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Introduction

One of the commonly used methods for multi attribute decision making is analytic hierarchy process (AHP). During last two decades, the analytic hierarchy process has been successfully applied to numerous decision areas. The essence of AHP is in permitting the decision-maker to perform pair-wise comparisons of each of the factors or *criteria* -- one-on-one -- to derive overall priorities. These pair-wise comparisons may be stated verbally as in "Criterion A is *equally, moderately more, or strongly more important* than criterion B." The adjectives *likely* or *preferable* may be substituted for *important*. These are converted to numerical values (generally in pre-specified range like 1 to 9) in the traditional, non-fuzzy AHP approach.

The AHP method may be used for such decisions as selecting a single course of action from several, for priority setting, and for resource allocation. For the *single decision-event*, AHP's use is based on the following assumptions, that for a significant decision, there are several courses of action (alternatives) available, from which one will be selected based on governing criteria, not all of which will be of equal weight.

Fuzzy Analytic Hierarchy Process

The Analytic Hierarchy Process is a method for formalizing decision making where there are a limited number of choices but each has a number of attributes and it is difficult to formalize some of those attributes. So instead of using exact numbers, we can use phrases like "much more important than" to extract the decision makers preferences. Fuzzy logic and values offer a more natural way of dealing with these preferences instead of exact values. Note that the traditional AHP approach is somewhat arbitrary, for example, use of a particular range of values like 1-9 range. And there are a number of "hidden assumptions", such as, if *i* is weakly preferred to *j* and *j* weakly preferred to *k*, then a consistent decision maker must have *i* absolutely preferred to *k*, which may not necessarily be true. Again, the use of fuzzy numbers and linguistic terms (Zadeh, 1965) would be more suitable in such a situation.

Several theoretical results have been presented by authors as to the application of fuzzy theory in analytic hierarchy process (Boender, et al., 1989 and Laarhoeven, et al., 1983). The overall Fuzzy AHP approach can be summarized as follows (Triantophyllou et al., 1996):

a) The decision-maker needs to ascertain fuzzy estimates of relative significance of each pair of decision factors. Similarly, the decision-maker needs to decide about each of the pair of alternative solutions based on each criteria. This process will result in a series of matrices.
b) Estimate the fuzzy eigenvector for each matrix. According to Saaty (1980), in original AHP, the right principal eigenvector of the matrix expresses the relative importance of the alternatives and factors. There are several alternative approaches to this step. One such way is to approximate the eigenvector by multiplying all the elements in a row and then taking the *n*th root.
c) The next step is to normalize each vector, by dividing each element by the sum of the entries in the vector.
d) Compute the priority scores of each alternative by multiplying criteria weights by the values in the column of each alternative and summing those values.
e) Finally, rank each of the alternatives and select the best one.

There are several possible ways to represent fuzzy numbers. One special class of fuzzy numbers is triangular fuzzy number, which is relatively easy to model and works well with most applications. The membership function of a triangular fuzzy number is defined as

$$\mu_M(x) = \begin{cases} \frac{1}{m-l}x - \frac{l}{m-l}, x \in [l,m], \\ \frac{1}{m-u}x - \frac{u}{m-u}, x \in [m,u], \\ 0 \text{ otherwise} \end{cases}$$

where $l \leq m \leq u$, *l* and *u* stand for lower and upper value of the support of M, and *m* for the modal value. Most of the basic mathematical operations on fuzzy triangular numbers have been defined (Laarhoeven, et al., 1983).

The most common implementation of fuzzy sets involves mapping a continuous real variable to a small collection of fuzzy sets representing linguistic labels. Some researchers have suggested using seven fuzzy sets to represent the range of a real variable (Kosko 1992). A typical example of such a mapping is given in Fig. 1. For example, somewhat high (SH) equals fuzzy triangular number (.5,.7,.9) and much higher (MH) equals (.9,1,1).

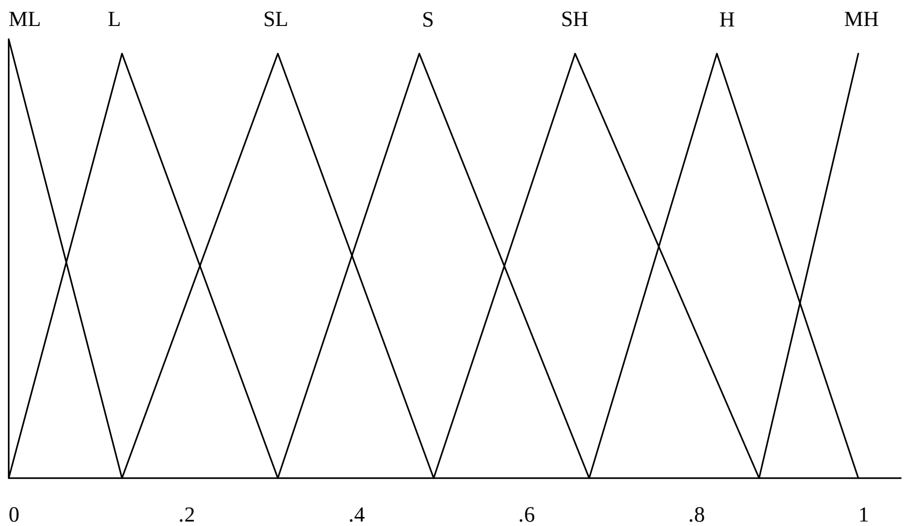

Fig. 1. Membership functions for linguistic values

Application of Fuzzy AHP to Determination of Service Quality in Telecommunication Networks

The Quality of Service (QoS) is crucially important in multimedia broadband services of the future. The QoS can only be properly understood when it is viewed from both the enterprise and service points of view. In order to support high QoS in a telecom network, an architecture of coordinating components is needed. According to Hamada et al. (1998), there are four basic elements of QoS: Service quality, Usage control, Network control and QoS Monitoring.

Over the years, when carriers market their services, they make certain claims about speed, latency (delay), reliability and security (QoS guarantees). Increasingly, users are demanding that carriers go beyond the claims and offer legally binding guarantees (Panko, 1999). Therefore, in this paper a methodology is developed that can be used to compare and evaluate the QoS offered by various competing carriers.

Hamada et al. propose that service quality function should be simple, intuitively appealing and easily understandable. Assuming multimedia applications, following four criteria can be used:

C1) Audio: notable audio service quality (e.g., CD, FM-radio etc.)
C2) Video: notable video quality (e.g., NTSC, MPEG2, HDTV etc.)
C3) Response time: the previous two indicate transport networks QoS, this criterion can determine signaling network's QoS
C4) Throughput: this will be useful in determining QoS for large file/data transfer.

Suppose the QoS evaluator wishes to compare three different carriers. The first task of the decision-maker or evaluator is to decide on the relative importance of the four decision criteria discussed above. Using pair-wise comparisons, the table containing the fuzzy values of relative importance is developed (Table 1). That is, the evaluator determines that C1 is somewhat higher than C3 and C4, and higher than C2. These linguistic terms are then converted to triangular fuzzy values using Fig. 1. In a similar fashion, the decision-maker makes a comparison of each alternative choice of telecom carrier based on each of the criteria separately. When a criteria or alternative is compared to itself, the triangular fuzzy number (1,1,1) is assigned.

Table 1. Pair-wise comparison of each decision criterion with other

	C1	**C2**	**C3**	**C4**	**Importance**
C1	1,1,1	.7,.9,1	.5,.7,.9	.5,.7,.9	.65,.81,.95
C2	1,1.11,1.43	1,1,1	.7,.9,1	.1,.3,.5	.51,.74,.92
C3	1.11,1.43,2	2,3.33,10	1,1,1	.3,.5,.7	.90,1.24,1.93
C4	1.11,1.43,2	1,1.11,1.43	1.43,2,3.33	1,1,1	1.12,1.33,1.76

The next step is to determine the importance of each factor (i.e., to approximate the eigenvector) resulting from the pair-wise comparison. This vector giving importance of each criteria can be found by multiplying each of the fuzzy triangular number in a row and taking the *nth* (4^{th} in this case) root of the resulting value (Table 1, last column). Now this vector needs to be normalized, which can be done by dividing each value by the sum of values of the vector. In case of triangular numbers, it is found by dividing lower values by the sum of upper values and vice versa. For modal values, each value is divided by the sum of the entries in its vector. After applying this procedure, the normalized weight vector is obtained (Table 2).

Table 2. Normalized vector for criteria weights

Criteria	**Normalized weight vector**
C1	.12,.2,.3
C2	.09,.18,.29
C3	.16,.30,.61
C4	.2,.32,.55

The same process needs to be applied to determine normalized vectors for each of the alternatives. First a pair-wise comparison of each alternative with each of the other alternatives is performed based on each of the four criteria. The decision-maker needs to determine, for example, considering criteria C1, how does alternative A1 compares to A2 and A3. This step is followed by determination of approximate eigenvector. The end result is to have a table with all the criteria (along with their weights) and each of the alternatives, this table can be used to determine priority scores for each alternative (Table 3).

Table 3. Computation of priority scores for each alternative

	Weights	**A1**	**A2**	**A3**
C1	.12,.2,.3	.49,.74,1.08	.14,.19,.29	.04,.06,.11
C2	.09,.18,.29	.67,.8,.93	.13,.16,.2	.04,.04,.06
C3	.16,.30,.61	.47,.71,1.04	.17,.24,.38	.04,.05,.07
C4	.2,.32,.55	.25,.6,.1.21	.17,.32,.77	.04,.07,.15
Total		.24,.7,1.89	.09,.24,.8	.02,.06,.18

Once the priority scores of each of the alternatives are obtained, a ranking of alternatives can be determined using any of the ranking procedures. If $\mu_i(x)$ denotes the membership function for a fuzzy number n_i, define

$$e_{ij} = \max_{x \geq y} \{\min(\mu_i(x), \mu_j(y))\}$$ for all i,j = 1,2,3, ….,m

The fuzzy number n_1 outranks n_2 if and only if $e_{ij} = 1$ and $e_{ji} < Q$, where Q is a fixed fraction less than 1 (Buckley, 1988). The common values for Q are .8 or .9. In this example, it can be seen that e_{12}=1 and e_{23}=1, while e_{21}=0.55 and e_{32}=0.4 approximately (Fig. 2). Thus, alternative A1 outranks A2 and alternative A2 outranks A3.

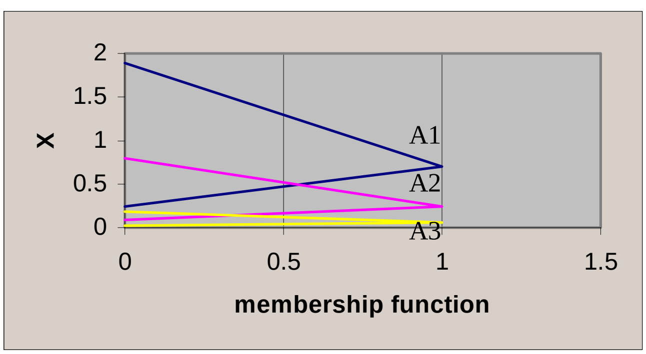

Fig. 2. Membership functions for alternatives A1, A2, A3

Conclusions

In this paper, the authors have presented an application of fuzzy Analytic Hierarchy Process to determining the best telecom carrier based on QoS offered. The major advantage of this approach is that it can process the importance of criteria and the assessment of alternatives based on each criterion when inputs are given in linguistic terms. The traditional, non-fuzzy approaches have difficulty in handling these imprecise assessments. Although the application given in the paper assumes single decision-maker, fuzzy AHP approach itself can handle assessments from multiple decision-makers (Laarhoeven et al., 1983). This paper shows that the fuzzy AHP methodology can be applied to modeling business decision-making situations. The approach can be used in various other applications including project selection, financial planning and other investment decisions. <u>References available upon request from the first author.</u>