Supplier Selection in E-Procurement

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Abstract **- In today's competitive business world, it is extremely important for decision makers to have access to decision support tools in order to make quick, right and accurate decisions. One of these decision making areas is supplier selection in e-procurement. Supplier selection is a multi-criteria decision making problem that deals with the optimization of conflicting objectives such as quality, cost, and delivery time. In spite of the fact that the term "supplier selection" is commonly used in the literature, and many methods and models have been designed to help decision makers, few efforts have been dedicated to develop a system based on any of these methods. In this paper, we review, categorize, and discuss the literature, as well as the most widely used supplier selection criteria and their relative importance. We propose a supplier selection system based on the analytic hierarchy process (AHP) method which has been commonly used for multi-criteria decision making problems. Inasmuch as we believe that fuzzy concepts extend the capability of any modeling approach, integrating fuzzy concepts into our model will lead to a more powerful system. To support this idea and to facilitate decision making in the supplier selection process, we implemented linear and non-linear fuzzy programming approaches on a chosen business scenario.**

I INTRODUCTION

In the early 2000s, business and governmental organizations began to realize that electronic procurement (e-procurement) can significantly improve their efficiency and reduce their costs. E-procurement is defined as the process of acquiring goods and services through electronic means, and more specifically using the Internet.

According to Kameshwaran and Narahari, "upgrading to e-procurement from traditional procurement helps organizations reduce operational costs, shorten the order fulfillment cycle time, lower inventory levels, and create collaborative partnerships" (Kameshwaran S. and Narahari Y., 2003).

Supplier selection in e-procurement (and in traditional procurement as well) is set to answer the question: "which suppliers to buy from and what quantity to buy from each supplier?"

Most techniques used to select the right supplier consider a number of criteria. Based on these criteria, new and existing suppliers are evaluated then ranked. The decision is based on the rankings.

At this point, two situations arise. In the first one, a single supplier can fulfill all the requirements of the buying organization. Consequently, managers only need to decide on the best supplier, and automatically order all their goods/services from that supplier. This situation is called single sourcing.

In the second situation, which is the real life case most of the time, more than one supplier is necessary to fulfill the requirements of the buying organization. This is called multiple sourcing and in this case managers are faced with a more complex task: "which suppliers to select, and how much to order from each one?" Depending on the procurement strategy of the buying organization, both single sourcing and multiple sourcing can be employed. Each strategy has its advantages and disadvantages. In this paper, we consider an approach to single sourcing supplier selection with the possibility that it can be extended to a multiple sourcing situation.

This paper consists of three main parts. In the first one we briefly address some basic concepts and discuss traditional and new methods used in the evaluation and selection of suppliers. In the second part, we review supplier selection literature and discuss the different approaches and their models from the perspective of buyer-supplier relationships. Our review of the literature points to the fact that Analytic Hierarchy Process (AHP) is a powerful and commonly used method in multi criteria decision making problems. Inasmuch as we believe that fuzzy concepts extend the capability of any modeling approach, integrating fuzzy concepts into our model will lead to a more powerful system. To illustrate and support this idea, the third part of the paper introduces our supplier selection system and presents a real life business scenario. We rely on that scenario to construct fuzzy AHP models applying (Mikhailov, 2003)'s linear and non-linear fuzzy programming methods.

II BACKGROUND

II.*A Criteria Issues*

(Dickson, 1966), one of the earliest researchers to study criteria issues in supplier selection, conducted a survey and suggested 23 different criteria to be considered in order to perform an appropriate supplier performance evaluation. Although different buyers can rank these criteria differently, the author proposed a score for each criterion based on its importance. The three highest scores went to "quality", "delivery" and "performance history", while the three lowest scores went to "amount of past business", "training aids" and "reciprocal arrangements".

Following (Dickson, 1966), a survey of supplier selection methods was conducted by (Weber et al., 1991). The survey was based on an extensive search in the academic literature. It classifies and reviews 74 articles published in the area of supplier selection between 1966 and 1990. The authors of the survey emphasize that most of the papers discussed some of Dickson's seven most important criteria excluding the third and fourth (i.e., "performance history" and "warranties and claim policies" respectively). This does not indicate, according to the authors, that a conflict exists between the research papers and Dickson's study, and it certainly does not question the usefulness of Dickson's two criteria. Rather, the two criteria might be considered as sub-elements of other criteria, and therefore had not been mentioned in most of the research papers.

(De Boer et al., 2001) also analyzed the literature from the perspective of supplier selection methodologies and proposed an extension to the research done by (Weber et al., 1991). The authors categorized the methodologies based on a framework developed by (De Boer, 1998). In this framework, the supplier selection process was divided into four phases. The first phase deals with defining the objective of supplier selection: What will be the outcome of the supplier selection process? Why do we want to select suppliers? Once the objective is clarified, criteria are defined in the second phase, and pre-selection of potential suppliers is done in the third phase. The final selection is performed in the fourth phase. The authors argue that supplier selection depends heavily on the type of goods and services to be procured. The selection process for a low valued routine item will be different from that of a strategic item. The paper reveals that for the pre-selection phase of suppliers, researchers used mainly AHP, data envelopment analysis (DEA), case based reasoning (CBR), and cluster analysis (CA). For the final selection of suppliers, many types of models are used including linear weighting models, total cost of ownership models, mathematical and statistical models, and artificial intelligence based models.

The recent paper (Bharadwaj, 2004) investigates decision criteria used for supplier selection in the procurement of electronic components. To determine the "key buying criteria" the author deployed a cross-sectional survey. On a seven-point scale, the ratings are outlined in Table 1.

Criterion	**Mean Rating (/ 7)**	**Normalized Mean Rating**	**Standard Deviation**
Quality	6.51	0.29	0.77
Delivery	5.88	0.26	1.07
Price	5.63	0.25	1.12
Service	4.64	0.20	1.45

Table 1: Relative Importance of Decision Criteria - adapted from (Bharadwaj, 2004)

II.*B Model Issues*

Researchers have used many different models for supplier selection and some of them are applied to e-procurement systems. Below, we classify supplier selection literature based on the approach taken: case based and electronic tool (e-tool) based.

II.*B.1 Case Based Approaches*

(Ghodsypour and O'Brien, 1998) presented an integrated approach of AHP and linear programming (LP) to solve the supplier selection problem and the order quantity optimization problem. The implementation aims to come up with the best suppliers with optimum number of order quantities. The study first settles the criteria to evaluate suppliers. AHP is used to figure out the weights of the factors, then a LP model is developed to select the vendors and to allocate the orders among them.

(Masella and Rangone, 2000) also used the AHP approach, but they argued that the type of relationship between the buyer and its suppliers plays a critical role in the supplier selection process. To support this idea, they introduced four different classes of Supplier Selection Systems (SSS) based on the type of relationship. The buyer might have either a *long-term* or *short-term* relationship with its suppliers. Also from the content perspective, buyer-supplier relationships are categorized in two classes: *logistic* and *strategic*. A logistic relationship cares about operational criteria such as quality, service support, and delivery time, while a strategic relationship insists on criteria such as joint design of new products. The authors suggested using AHP for supplier selection not only because it has the ability to deal with both qualitative and quantitative measures, but also because of its effectiveness on supplier selection problems. Classifying suppliers based on relationships prevents the buyer from adding irrelevant measures to the AHP model. It is very important to have appropriate criteria in the AHP model to get a correct evaluation.

(Bhutta and Huq, 2002) examined the Total Cost of Ownership (TCO) and AHP approaches and discussed their advantages and disadvantages when applied to supplier selection. As defined in (Ellram, 1994), TCO deals with monetary factors and criteria that are associated with the procurement of each good from each supplier and determines the total cost originated from these factors. Suppliers' performances are determined by this total cost. Currently, as stated by the authors, there is a debate among researchers on the issue of how non-monetary criteria such as quality and delivery would be added to the model.

Recently artificial intelligence (AI) techniques were implemented in supplier selection systems. (Ding et al., 2003) combined simulation and optimization approaches using a genetic algorithm (GA). A GA uses a probabilistic approach rather than the deterministic approach used in mathematical programming methods. The authors proposed a discrete event simulation model using an integrated GA as a search mechanism for optimal supplier selection. Although the authors claim that their approach is better than the other selection methods, and simulation results look satisfactory, there is no base to support this claim since the performance of the model has not been tested against other models.

(Kahraman et al., 2003) also approached the multi-criteria supplier selection problem from the perspective of AHP. They claim that not only the cost but also the common set of criteria and measures affect the buyer's decision on supplier selection. To get the advantage of using imprecise knowledge rather than precise knowledge, they integrated AHP with fuzzy concepts. Catching the imprecise data and using it for evaluation purposes enabled them to see most of the hidden points of measures and criteria. Since it is rather difficult to assign crisp evaluation scores when comparing two measures, fuzzy linguistic variables were introduced in the questionnaires. For instance, the importance of one attribute over another was requested using words such as "absolute", "very strong", "weak", etc. The authors performed supplier selection in an aspirator production firm using a fuzzy AHP methodology. Comparison matrices were built based on measures and criteria and data acquired through questionnaires.

Finally, (Wang et al., 2004) propose a supplier selection model using an integrated AHP and preemptive goal programming (PGP) methodology. AHP is used for selecting suppliers and PGP for determining optimal order quantities from selected suppliers. In their model, the authors used the supply chain operations reference model (SCOR) constructed by the Supply Chain Council (SCC)[1]. The SCOR model suggests using twelve performance criteria in four categories. These categories are "delivery reliability", "flexibility and responsiveness", "cost", and "assets". AHP results and the priority of alternatives are input into the PGP model, along with the capacity constraints. This determines the optimal order quantity from each supplier by minimizing the total value of purchase and maximizing the total cost of purchase.

II.*B.2 E-Tool Based Approaches*

If we do not count commercial electronic supplier relationship management (e-SRM) solutions, there is a limited number of tool based approaches to supplier selection in the literature. The first commercial tool was developed in a partnership between Dun & Bradstreet[2] and SAS[3], who tried to find out if they could decrease sourcing times by utilizing web-based technologies to execute supplier selection and allocation processes. Eventually, they created one of the components of SAS e-SRM solution, which is called "Supplier Portfolio Optimizer". Supplier Portfolio Optimizer uses a mixed-integer programming approach to solve the selection problem. The output of the optimization process is a portfolio of suppliers that satisfies all the conditions specified by the design parameters and maximizes leverage in future negotiations (Cohen M.D. et al., 2001).

(Choy K.L. et al., 2003) use an artificial intelligence based tool in the outsourcing functions of supplier relationship management to select appropriate suppliers from a pool of suppliers. The authors aimed to reduce the time cycle of the supplier selection phase in the outsourcing process by using a hybrid case based/neural networks approach. The paper introduces two main modules in the decision making system. The first module is called "case based supplier selection module". Basically, case based reasoning (CBR) is a method which uses technological tools and applies the results of past experiences to find solutions for new problems. In the first step, the user takes a request and finds the most similar case from the past experiences database. In the second step, the user adapts a solution to the new problem by looking at a similar case. The third step is verification. If the new solution satisfies the problem's requirements, it will be accepted and added to the database for future use. The second module, called "neural networks (NN) based supplier benchmarking module" (NNSBM), performs supplier benchmarking. A NN mimics the operation of the human brain. It is composed of one input, one output and one or more hidden layers with some nodes in every layer. These nodes act like neurons in the human brain. A NN can be trained using historical or empirical data and can be used for forecasting, prediction, or optimization. In order to find the most suitable supplier, the NNBSM module gets the list of potential suppliers from the CBR module and benchmarks them by comparing the performance scores using a NN module.

III CONTRIBUTION

In fuzzy AHP literature, a scale with fuzzy numbers is used instead of a traditional crisp numbered scale. The fuzzy scale has pre-determined fuzzy numbers to capture vagueness in the human mind. However, having a decision maker perform pair-wise comparisons is not always successful because he/she may not be certain about his/her comparisons and/or incomplete information or knowledge might lead him/her to make the wrong decision (Mikhailov, 2003). In this case, even fuzziness cannot reflect the real situation. We believe that empirical data is always useful for decision making. We therefore intend to use it to generate pair-wise comparisons, and if no data is available, the decision maker will use a linguistic enabled comparison scale.

Empirical data is brought into the system either from back-end systems or from a third party (offering the data through a web service for instance). It is the decision maker's choice to accept the data "as is" or modify it. This approach gives us an opportunity to reflect real comparisons of the criteria and rates.

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[1] http://www.supply-chain.org/
[2] http://www.dnb.com/us
[3] http://www.sas.com

As a second contribution we designed a flexible web-based decision support system for supplier selection. If we look at the applications of different models in the literature, most are case based examples with a pre-determined number of suppliers and criteria that are collected through questionnaires. The lack of flexibility results from the fact that adding or removing a supplier or criterion requires repeating the whole process. There are some academic (Web-Hipre[4]) and commercial (ExpertChoice[5]) tools using traditional AHP, but they are not specifically designed for e-procurement. Moreover, these tools lack the ability to capture vagueness in the decision maker's mind. They use crisp numbers with the static scale proposed by (Saaty, 1980).

Our proposed support system combines the power of web based tools, fuzzy concepts and empirical data, which makes it more flexible than the systems described in the literature.

IV Methodology

IV.*A AHP Modeling*

AHP was first introduced by Thomas Saaty in the 1970's and since then it has been used in many areas including finance, marketing, energy resource planning, sociology, and architecture. It can be defined as a multi-criteria decision making approach which compares all defined measures in pairs and calculates their relative importance (Fig. 1). Most of the time, AHP is used in the choice phase of decision making. Afterwards, other techniques such as linear programming, queuing, or multiple objective decision making are used to solve the problem. In fact, the aim of AHP is to combine quantitative factors to evaluate all the objectives (Saaty, 1994).

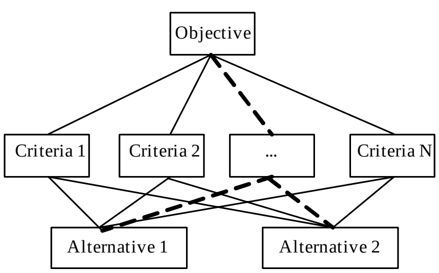


Fig. 1: Analytical Hierarchy Process Design

The evaluation phase is divided into four steps as explained below:

1. Generate pair-wise matrices;
2. Generate the weights of the measures;
3. Normalize weights to get the consistency among measures;
4. Calculate the overall ratings of suppliers.

4 http://www.hipre.hut.fi
5 http://www.expertchoice.com

IV.*B Integrated Fuzzy AHP Modeling*

Integrated fuzzy AHP modeling with trapezoidal fuzzy numbers was first introduced by (Buckley, 1985) as an extension to (Saaty, 1980)'s AHP. In fuzzy AHP modeling, fuzzy ratios rather than crisp ratios are used for pair-wise comparisons. Let us suppose that a buyer wants to compare suppliers based on some criteria. Assume that one of the criteria is service performance. If the buyer had to perform pair-wise comparisons using normal AHP in order to build a comparison matrix, then he/she would have to choose a score from 0 to 9 to show how one supplier compares to another in terms of service performance. Although the comparison scales provide flexibility for a decision maker to set scores, in some conditions this flexibility does not guarantee a satisfactory decision. A fuzzy approach, on the other hand, captures the uncertainty in the decision maker's mind.

In fuzzy AHP literature, there are several approaches for deriving priorities from fuzzy pair-wise comparison judgments or matrices. Table 2 below lists some of these approaches.

Paper	**Fuzzy AHP Method**	**Type of Fuzzy Number**
(Van Laarhoven and Pedrycz, 1983)	Fuzzy logarithmic least squares method	Triangular
(Buckley, 1985)	Fuzzy geometric mean method	Trapezoidal
(Cheng and Mon, 1994)	Interval arithmetic	Triangular
(Chang, 1996)	Synthetic extent analysis	Triangular
(Xu, 2000)	Fuzzy least-squares priority method	Triangular
(Mikhailov, 2003)	Fuzzy linear and non-linear programming method	Crisp or Triangular

Table 2: Fuzzy AHP Approaches in the Literature

IV.*C Linear and Non-Linear Programming Methods for Fuzzy AHP*

We selected Mikhailov's fuzzy linear and non-linear programming methods among the methods presented in Table 2. As outlined in (Mikhailov, 2003), current methods have some clear disadvantages. They require heavy computations, may result in unacceptable final fuzzy scores, and need additional fuzzy ranking procedures. Fuzzy preference programming methods do not require constructing fuzzy comparison matrices. Also, priorities can be derived from an incomplete set of fuzzy judgments. This means knowing the fuzzy comparison number $\tilde{a}_{ij}$ (importance of $\tilde{a}_i$ over $\tilde{a}_j$) is enough for solving the problem, and it does not require $\tilde{a}_{ji}$ or $\tilde{a}_{ij}^{-1}$.

Fuzzy Linear Programming is an optimization method that aims to maximize the consistency index and results in finding the weights as shown below.

$$
\begin{aligned}
& maximize\ \lambda \\
& Subject\ to \\
& d_i\ \lambda + w_i - u_{ij}(\alpha) w_j \le d_i \\
& d_j\ \lambda - w_i + l_{ij}(\alpha) w_j \le d_j \\
& \sum_{k=1}^{n} w_k = 1, w_k \ge 0, k = 1,2,...n \\
& i = 1,2,...,n \quad j = 2,3,...n \quad j > i \\
& where \\
& \tilde{a}_{ij}\ is\ a\ triangular\ fuzzy\ number = (l_{ij}, m_{ij}, u_{ij}) \\
& l_{ij}(\alpha) = \alpha(m_{ij} - l_{ij}) + l_{ij} \\
& u_{ij}(\alpha) = \alpha(m_{ij} - u_{ij}) + u_{ij} \\
& \alpha, \mathrm{d_i} = 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1 \\
& i = 1,2,...n \ \ \mathrm{j = 1,2,..., n \quad j > i}
\end{aligned}
$$

The value of λ is called consistency index and has a value greater than one if the interval judgments are consistent, otherwise there will be a degree of inconsistency depending on the value of λ between zero and one. d_i is a tolerance parameter and can be set to one if all comparisons are symmetric. Overall, priorities can be calculated through aggregation of the priorities. Detailed information about fuzzy linear and non-linear methods can be found in (Mikhailov, 2003).

IV.*D Web-Based Supplier Selection and Model Comparison System*

The system has four main components as can be seen in Fig. 2. The first is a database component in which information about new and existing suppliers as well as criteria information is stored. The second is a data process component that allows decision makers to define criteria and select the suppliers to be ranked. Ratings for some of the criteria can also be acquired from a third party or from back end systems such as enterprise resource planning (ERP) systems. The third and fourth components are calculation and optimization engines. The third component uses AHP with options of fuzzy linear and non-linear programming modules that are implemented using the Lindo API[6] optimization module. Supplier ranking and selection is performed by the third component, but in case the decision maker needs to determine the optimal quantity of goods to order from selected suppliers, he/she can use the fourth component. In this last situation, constraints such as the capacity of suppliers must be taken into account.

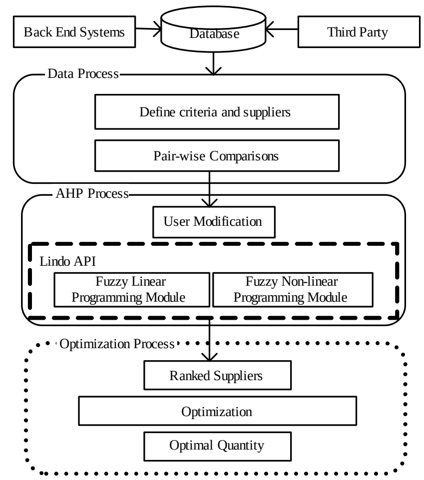
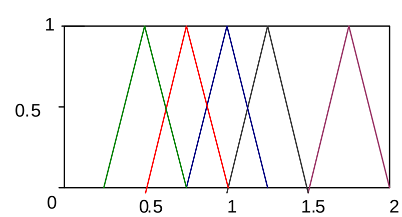


Fig. 2: Supplier Selection and Model Comparison System

IV.*E A Simple Business Scenario*

The following scenario shows the importance of fuzzy AHP methodology in a supplier selection decision making process and illustrates the use of the support system.

Suppose a hospital needs to procure medical supplies. They consider using four criteria to rank their suppliers. These criteria, believed to be the most important ones in the literature, are quality, delivery, price and service. The procurement department thinks that the importance of these four criteria is the same for any procurement process, thus they decide to use (Bharadwaj, 2004)'s ratings (See Table 1). The scale used for these ratings is between zero and seven. By using mean ratings and standard deviations ($\pm\ \sigma$) the system produces triangular fuzzy numbers and gives ratio of these fuzzy numbers as comparison values. When producing these numbers, in order to prevent from going outside the scale boundary, the upper value of the triangular fuzzy number is defined as $Min(7,(\bar{x}+\sigma))$ and the lower value is defined as $Max(0,(\bar{x}-\sigma))$. Decision makers have the option to change these numbers if they wish. In case there is no comparison available, the decision maker can make his/her decision by using linguistic comparison values (see Fig. 3).



	Lower	Mean	Upper
Extremely Strong	1. 50	1. 75	2. 00
Strong	1. 00	1. 25	1. 50
Same	0. 75	1. 00	1. 25
Weak	0. 50	0. 75	1. 00
Extremely Weak	0. 25	0. 50	0. 75

Fig. 3: Linguistic Variables and their Membership Functions

[6] http://www.lindo.com/dllf.html

Pair-wise comparisons for criteria are given below as triangular fuzzy numbers.

$$\tilde{a}_{(Q/D)} = (0.83, 1.11, 1.46)$$
$$\tilde{a}_{(Q/P)} = (0.85, 1.16, 1.55)$$
$$\tilde{a}_{(Q/S)} = (0.94, 1.40, 2.19)$$
$$\tilde{a}_{(D/P)} = (0.71, 1.04, 1.54)$$
$$\tilde{a}_{(D/S)} = (0.79, 1.27, 2.18)$$
$$\tilde{a}_{(P/S)} = (0.74, 1.21, 2.12)$$

From here the system builds an optimization problem and calculates the weight of each criterion using a non-linear fuzzy programming method.

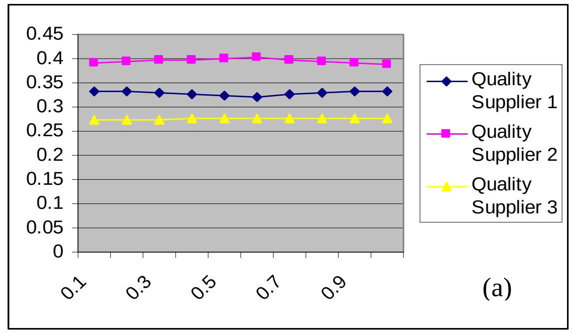
The resulting weights are:

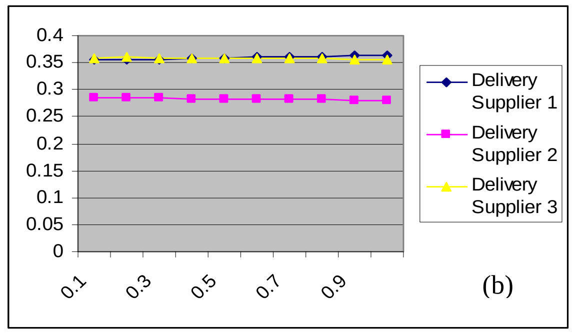
$$W_Q = 0.288,\ W_P = 0.258,\ W_S = 0.250, W_D = 0.204$$

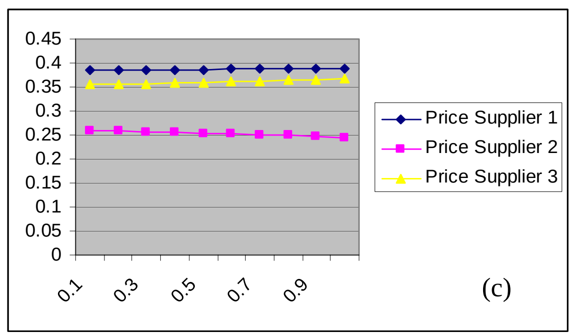
Since the decision maker didn't change any of the ratings, the calculated weights of the criteria are almost the same as the initial normalized ratings (See Table 1).

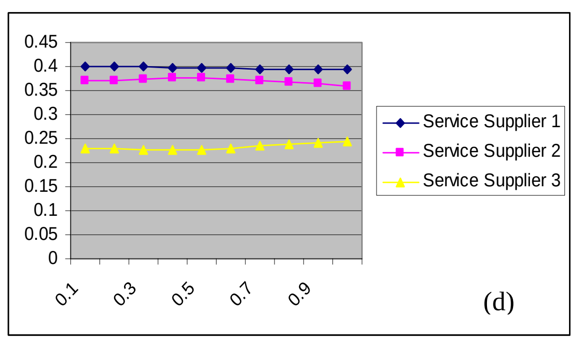
The second step consists of pair-wise comparisons of suppliers based on each criterion. For the sake of the example, we assume that the last supplier (Supplier 3) is a new supplier and that there is no empirical data available for this supplier. Ratings for Supplier 3 are acquired from a third party provider (non-profit or commercial organization) in the form of ranges that are converted to triangular fuzzy numbers. Moreover, we assume that service rating for Supplier 1 and delivery rating for Supplier 2 are not available. Thus pair-wise comparisons need to be performed by the decision maker using fuzzy linguistic variables.

The system then calculates weights of each supplier against each criterion along alpha-cut levels. Criteria and overall rankings of suppliers are illustrated in Fig. 4. Supplier 2 for instance, is the overall winner (Fig. 4-e) despite the fact that it has lower quality than Supplier 1 (Fig. 4-a). The problem can be extended under given constraints to enable the buyer to order an optimal quantity from each supplier. The system provides flexibility and ease of use, and allows the user to make quick and accurate decisions and try different alternatives.









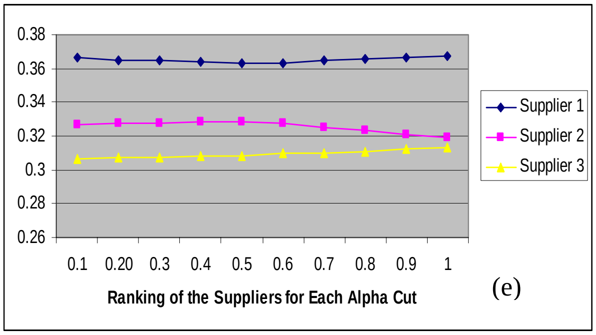


Fig. 4: Rankings of the Suppliers (a, b, c, d, e)

V Conclusion

Several fuzzy AHP models are applied to supplier selection as well as other areas. Many of these models are static, case-based and problem oriented. Related criteria and objectives have to be well defined in advance, thus adding or removing a criterion would require questionnaires to be redesigned and calculations to be restarted. Moreover, to our knowledge, all supplier selection solutions in the literature depend on the expert's choices and comparisons.

We propose that the expert be supported with empirical data. If no empirical data is available, comparison for each criterion can be performed by one single expert or by different experts in different departments (i.e., the quality department compares quality, the warehouse compares delivery).

Using a decision support system gives the expert more flexibility. Being web based and platform independent, comparison for certain criteria can be acquired from anywhere, without need for static private networks.

References

Bharadwaj Neeraj, "Investigating the Decision Criteria Used in Electronic Components Procurement", *Industrial Marketing Management*, 33, 2004

Bhutta Khurrum S. and Huq Faizul , "Supplier Selection Problem: A Comparison of the Total Cost of Ownership and Analytical Hierarchy Process Approaches", *Supply Chain Management: An International Journal,* 2002

Buckley J. J., "Fuzzy Hierarchical Analysis", *Fuzzy Sets and Systems*, 17, 1985

Chang, D. Y., "Applications of the Extent Analysis Method on Fuzzy AHP", *European Journal of Operational Research,* 95, 1996

Cheng, C.H. and D.L. Mon, "Evaluating Weapon System by Analytical Hierarchy Process Based on Fuzzy Scales", *Fuzzy Sets and System*s 63, 1994

Choy K. L., et al., "Design Of An Intelligent Supplier Relationship Management System: A Hybrid Case Based Neural Network Approach" *Expert Systems with Applications*, 2003

Cohen Marc-David et al., "Decision Support with Web-Enabled Software", *SAS Institute,* 2001

Dickson G. W., "An Analysis of Vendor Selection Systems and Decisions", *Journal of Purchasing*, 1966

De Boer, Lutzien, Labro Eva, Morlacchi Pierangela, "A Review of Methods Supporting Supplier Selection", *European Journal of Purchasing & Supply Management*, 7, 2001

Ding et al. , "A Simulation-Optimization Approach using Genetic Search for Supplier Selection", *Proceedings of the 2003 Winter Simulation Conference,* 2003

Ellram Lisa M., "Total Cost Modeling in Purchasing", *Center for Advanced Purchasing Studies*, 1994

Ghodsypour S. H., and C. O'Brien., "A Decision Support for Supplier Selection Using an Integrated Analytic Hierarchy Process and Linear Programming", *International Journal of Production Economics,* 1998

Kahraman C., Cebeci U., Ulukan Z., "Multi-Criteria Supplier Selection Using Fuzzy AHP", *Logistics Information Management,* 16-6, 2003

Kameshwaran S., and Narahari Y., "e-Procurement Using Goal Programming" *E-Commerce and Web Technologies Proceedings*, 2003

Masella, C. & Rangone, A. "A Contingent Approach to the Design of Vendor Selection Systems for Different Types of Cooperative Customer/Supplier", *International Journal of Operations and Production Management*, 2000

Mikhailov, L., "Deriving Priorities from Fuzzy Pairwise Comparison Judgements", *Fuzzy Sets and Systems*, 134, 2003

P.J.M. van Laarhoven, W. Pedrycz, "Fuzzy Extension for Saaty's Priority Theory", *Fuzzy Sets and Systems*, 24, 1983

Saaty, T. L., "Analytical Hierarchy Process", McGraw Hill, New York, 1980

Saaty, T. L. , "Highlights and Critical Points in the Theory and Application of the Analytic Hierarchy Process", *European Journal of Operational Research*, 1994

Wang, Ge, Huang, Samuel H., Dismukes, John P., "Product-Driven Supply Chain Selection Using Integrated Multi-Criteria Decision-Making Methodology", *International Journal of Production Economics*, 91, 2004

Weber, C.A., Current, J.R., Benton, W.C., "Vendor selection criteria and methods", *European Journal of Operational Research*, 1991