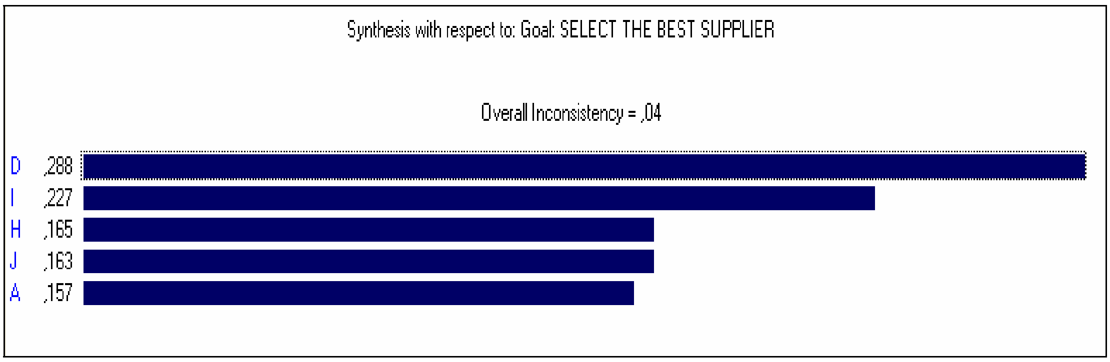

Figure 3: Alternatives priorities order

Supported by the tool, the decision maker can make several analyses to select the supplier with confidence. As pointed out previously, AHP is an excellent decision support method being applied in several cases. However, it is essential to understand the problem and structure it correctly so that the obtained results are in harmony with the decision maker(s)' preferences.

6. Conclusion

In the last years, actions which demand a more and more efficient supply chain are done where all members must have excellent quality levels, besides satisfying the customer's needs. When a bad supplier is selected, things can happen like customer's dissatisfaction and a terrible damage, both operational and financial, to all who make part of the supply chain.

It is clear that the supplier selection process is very important, because it helps managers to structure their decision for selection, and a good supplier can contribute to a significant increase of the firm profit. The proposal of this paper was to present the methods DEA and AHP and to apply these two methods in a decision problem of supplier selection of a goods capital company.

Through the DEA method, it was possible to identify the five most efficient suppliers among nine previously existent. The AHP method application allowed quantitative and qualitative information to be merged, extending the criteria for evaluation. Figure 3 shows the decision maker preference for supplier D, however the gap with the second favorite is narrow, with a small difference of 0,064. Therefore, the decision maker would have a second acceptable option, which will satisfy his/her needs.

For future work, it would be interesting to accomplish the sensitivity analysis with the criteria weights, so that it would be possible to verify how these changes would influence in the weights of the alternatives and, consequently, in their priority order. It would also be interesting to apply other theoretical methods, comparing the results obtained with this work, for example, the Principal Components Analysis.

7. References

Akarte, M. M., Surendra, N. V., Ravi, B. and Rangaraj, N. (2001) "Web based casting supplier evaluation using analytical hierarchy process," *The Journal of the Operational Research Society*, 52(5), 511-522.

Avellar, J. V. G., Araújo, A. H. Jr., Marins, F. A. S.and Milioni, A. Z. (2006) Eficiência e Desempenho do Transporte Aéreo Regional Brasileiro. Proceedings of the IX Simpósio de Pesquisa Operacional e Logística da Marinha. Rio de Janeiro. RJ, 42-47

Ballou, R. (2006) *Gerenciamento da Cadeia de Suprimentos/Logística Empresarial*, Porto Alegre: Bookman.

Bayazit, O. (2006), "Use of analytic network process in vendor selection decisions," *Benchmarking: International Journal*, 13, 566-579.

Bhutta, K.S. (2003) "Supplier selection problem: Methodology Literature Review," *Supply Chain Management: International Journal*, 7, 126-35.

Ellram, L. M. (1995) "Total Cost of Ownership: An Analysis Approach for Purchasing," *International Journal of Physical Distribution and Logistics*, 25, 4-23.

Expert Choice (1999), Expert Choice Software, Expert Choice Inc., Pittsburgh, PA.US.

Ghodyspour, S. H. and O'Brien, C. (1998) "A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming," *International Journal of Production Economics*, 56-57, 199-212.

Gomes, L. F. A. M., Araya, M. C. G. and Carignano, C. (2004) *Tomada de Decisões em Cenários Complexos*, São Paulo: Pioneira Thompson Learning.

Gomes, L. F. A. M, Gomes, C. F. S. and Almeida, A. T. (2006) *Tomada de Decisão Gerencial: Enfoque Multicritério*, São Paulo: Atlas.

Guedes, E. C. C.and Milioni, A. Z. (2006) "Modelo de Fronteira Esférica Aperfeiçoada". *Proceedings of the VIII Simpósio de Guerra Eletrônica*, São José dos Campos, 1- 4

Karpak, B., Kumcu, E.and Kasuganti, R. R. (2001) "Purchasing materials in the supply chain: managing a multi-objective task," *European Journal of Purchasing & Supply Management*, 7, 209-16.

Korpela, J., Lehmusvaara, A. and Tuominen, M. (2001) "Customer service based design of the supply chain," *International journal of production economics*, 69, 93-204.
Lin, Z. and Yang, C. (1996) "Evaluation of Selection by the AHP Method," *Journal of Materials Processing Technology*, 57, 253-258.
Masella, C.and Rangone, A. (2000) "A Contingent Approach to the Design of Vendor Selection Systems for Different Types of Co-Operative Customer/Supplier Relationships," *International Journal of Operations & Production Management*, 20, 70-84.
Nascimento, F. S., Lessa, N. O., Correia, A. R. and Belderrain, M. C. N. (2005) "Seleção de Modelo de Custos Logísticos com Apoio Multicritério à Decisão," *Proceedings Simpósio de Guerra Eletrônica*, São José dos Campos. SP, 1-15.
Petroni, A.and Braglia, M. (2000) "Vendor Selection Using Principal Component Analysis," *The Journal of Supply Chain Management: A Global Review of Purchasing and Supply*, 36(2), 63-69.
Ragsdale, C.T. (2006) *Spreadsheet Modeling & Decision Analysis: A Practical Introduction to Management Science*, USA, Thomson Learning.
Saaty, T. L. (1990) "How to Make a Decision: The Analytic Hierarchy Process," *European Journal of Operational Research*, 48, 9-26.
Saaty, T. L. and Ozdemir, M. S. (2003) "Why the Magic Number Seven Plus or Minus Two," *Mathematical and Computer Modelling*, 38, 233-244.
Sarkis, J. and Talluri, S. (2002) "A model for strategic supplier selection," *Journal of Supply Chain Management*, 38(1), 18-28.
Vargas, L.G. (1990) "An Overview of the Analytic Hierarchy Process and its Applications," *European Journal of Operational Research*, 48, 2-8.
Yang, T. and Kuo, C. (2003) "A Hierarchical AHP/DEA Methodology for the Facilities Layout Design Problem," *European Journal of Operational Research*, 147, 128-136.
Wang G., Huang S. H. and Dismukes J. P. (2004) "Product-driven supply chain selection using integrated multi-criteria decision-making methodology," *International Journal of Production Economics*, 91,1-15.
Wang G., Huang S. H. and Dismukes J. P. (2005) "Manufacturing supply chain design and evaluation," *The International Journal of Advanced Manufacturing Technology*, 25, 93-100.
Weber, C. A. and Ellram, L. M. (1993) "Supplier selection using multi-objective programming: A decision support system approach," *International Journal of Physical Distribution & Logistics Management*, 23(2), 3-14.
Weber, C. A. (1996) "A data envelopment analysis approach to measuring vendor performance," *Supply Chain Management*, 1(1), 28-39.
Zaim, S., Sevkii, M. and Tarim, M. (2003) "Fuzzy analytic hierarchy base approach for supplier selection," *Logistics Information Management*, 12 (3/4),147-176.Xia, W. and Wu, Z. (2005) "Supplier selection with multiple criteria in volume discount environments," *The International Journal of Management Science***,** 35(5), 494-505.