Multi-criteria supplier selection using fuzzy AHP

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Keywords

Supplier evaluation, Fuzzy logic,
Analytic hierarchy process,
Group decision support systems, Decision making, Turkey

Abstract

A supplier selection decision inherently is a multi-criterion problem. It is a decision of strategic importance to companies. The nature of this decision usually is complex and unstructured. Management science techniques might be helpful tools for these kinds of decision-making problems. The aim of this paper is to use fuzzy analytic hierarchy process (AHP) to select the best supplier firm providing the most satisfaction for the criteria determined. The purchasing managers of a white good manufacturer established in Turkey were interviewed and the most important criteria taken into account by the managers while they were selecting their supplier firms were determined by a questionnaire. The fuzzy AHP was used to compare these supplier firms.

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Introduction

The objective of supplier selection is to identify suppliers with the highest potential for meeting a firm's needs consistently and at an acceptable cost. Selection is a broad comparison of suppliers using a common set of criteria and measures. However, the level of detail used for examining potential suppliers may vary depending on a firm's needs. The overall goal of selection is to identify high-potential suppliers.

To select prospective suppliers, the firm judges each supplier's ability to meet consistently and cost-effectively its needs using selection criteria and appropriate measures. Criteria and measures are developed to be applicable to all the suppliers being considered and to reflect the firm's needs and its supply and technology strategy. It may not be easy to convert its needs into useful criteria, because needs are often expressed as general qualitative concepts while criteria should be specific requirements that can be quantitatively evaluated. The firm can set measures while it is developing selection criteria to ensure that the criteria will be practical to use. Often, developing criteria and measures overlaps with the next step, gathering information. Gathering information may offer insight into the number and type of criteria that will be required for the evaluation and the type of data that is available. However, gathering information without specific criteria and measures in place can lead to extraneous effort. Selection criteria typically fall into one of four categories: supplier criteria, product performance criteria, service performance criteria, or cost criteria.

Some criteria may be impractical to evaluate during selection. Information may be difficult to obtain, complex to analyze, or there may not be sufficient time. The firm's criteria should be appropriate to its planned level of effort. Also, the firm may initially develop criteria or measures that it eventually finds are inapplicable to some suppliers or certain products and services. Applying common criteria to all suppliers makes objective comparisons possible.

Supplier criteria

A firm uses supplier criteria to evaluate whether the supplier fits its supply and

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technology strategy. These considerations are largely independent of the product or service sought. Supplier criteria are developed to measure important aspects of the supplier's business: financial strength, management approach and capability, technical ability, support resources, and quality systems:

- *Financial.* The firm should require its suppliers to have a sound financial position. Financial strength can be a good indicator of the supplier's long-term stability. A solid financial position also helps ensure that performance standards can be maintained and that products and services will continue to be available.
- *Managerial.* To form a good supplier relationship, companies need to have compatible approaches to management, especially for integrated and strategic relationships. Maintaining a good supplier relationship requires management stability. The firm should have confidence in its supplier's management's ability to run the company. It is also important that the supplier's management be committed to managing its supply base. The supplier's level of quality, service, and cost are directly affected by its suppliers" ability to meet its needs.
- *Technical.* To provide a consistently high-quality product or service, promote successful development efforts, and ensure future improvements, a firm needs competent technical support from its suppliers. This is particularly important when the firm supply and technology strategy includes development of a new product or technology or access to proprietary technology. Technical criteria may motivate a firm to move into the global marketplace. Sometimes a desirable technology has been developed overseas and is not available to domestic suppliers.
- *Support resource.* The supplier's resources need to be adequate to support product or service development (if necessary), production, and delivery. Criteria need to consider the supplier's facilities, information systems, and provisions for education and training. When considering international suppliers, a firm needs to carefully examine the industrial infrastructure that supports the supplier. With international suppliers, a firm also needs to establish appropriate mechanisms to handle financial transactions and product deliveries, as well as any related legal and regulatory matters. Some form of global customer service may be required to support project implementation and day-to-day operations.
- *Quality systems and process.* The supplier's quality systems and processes that maintain and improve quality and delivery performance are key factors. Selection criteria may consider the supplier's quality assurance and control procedures, complaint handling procedures, quality manuals, ISO 9000 standard registration status, and internal rating and reporting systems. As the customer, a firm especially wants to examine the supplier's programs or processes for assessing and addressing customer needs.
- *Globalization and localization.* A firm's sourcing strategy may recognize definite advantages or disadvantages associated with choosing suppliers in a particular region or country. The firm's risk assessment should have identified potential risks, such as currency fluctuations, shifts in political policy, and the accompanying domestic or international regulatory and market changes that result.

Product performance criteria

A firm can use product performance criteria to examine important functional characteristics and measure the usability of the product being purchased. The exact criteria depend on the type of product being considered. A firm may need to examine conformance to specifications in any of the following areas:

- *End use:* quality, functionality (speed, capacity, etc.), reliability, maintainability, compatibility, durability/damage tolerance.
- *Handling:* packaging, shelf-life, storage requirements.
- *Use in manufacturing (components):* quality, testability, manufacturability, compatibility, end-use performance.
- *Other business considerations:* environmentally-friendly features such as recycled product content, ergonomic

features, product availability, stage of the technology life cycle, market trends.

If the product or service is yet to be developed, the firm's supplier criteria needs to examine whether the supplier has the basic management, technical, and quality support necessary to develop the product or service. In the international market, technical standards may vary between countries. The firm either needs to become familiar with manufacturer's standards or test the product using its own standards. Products may have to be reworked to be compatible or interchangeable with domestic products.

Service performance criteria

A firm can use service performance criteria to evaluate the benefits provided by supplier services. When considering services, a firm needs to clearly define its expectations since there are few uniform, established service standards to draw upon. Because any purchase involves some degree of service, such as order processing, delivery, and support, a firm should always include service criteria in its evaluation. If the supplier provides a solution combining products and services, the firm should be sure to adequately represent its service needs in the selection criteria. The service aspect can easily be lost amid product specifications when purchasing a highly technical product. Some of the concepts employed to judge products also apply to services, however, the terminology is often different, and services require other considerations. When assessing the fitness of services, a firm may need to examine the following areas:

- *Customer support:* accessibility, timeliness, responsiveness, dependability.
- *Customer satisfiers*: value-added.
- *Follow-up:* to keep customer informed, to verify satisfaction.
- *Professionalism:* knowledge, accuracy, attitude, reliability.

Cost criteria

Cost criteria recognize important elements of cost associated with the purchase. The most obvious costs associated with a product are "out of pocket" expenses, such as purchase price, transportation cost, and taxes. These are typically considered during selection. Operational expenses, such as transaction processing and cost of rejects, may also be included, although these require more effort to estimate. Although a firm can express any criteria in terms of estimated cost, in some cases, obtaining reliable estimates may be too involved for the level of analysis in selection. A firm should re-evaluate cost in more detail during qualification.

To evaluate suppliers based on a firm's selection criteria it needs to develop measures of supplier performance, product or service performance, and cost. There should be consensus within the team or organization on the measures, standards, and methods used to rate or compare suppliers. A firm needs to develop effective measures for each of its selection criteria. A firm can evaluate the effectiveness of a measure of quality by determining the degree to which it is: related to customer requirements, developed with inputs from and consensus with work groups, specific, easy to understand, practical to implement, able to drive desired behavior.

The organization of this paper is as follows. First, supplier selection applications in literature are given, and then fuzzy sets theory and fuzzy AHP, fuzzy AHP applications in literature, extent analysis method on fuzzy AHP, a case study, and finally a conclusion are given.

Supplier selection applications in literature

Choy and Lee (2002) propose a case-based supplier management tool (CBSMT) using the case-based reasoning (CBR) technique in the areas of intelligent supplier selection and management that will enhance performance as compared to using the traditional approach. Cebeci and Kahraman (2002) and Cebeci (2001) measure customer satisfaction of catering service companies in Turkey by using fuzzy AHP. Ghodsypour and O'Brien (2001) present a mixed integer non-linear programming model to solve the multiple sourcing problem, which takes into account the total cost of logistics, including net price, storage, transportation and ordering costs. Buyer limitations on budget, quality, service, etc. can also be considered in the model. Feng *et al.* (2001) present a stochastic integer programming approach for simultaneous

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selection of tolerances and suppliers based on the quality loss function and process capability indices. Boer *et al.* (2001) present a review of decision methods reported in the literature for supporting the supplier selection process. The review is based on an extensive search in the academic literature. Masella and Rangone (2000) propose four different vendor selection systems (VSSs) depending on the time frame (short-term versus long-term) and on the content (logistic versus strategic) of the co-operative customer/supplier relationships. Liu *et al.* (2000) compare suppliers for supplier selection and performance improvement using data envelopment analysis (DEA). Braglia and Petroni (2000) describe a multi-attribute utility theory based on the use of DEA, aiming at helping purchasing managers to formulate viable sourcing strategies in the changing market place. Dowlatshahi (2000) focuses on facilitating ah interface and collaboration among designer at three planning horizons: strategic, tactical, and operational with respect to supplier relations. To accomplish this interface, nine propositions for all areas of interface at three levels of planning are presented. Motwani *et al.* (1999) attempt to fill a void in supplier selection research by developing a model for sourcing and purchasing in an international setting, particularly in developing countries. Ittner *et al.* (1999) examine whether supplier selection and monitoring practices affect the association between supplier strategies and organizational performance. Ganeshan *et al.* (1999) examine the dynamics of a supply chain that has the option of using two suppliers-one reliable, and the other unreliable. They analyze the cost economics of two suppliers in a broader inventory-logistics framework, one that includes in-transit inventories and transportation costs. Verma and Pullman (1998) examine the difference between managers" rating of the perceived importance of different supplier attributes and their actual choice of suppliers in an experimental setting. Boer *et al.* (1998) show by means of a supplier selection example, that an outranking approach may be very well suited as a decision-making tool for initial purchasing decisions. O'Brien and Ghodsypour (1998) propose an integration of an analytical hierarchy process and linear programming to consider both tangible and intangible factors in choosing the best suppliers and placing the optimum order quantities among them such that the total value of purchasing becomes maximum. Noci (1997) designs a conceptual approach that first identifies measures for assessing a supplier's environmental performance and, secondly, suggests effective techniques for developing the supplier selection procedure according to an environmental viewpoint. Choi and Hartley (1996) compare supplier selection practices based on a survey of companies at different levels in the auto industry. Mummalaneni *et al.* (1996) report the results of an exploratory study examining the trade-offs made by Chinese purchasing managers among the six attributes identified earlier. Swift (1995) examines the supplier selection criteria of purchasing managers who have a preference for single sourcing and those who have a preference for multiple sourcing. Chao *et al.* (1993) highlight six key criteria of supplier selection and describes the responses of a sample of Chinese purchasing managers. They segment the respondents into three clusters, based on similarities in their supplier evaluation processes and differentiate these clusters in terms of whether the managers emphasize reliable deliveries, price/cost considerations, or product quality. Weber and Ellram (1993) explore the use of a multi-objective programming approach as a method for supplier selection in a just-in-time (JIT) setting. Partovi *et al.* (1990) review the published applications of AHP in supplier selection. Willis and Huston (1990) discuss the various attributes that are important in implementing JIT into the purchasing process and introduce a new dimensional analysis model that has certain advantages over the traditional methods.

Fuzzy sets theory and fuzzy AHP

To deal with vagueness of human thought, Zadeh (1965) first introduced the fuzzy set theory, which was oriented to the rationality of uncertainty due to imprecision or vagueness. A major contribution of fuzzy set theory is its capability of representing vague data. The theory also allows mathematical operators and programming to apply to the fuzzy domain. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function, which assigns to

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each object a grade of membership ranging between zero and one. A tilde " ~ " will be placed above a symbol if the symbol represents a fuzzy set. Therefore, $\tilde{P}$, $\tilde{r}$, $\tilde{n}$ are all fuzzy sets. The membership functions for these fuzzy sets will be denoted by $\mu(x|\tilde{P})$, and $\mu(x|\tilde{n})$ respectively. A triangular fuzzy number (TFN), $\tilde{M}$, is shown in Figure 1. A TFN is denoted simply as $(m_1/m_2, m_2/m_3)$ or (m_1, m_2, m_3). The parameters m_1, m_2 and m_3 respectively denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event.

Each TFN has linear representations on its left and right side such that its membership function can be defined as:

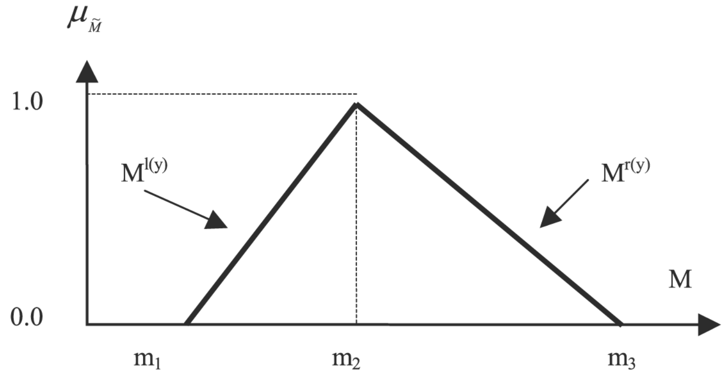
$$\mu(x|\tilde{M}) = \begin{cases} 0 & , x < m_1 \\ (x - m_1)/(m_2 - m_1) & , m_1 \leq x \leq m_2 \\ (m_3 - x)/(m_3 - m_2) & , m_2 \leq x \leq m_3 \\ 0 & , x > m_3 \end{cases} \quad (1)$$

A fuzzy number can always be given by its corresponding left and right representation of each degree of membership:

$$\begin{aligned} \tilde{M} &= (M^{l(y)}, M^{r(y)}) \\ &= (m_1 + (m_2 - m_1)y, m_3 + (m_2 \\ &\quad - m_3)y).y \in [0, 1], \end{aligned} \quad (2)$$

where $l(y)$ and $r(y)$ denotes the left side representation and the right side representation of a fuzzy number respectively. Many ranking methods for fuzzy numbers have been developed in the literature. These methods may give different ranking results and most methods are tedious in graphic manipulation requiring complex mathematical calculation. The algebraic operations with fuzzy numbers are given in Appendix 1.

Figure 1 A triangular fuzzy number, $\tilde{M}$



Many decision-making and problem-solving tasks are too complex to be understood quantitatively, however, people succeed by using knowledge that is imprecise rather than precise. Fuzzy set theory resembles human reasoning in its use of approximate information and uncertainty to generate decisions. It was specifically designed to mathematically represent uncertainty and vagueness and provide formalized tools for dealing with the imprecision intrinsic to many problems. By contrast, traditional computing demands precision down to each bit. Since knowledge can be expressed in a more natural by using fuzzy sets, many engineering and decision problems can be greatly simplified. Fuzzy set theory implements classes or groupings of data with boundaries that are not sharply defined (i.e. fuzzy). Any methodology or theory implementing "crisp" definitions such as classical set theory, arithmetic, and programming, may be "fuzzified" by generalizing the concept of a crisp set to a fuzzy set with blurred boundaries. The benefit of extending crisp theory and analysis methods to fuzzy techniques is the strength in solving real-world problems, which inevitably entail some degree of imprecision and noise in the variables and parameters measured and processed for the application. Accordingly, linguistic variables are a critical aspect of some fuzzy logic applications, where general terms such a "large," "medium," and "small" are each used to capture a range of numerical values. Fuzzy set theory encompasses fuzzy logic, fuzzy arithmetic, fuzzy mathematical programming, fuzzy topology, fuzzy graph theory, and fuzzy data analysis, though the term fuzzy logic is often used to describe all of these.The analytic hierarchy process (AHP) is one of the extensively used multi-criteria decision-making methods. One of the main advantages of this method is the relative ease with which it handles multiple criteria. In addition to this, AHP is easier to understand and it can effectively handle both qualitative and quantitative data. The use of AHP does not involve cumbersome mathematics. AHP involves the principles of decomposition, pair-wise comparisons, and priority vector generation and synthesis. Though the purpose of AHP is to capture the expert's knowledge, the conventional AHP still cannot reflect the human thinking style. Therefore, fuzzy AHP, a fuzzy extension of AHP, was developed to solve the hierarchical fuzzy problems.

The decision-maker can specify preferences in the form of natural language expressions about the importance of each performance attribute (hygiene, quality of meals, quality of service). The system combines these preferences using fuzzy-AHP, with existing data (from industrial surveys and statistical analysis) to re-emphasize attribute priorities. In the fuzzy-AHP procedure, the pairwise comparisons in the judgment matrix are fuzzy numbers that are modified by the designer's emphasis. Using fuzzy arithmetic and α-cuts, the procedure calculates a sequence of weight vectors that will be used to combine the scores on each attribute. The procedure calculates a corresponding set of scores and determines one composite score that is the average of these fuzzy scores.

Fuzzy AHP applications: literature review

There are many fuzzy AHP methods proposed by various authors. These methods are systematic approaches to the alternative selection and justification problem by using the concepts of fuzzy set theory and hierarchical structure analysis. Decision makers usually find that it is more confident to give interval judgments than fixed value judgments. This is because usually he/she is unable to explicit about his/her preferences due to the fuzzy nature of the comparison process.

The earliest work in fuzzy AHP appeared in van Laarhoven and Pedrycz (1983), which compared fuzzy ratios described by triangular membership functions. Buckley (1985) determines fuzzy priorities of comparison ratios whose membership functions trapezoidal. Stam *et al.* (1996) explore how recently developed artificial intelligence techniques can be used to determine or approximate the preference ratings in AHP. They conclude that the feed-forward neural network formulation appears to be a powerful tool for analyzing discrete alternative multi-criteria decision problems with imprecise or fuzzy ratio-scale preference judgments. Chang (1996) introduces a new approach for handling fuzzy AHP, with the use of triangular fuzzy numbers for pairwise comparison scale of fuzzy AHP, and the use of the extent analysis method for the synthetic extent values of the pairwise comparisons. Ching-Hsue (1997) proposes a new algorithm for evaluating naval tactical missile systems by the fuzzy analytical hierarchy process based on grade value of membership function. Weck *et al.* (1997) present a method to evaluate different production cycle alternatives adding the mathematics of fuzzy logic to the classical AHP. Any production cycle evaluated in this manner yields a fuzzy set. The outcome of the analysis can finally be defuzzified by forming the surface center of gravity of any fuzzy set, and the alternative production cycles investigated can be ranked in order in terms of the main objective set. Kahraman *et al.* (1998) use a fuzzy objective and subjective method obtaining the weights from AHP and make a fuzzy weighted evaluation. Deng (1999) presents a fuzzy approach for tackling qualitative multi-criteria analysis problems in a simple and straightforward manner. Lee *et al.* (1999) review the basic ideas behind the AHP. Based on these ideas, they introduce the concept of comparison interval and propose a methodology based on stochastic optimization to achieve global consistency and to accommodate the fuzzy nature of the comparison process. Cheng *et al.* (1999) propose a new method for evaluating weapon systems by analytical hierarchy process based on linguistic variable weight. Zhu *et al.* (1999) make a discussion on extent analysis method and applications of fuzzy AHP. Chan *et al.* (2000a) present a technology selection algorithm to quantify both tangible and intangible benefits in fuzzy environment. They describe an application of the theory of fuzzy sets to hierarchical structural analysis and economic evaluations. By aggregating the hierarchy, the preferential weight of each alternative technology is found, which is called fuzzy appropriate index. The fuzzy appropriate indices of different technologies are then ranked and preferential ranking orders of technologies are found. From the economic evaluation perspective, a fuzzy cash flow analysis is employed. Chan *et al.* (2000b) report an integrated approach for the automatic design of FMS, which uses simulation and multi-criteria decision-making techniques. The design process consists of the construction and testing of alternative designs using simulation methods. The selection of the most suitable design (based on AHP) is employed to analyze the output from the FMS simulation models. Intelligent tools (such as expert systems, fuzzy systems and neural networks) are developed for supporting the FMS design process. Active X technique is used for the actual integration of the FMS automatic design process and the intelligent decision support process. Leung and Cao (2000) propose a fuzzy consistency definition with consideration of a tolerance deviation. Essentially, the fuzzy ratios of relative importance, allowing certain tolerance deviation, are formulated as constraints on the membership values of the local priorities. The fuzzy local and global weights are determined via the extension principle. The alternatives are ranked on the basis of the global weights by application of maximum-minimum set ranking method. Kuo *et al.* (2002) develop a decision support system for locating a new convenience store. The first component of the proposed system is the hierarchical structure development for fuzzy analytic process.

Extent analysis method on fuzzy AHP

In the following, first the outlines of the extent analysis method on fuzzy AHP are given and then the method is applied to a supplier selection problem.

Let $X = \{x_1, x_2, \ldots, x_n\}$ be an object set, and $U = \{u_1, u_2, \ldots, u_m\}$ be a goal set. According to the method of Chang's (1992) extent analysis, each object is taken and extent analysis for each goal is performed respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs:

$$M_{g_i}^1, M_{g_i}^2, \ldots, M_{g_i}^m, i = 1, 2, \ldots, n, \qquad (3)$$

where all the $M_{g_i}^j (j = 1, 2, \ldots, m)$ are triangular fuzzy numbers.

The value of fuzzy synthetic extent with respect to the ith object is defined as:

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]^{-1} \qquad (4)$$

The degree of possibility of $M_1 \geq M_2$ is defined as:

$$V(M_1 \geq M_2) = \sup_{x \geq y} \lfloor \min(\mu_{M_1}(x), \mu_{M_2}(y) \rfloor. \qquad (5)$$

When a pair (x, y) exists such that $x \geq y$ and $\mu_{M_1}(x) = \mu_{M_2}(y)$, then we have $V(M_1 \geq M_2) = 1$. Since M_1 and M_2 are convex fuzzy numbers we have that:

$$V(M_1 \geq M_2) = 1 \quad \text{iff} \quad m_1 \geq m_2, \qquad (6)$$

$$\begin{aligned} V(M_1 \geq M_2) &= \text{hgt}\,(M_1 \cap M_2) \\ &= \mu_{M_1}(d), \end{aligned} \qquad (7)$$

where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2} (see Figure 2).

When $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$, the ordinate of D is given by equation (8):

$$\begin{aligned} V(M_2 \geq M_1) &= \text{hgt}\,(M_1 \cap M_2)) \\ &= \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}. \end{aligned} \qquad (8)$$

To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i $(i = 1, 2, \ldots k)$ can be defined by:

$$\begin{aligned} &V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1) \\ &\text{and } (M \geq M_2) \text{ and } \ldots \text{ and } (M \geq M_k)] \\ &= \min V(M \geq M_i), i = 1, 2, 3, \ldots, k. \end{aligned} \qquad (9)$$

Assume that:

$$d'(A_i) = \min V(S_i \geq S_k). \qquad (10)$$

For $k = 1, 2, \ldots, n$; $k \neq i$. Then the weight vector is given by:

$$W' = (d'(A_1), d'(A_2'), \ldots, d'(A_n))^T, \qquad (11)$$

where $A_i (i = 1, 2, \ldots, n)$ are n elements.

Via normalization, the normalized weight vectors are:

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T, \qquad (12)$$

where W is a nonfuzzy number.

A numerical example

One of the biggest white good manufacturers in Europe, established in Turkey, needs to select a supplier for a new model of aspirators. The firm should take into account a lot of criteria because the competition is very high. The firm wants to make an existing supplier produce a plastic part, scroll housing. A scroll housing is used in aspirators and produced in plastic injection machines. The number of the existing suppliers considered in the

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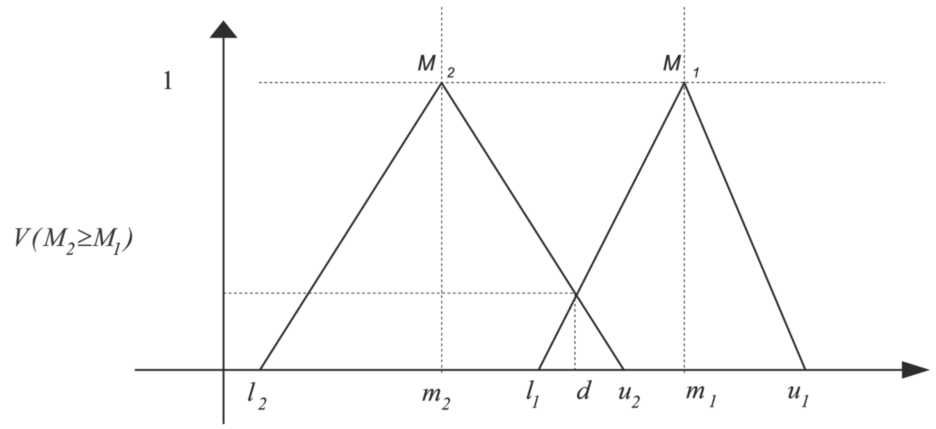
Figure 2 The intersection between M_1 and M_2



comparison is three. The criteria taken into account are the ones given in Introduction. The hierarchy is given in Figure 3.

From Table I, the following values are obtained:

$S_{SC} = (3.17, 4.00, 5.00) \otimes (1/12.34, 1/10.00, 1/8.14) = (0.26, 0.40, 0.61)$,

$S_{PP} = (2.90, 3.50, 4.17) \otimes (1/12.34, 1/10.00, 1/8.14) = (0.24, 0.35, 0.51)$,

$S_{SP} = (2.07, 2.50, 3.17) \otimes (1/12.34, 1/10.00, 1/8.14) = (0.17, 0.25, 0.39)$.

Using these vectors, $V(S_{SC} \geq S_{PP}) = 1.0$, $V(S_{SC} \geq S_{SP}) = 1.0$, $V(S_{PP} \geq S_{SC}) = 1.0$, $V(S_{PP} \geq S_{SP}) = 0.84$, $V(S_{SP} \geq S_{SC}) = 0.47$, and $V(S_{SP} \geq S_{PP}) = 0.61$ are obtained. Thus, the weight vector from Table I is calculated as $W'G = (0.43, 0.37, 0.20)^T$. The decision-making group then compares the sub-attributes with respect to main-attributes. The other tables will not be given in the paper because the calculation is similar. The questionnaires to obtain the preference weights among main-attributes, sub-attributes and alternatives are given in Appendix 2. The combination of priority weights for sub-attributes, attributes, and alternatives to determine priority weights for the best supplier firm are given in Tables II-V. FXM is the supplier firm selected.

Conclusions

Decisions are made today in increasingly complex environments. In more and more cases the use of experts in various fields is necessary, different value systems are to be taken into account, etc. In many of such decision-making settings the theory of fuzzy decision-making can be of use. Fuzzy group decision-making can overcome this difficulty.

Figure 3 Hierarchy of the numerical example

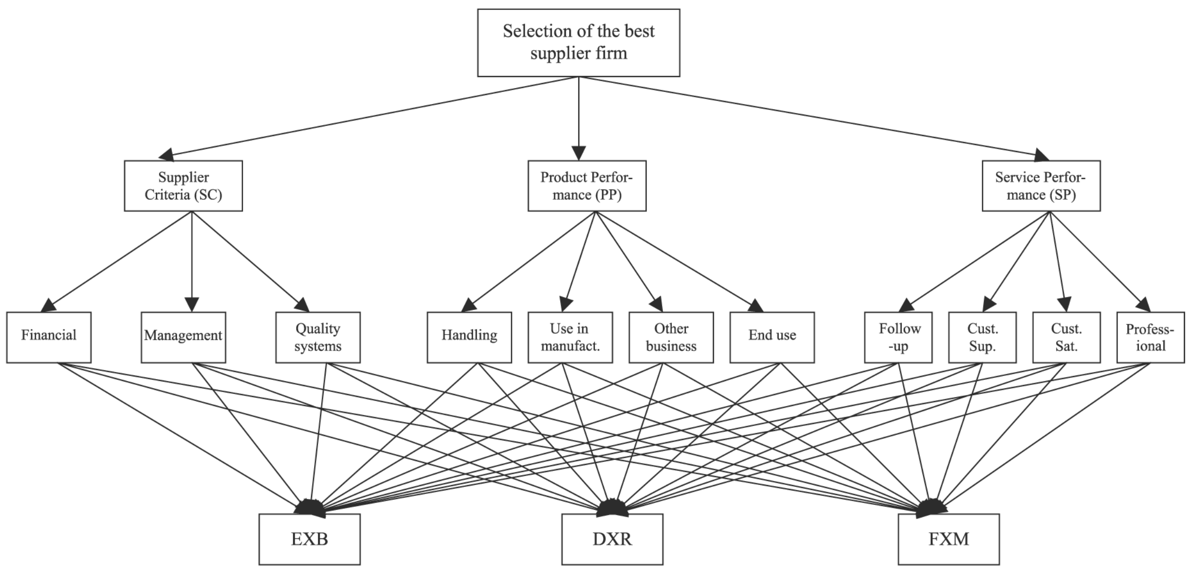


Table I The fuzzy evaluation matrix with respect to the goal

	SC	PP	SP
SC	(1, 1, 1)	(3/2, 2, 5/2)	(2/3, 1, 3/2)
PP	(2/5, 1/2, 2/3)	(1, 1, 1)	(3/2, 2, 5/2)
SP	(2/3, 1, 3/2)	(2/5, 1/2, 2/3)	(1, 1, 1)

Table II Summary combination of priority weights: sub-attributes of supplier criteria

	Financial	Management	Quality Sys.	Alternative priority weight
Weight	0.70	0.15	0.15	
Alternative				
EXB	0.66	0	0	0.46
DXR	0	0	0	0.00
FXM	0.34	1	1	0.54

Table III Summary combination of priority weights: sub-attributes of product performance criteria

	Hand.	Use in	Other	End use	Alternative priority weight
Weight	0.19	0.04	0.77	0.00	
Alternative					
EXB	0	0.87	0	0.27	0.03
DXR	0	0	0.31	0.18	0.24
FXM	1	0.13	0.69	0.55	0.73

Table IV Summary combination of priority weights: sub-attributes of service performance criteria

	Fol.-up	C. Sup.	C. Sat.	Prof.	Alternative priority weight
Weight	0.00	0.05	0.00	0.95	
Alternative					
EXB	1	0.05	0.72	0	0.003
DXR	0	0.64	0	0	0.032
FXM	0	0.31	0.28	1	0.965

Table V Summary combination of priority weights: main attributes of the goal

	SC	PP	SP	Alternative priority weight
Weight	0.43	0.37	0.20	
Alternative				
EXB	0.46	0.03	0.003	0.21
DXR	0	0.24	0.032	0.10
FXM	0.54	0.73	0.965	0.69

In general, many concepts, tool and techniques of artificial intelligence, in particular in the field of knowledge representation and reasoning, can be used to improve human consistency and implementability of numerous models and tools in broadly perceived decision-making and operations research. In this paper, supplier firms were compared using fuzzy AHP. Humans are often uncertain in assigning the evaluation scores in crisp AHP. Fuzzy AHP can capture this difficulty. There are many other methods to use in comparing csupplier firms. These are multi-attribute evaluation methods such as ELECTRE, DEA, and TOPSIS. These methods have been recently developed to use in a fuzzy environment. Further research may be the application of these methods to the supplier selection problem and the comparison of the results.

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Appendix 1

One of the most basic concepts of fuzzy set theory which can be used to generalize crisp mathematical concepts to fuzzy sets is the extension principle. Let X be a Cartesian product of universes $X = X_1 \ldots X_r$, and $\tilde{A}_1, \ldots, \tilde{A}_r$ be r fuzzy sets in $X_1, \ldots, X_r$, respectively. f is a mapping from X to a universe Y, $y = f(x_1, \ldots, x_r)$. Then the extension principle allows us to define a fuzzy set $\tilde{B}$ in Y by Zimmerman (1994):

$$\tilde{B} = \{(y, \mu_{\tilde{B}}(y)|y = f(x_1, \ldots, x_r), (x_1, \ldots, x_r) \in X\}, \tag{A1}$$

where:

$$\mu_{\tilde{B}}(y) = \begin{cases} \sup\limits_{(x_1,\ldots,x_r)\in f^{-1}(y)} \min\{\mu_{\tilde{A}1}(x_1), \ldots, \mu_{\tilde{A}_r}(x_r)\}, & \text{if } f^{-1}(y) \neq \varnothing \\ 0 & \text{, otherwise} \end{cases} \tag{A2}$$

where f^{-1} is the inverse of f.

Assume $\tilde{P} = (a, b, c)$ and $\tilde{Q} = (d, e, f)$. a, b, c, d, e, f are all positive numbers. With this notation and by the extension principle, some of the extended algebraic operations of triangular fuzzy numbers are expressed in the following.

Changing sign

$$-(a, b, c) = (-c, -b, -a), \tag{A3}$$

or

$$-(d, e, f) = (-f, -e, -d) \tag{A4}$$

Addition

$$\tilde{P} \oplus \tilde{Q} = (a + d, b + e, c + f), \tag{A5}$$

and

$$k \oplus (a, b, c) = (k + a, k + b, k + c), \tag{A6}$$

or

$$k \oplus (d, e, f) = (k + d, k + e, k + f), \tag{A7}$$

if k is an ordinary number (a constant).

Subtraction

$$\tilde{P} - \tilde{Q} = (a - f, b - e, c - d), \tag{A8}$$

and

$$(a, b, c) - k = (a - k, b - k, c - k), \tag{A9}$$

or

$$(d, e, f) - k = (d - k, e - k, f - k), \tag{A10}$$

if k is an ordinary number.

Multiplication

$$\tilde{P} \otimes \tilde{Q} = (ad, be, cf), \tag{A11}$$

and

$$k \otimes (a, b, c) = (ka, kb, kc), \tag{A12}$$

or

$$k \otimes (d, e, f) = (kd, ke, kf), \tag{A13}$$

if k is an ordinary number.

Appendix 2

Figure A1 Questionnaire forms used to facilitate comparisons of main and sub-attributes

With respect to: the Best supplier firm	Importance (or preference) of one main-attribute over another									
Attribute	(7/2, 4, 9/2) Absolute	(5/2, 3, 7/2) Very strong	(3/2, 2, 5/2) Fairly strong	(2/3, 1, 3/2) Weak	(1, 1, 1) Equal	(2/3, 1, 3/2) Weak	(3/2, 2, 5/2) Fairly strong	(5/2, 3, 7/2) Very strong	(7/2, 4, 9/2) Absolute	Attribute
SC										PP
SC										SP
PP										SP

With respect to: SP	Importance (or preference) of one sub-attribute over another									
Sub-attribute	(7/2, 4, 9/2) Absolute	(5/2, 3, 7/2) Very strong	(3/2, 2, 5/2) Fairly strong	(2/3, 1, 3/2) Weak	(1, 1, 1) Equal	(2/3, 1, 3/2) Weak	(3/2, 2, 5/2) Fairly strong	(5/2, 3, 7/2) Very strong	(7/2, 4, 9/2) Absolute	Sub-attribute
F										M
F										QS
M										QS

With respect to: PP	Importance (or preference) of one sub-attribute over another									
Sub-attribute	(7/2, 4, 9/2) Absolute	(5/2, 3, 7/2) Very strong	(3/2, 2, 5/2) Fairly strong	(2/3, 1, 3/2) Weak	(1, 1, 1) Equal	(2/3, 1, 3/2) Weak	(3/2, 2, 5/2) Fairly strong	(5/2, 3, 7/2) Very strong	(7/2, 4, 9/2) Absolute	Sub-attribute
H										UM
H										OBC
H										EU
UM										OBC
UM										EU
OBC										EU

With respect to: SP	Importance (or preference) of one sub-attribute over another									
Sub-attribute	(7/2, 4, 9/2) Absolute	(5/2, 3, 7/2) Very strong	(3/2, 2, 5/2) Fairly strong	(2/3, 1, 3/2) Weak	(1, 1, 1) Equal	(2/3, 1, 3/2) Weak	(3/2, 2, 5/2) Fairly strong	(5/2, 3, 7/2) Very strong	(7/2, 4, 9/2) Absolute	Sub-attribute
FU										CSo
FU										CSa
FU										P
Cso										CSa
CSo										P
Csa										P

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Figure A2 Two of the 11 questionnaire forms used to facilitate comparisons of alternatives

With respect to: F	Importance (or preference) of one alternative over another									
Alternative	(7/2, 4, 9/2) Absolute	(5/2, 3, 7/2) Very strong	(3/2, 2, 5/2) Fairly strong	(2/3, 1, 3/2) Weak	(1, 1, 1) Equal	(2/3, 1, 3/2) Weak	(3/2, 2, 5/2) Fairly strong	(5/2, 3, 7/2) Very strong	(7/2, 4, 9/2) Absolute	Alternative
EXB EXB										DXR FXM
DXR										FXM

With respect to: Professional	Importance (or preference) of one alternative over another									
Alternative	(7/2, 4, 9/2) Absolute	(5/2, 3, 7/2) Very strong	(3/2, 2, 5/2) Fairly strong	(2/3, 1, 3/2) Weak	(1, 1, 1) Equal	(2/3, 1, 3/2) Weak	(3/2, 2, 5/2) Fairly strong	(5/2, 3, 7/2) Very strong	(7/2, 4, 9/2) Absolute	Alternative
EXB EXB										DXR FXM
DXR										FXM