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COMBINING BOOLEAN CONSISTENT FUZZY LOGIC AND AHP ILLUSTRATED ON THE WEB SERVICE SELECTION PROBLEM

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Abstract

The Analytical Hierarchy Process (AHP) idealistically assumes the independence of the criteria which are often interrelated, conflicting or can be traded-off. It is, therefore, proposed that AHP could be extended by applying fuzzy logic to adequately incorporate the different relationships that may exist among the criteria. It is shown that the conventional and consistent fuzzy approaches could actually lead to different choices and an explanation is provided. Finally, two different application scenarios are illustrated on the web service selection problem.

Keywords: Fuzzy logic, Boolean consistent fuzzy logic, AHP, Logical aggregation, Web service selection

1. Introduction

Multiple Criteria Decision Making (MCDM) involves the choice of an alternative among a number of possible alternatives on the basis of multiple, usually conflicting criteria. The aim is to choose the alternative which best fulfills a goal or an entire set of goals *i.e.* which is best in terms of all of the regarded criteria.

One of the most widely used methods for MCDM is the Analytic Hierarchy Process method (AHP).[1] It uses a hierarchical structure of goals, criteria, subcriteria and alternatives and assumes that elements of a certain level are dependent on the elements in the previous level (the goal depends on the criteria, criteria on subcriteria *etc.*)

The main idea is to evaluate pairs of elements one level at a time to determine their relative priorities with respect to the element above them in the hierarchy. Ultimately, the weighted relative priorities of every level in the hierarchy are aggregated thus enabling the ranking of the given alternatives.

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In fuzzy decision making the criteria, weights and goals can all be fuzzy sets. The pairwise comparisons of elements allow decision makers to bring their own valuable experience into the decision making process. Since experience is better represented by linguistic means than by the customary numerical rankings, fuzzy logic has been used to extend the traditional AHP method to more adequately incorporate this experience (Fuzzy AHP) (See Refs.2–6).

Another challenge arises from the fact that the goal can be, and usually is, a logical demand formulated to reflect the fact that the criteria upon which the decision should be made may be interrelated or conflicting or the fact that the decision maker might want to trade off one criterion against another.

The traditional AHP method lacks support for this type of problem since it assumes the independence of the criteria. For complicated decision problems the Analytical Network Process method (ANP) allows interdependent influences to be specified in the model.[7] However, as stated in Ref. 8, ANP can only express relationships among different elements through relative weights generated from pair-comparisons and the convergence of a so-called super-matrix and it cannot quantify or explicitly demonstrate influences among the elements. The existence of linguistic problems is also addressed in Ref. 9 where the authors point out that the semantics used in pairwise comparison (*e.g.*, “how much more important”) often do not keep up with more complex issues when comparing elements in a network structure.

Bearing in mind that trade-offs can only be adequately described by logical functions it is proposed that AHP could be extended by using fuzzy logic when defining the criteria. A similar technique has been proposed in Ref. 10. However, since no conventional fuzzy set theory (fuzzy logic, theory of fuzzy relation) is in the Boolean frame[11] it is proposed that consistent fuzzy logic, introduced in Ref. 12, should be used instead. This approach is based on the Interpolative realization of Boolean algebra (IBA) which treats logical functions as a Generalized Boolean polynomial (GBP).

The approach proposed in this paper assumes that correlation and trade-offs can only be adequately described by logical functions. Logical functions (*i.e.* Logical Aggregation) result in a new structure of the components as opposed to the weighted sum approach. It is proposed that the traditional AHP method could be extended to cover this situation by applying fuzzy logic when defining the criteria or goal. The extension of the AHP method with both conventional and Boolean consistent fuzzy logic will be demonstrated, though it will be shown why the application of Boolean consistent fuzzy logic is preferred.

The proposed approach will be illustrated on the web service selection problem. Web services are software components, accessible on the Internet, which provide certain functionality. With the proliferation of web services offering similar functionality the problem of how to choose the best one according to multiple non-functional Quality of Service (QoS) attributes has become increasingly important.

The paper is structured as follows: Section 2 is devoted to MCDM and an overview of the AHP method, Section 3 gives the basic concepts of fuzzy logic and Boolean consistent fuzzy logic and Section 4 outlines the web service selection problem. The proposed solution is outlined in Section 5 and two different application scenarios are detailed, showing that the proposed approach can be used at different levels of the AHP hierarchy model. The examples point out that the conventional and consistent fuzzy approaches can lead to the choice of different alternatives. The examples also demonstrate that the use of different aggregation methods (namely additive and logical aggregation) for obtaining global priorities can also lead to a different ranking of alternatives. Related work is given in Section 6, and finally, Section 7 concludes the paper and discusses future work.

2. Multiple Criteria Decision Making

Decision making is an integral part of every aspect of life and involves choosing an alternative among a number of possible alternatives which best fulfills a goal or an entire set of goals. In almost every real-world problem there exists a number of factors influencing the decision. Each of these factors represents a criterion and an alternative can be characterized in terms of its attainment of the criteria. Therefore, since each alternative is defined by a set of attributes, the criteria actually represent a set of attributes the decision maker has selected for representing the goal. However, in almost all decision making real-world problems the relevant criteria are very heterogeneous in nature, defined using various metrics and in addition they are usually partially or completely conflicting. This indicates that the final solution cannot be determined without the involvement of the decision maker. Therefore, Multiple Criteria Decision Making (MCDM) involves the choice of an alternative among a number of possible alternatives on the basis of multiple, usually conflicting criteria. The aim is to choose the alternative which is best in terms of all of the regarded criteria.

One of the most commonly used approaches in MCDM is the simple additive weight method (SAW) in which each of the criteria is assigned a weight representing its importance.[13] One of the main drawbacks of this approach is the fact that it does not allow any interaction among the attributes so new methods such as AHP or new tools such as Fuzzy Logic and theory of aggregation operators have been proposed to improve MCDM methods.[5]

2.1. *AHP method*

The Analytic Hierarchy Process (AHP) introduced by Saaty[1] is one of the most widely used methods for MCDM.[14] The main idea is to decompose the original complex problem into a set of hierarchically organized sub-problems which are easier to address. It uses a hierarchical structure of goals, criteria, subcriteria and alternatives and assumes that elements of a certain level are dependent on the elements in the previous level.

The elements will be evaluated one level at a time to determine their relative priorities (weights) with respect to the element above them in the hierarchy. When evaluating the attributes a problem arises from the fact that they are usually heterogeneous and defined using different metrics. Since different scales cannot be combined the concept of priority is used to represent an abstract unit valid across all scales.[1] The priorities are defined in accordance with a preference scale of numbers that indicate how many times more important or dominant one element is over another with respect to the property with respect to which they are compared.[15] Saaty’s 9-point scale expresses preferences between options as equally, moderately, strongly, very strongly or extremely preferred (1, 3, 5, 7 and 9 respectively) with 2, 4, 6 and 8 as intermediate values. Thus, one of the main benefits of AHP is that it enables decision making based on both qualitative and quantitative data (regardless of their measurement units) at the same time.

A preference will be given for every pair of elements with respect to a common property they share (their parent element). So, the evaluations are accomplished through pairwise comparisons and the decision maker will assign a number for every pair of elements thereby indicating his degree of preference. The results are presented in comparison matrices which are reciprocal (for matrix $A=(a_{ij})$, i, $j=1,\ldots n$, the following holds for all elements: $a_{ji}=1/a_{ij}$).

The local priorities of the elements compared in a pairwise comparison matrix can be obtained from its normalized principal right eigenvector.[1]

The global priorities of the elements with respect to the goal are obtained through the aggregation of the local priorities of every hierarchy element in all paths from the alternative to the goal. There exist various methods of aggregation *e.g.* additive aggregation methods[1] or multiplicative aggregation methods (Refs. 16 and 17). A detailed review of the different approaches can be found in Ref. 18.

The final step is to evaluate the consistency of the decision maker's judgments. A lack of consistency might lead to inconsistent conclusions.[15] If the principle eigenvector of a comparison matrix is equal to its trace ($\lambda_{max}=n$) the decision maker has been absolutely consistent. Otherwise, his consistency can be evaluated by calculating the Consistency Ratio (CR). First the Consistency Index (CI), representing the negative average of the other roots of the characteristic polynomial of the matrix[15], is calculated:

$$CI=\frac{\lambda_{\max}-n}{n-1}. \tag{1}$$

Finally the Consistency Ratio (CR) is calculated which shows how consistent the judgments have been in comparison to large samples of purely random judgments. The Random Consistency Index (RI) is the average value of CI over a large number of matrices of the same order whose entries are randomly chosen from Saaty's scale. *Table 1* (taken from Ref. 15) gives the values of RI for different matrix sizes.

Table 1. Random Consistency Index values

Matrix size	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Thus, CR is calculated as follows:

$$CR = \frac{CI}{RI}. \tag{2}$$

According to Saaty[15] if this ratio exceeds 10% the set of judgments may be too inconsistent to be reliable and the judgments should be revised (though in practice values over 10% are sometimes accepted). A CR of 0% means that the judgments are perfectly consistent.

Therefore, the traditional AHP method (for a simplified problem which includes only goals, criteria and alternatives) involves the following steps:

(i) Defining the problem *i.e.* constructing the hierarchical model.
(ii) Determining the relative importance or weight of the criteria with respect to the goal as well as the alternatives with respect to each criterion through pairwise comparisons. The results are presented in comparison matrices.
(iii) Evaluating the alternatives with respect to the criteria and the criteria with respect to the goal by means of relative weights.
(iv) The relative weights are estimated by finding the principal right eigenvector of each comparison matrix.
(v) Finally, a composite vector is created, representing the product of relative weight vectors of every level. The results are the relative priorities of every alternative with respect to the goal, which ultimately enables their ranking.

3. Fuzzy Logic

Fuzzy logic, introduced by Lofti Zadeh[19] is envisaged to extend binary values 0 and 1 representing strict presence or absence of an entity to any other value in between, indicating an entity's relative presence or absence.

It is especially useful for working with linguistic variables which can be mapped to this interval by corresponding membership functions. On the other hand, the relationships among the criteria in decision making problems can sometimes only be expressed by vague verbal statements. The use of the fuzzy approach is only natural since it is adjusted in accordance with the qualitative descriptions people use in everyday communication. The fuzzy set theory enables the transformation of such descriptions or statements into mathematical expressions. Another advantage is its ability to take into consideration the correlation existing among elements or the situation in which the decision maker might want to trade off one element against another which should be expressed by logical functions.

However, no conventional fuzzy set theory (fuzzy logic, theory of fuzzy relation) is in the Boolean frame[11] and therefore, it is proposed that consistent fuzzy logic, introduced in Ref. 12, should be used for expressing logical functions.

3.1. *Boolean consistent fuzzy logic*

Conventional fuzzy set theory does not satisfy all Boolean axioms and theorems, foremost the axioms of excluded middle and contradiction. The excluded middle axiom states that:

$$a \wedge \neg a = 0. \tag{3}$$

and can be explained as follows: if an entity has a property with a membership of 0.3 then it could be said that the absence of the property has a membership of 0.7. The following example proves that the axiom does not hold (the product is chosen as the T norm).

$$\begin{aligned} a &= 0.3, (1-a) = 0.7 \\ a \vee \neg a &= a + (1-a) - a * (1-a) = \\ &= 0.3 + 0.7 - 0.21 = \\ &= 0.79 \neq 1. \end{aligned} \tag{4}$$

The same can be shown for the contradiction axiom (the minimum operator is chosen as the T norm):

$$\begin{aligned} a \wedge \neg a &= \min\left(a, (1-a)\right) = \\ &= \min\left(0.3, 0.7\right) = \\ &= 0.3 \neq 0. \end{aligned} \tag{5}$$

In light of the previous assertions the use of the Interpolative realization of Boolean algebra (IBA) is proposed. IBA is an illustrative name for the real-valued and/or *[0, 1]*-valued realization of Boolean algebra.[12] Any logical function can be uniquely transformed into a corresponding generalized Boolean polynomial (GBP) using IBA.[12] Only once the transformations have been conducted and the final structure established will the values be introduced and computed. This is the main difference between the conventional and Boolean consistent approaches which can, in certain cases, lead to different results, as will be shown in Section 5.1.

The GBP maps a corresponding element of Boolean algebra into its value from the real unit interval *[0, 1]* on the value level, so that a partial order on the value level is preserved contrary to other many-valued (MV) and/or fuzzy approaches.[20] The GBP is a polynomial whose variables are elements of the Boolean algebra and the operators are standard +, standard – and generalized product $\otimes$. The generalized product can be any function which maps *[0,1]x[0,1]→[0,1]* and is a subclass of the conventional fuzzy T norm satisfying the non-negativity axiom.[21]

Since the Boolean consistent approach requires that a set of structural transformations be executed before the values can be introduced the excluded middle and contradiction axioms will hold (*Eqs. (6)* and *(7)* respectively).

The excluded middle axiom:

$$\begin{aligned} a \vee \neg a &= a + (1-a) - a \otimes (1-a) = \\ &= a + 1 - a - a \otimes 1 + a \otimes a = \\ &= a + 1 - a - a + a = 1. \end{aligned} \tag{6}$$

It should be noted that in the case of the conjunction of a variable with itself the elements of the conjunction are undoubtedly correlated so the only reasonable operator to use for the generalized product is the minimum operator. Similarly, for the contradiction axiom:

$$\begin{aligned} a \wedge \neg a &= a \otimes (1-a) = \\ &= a \otimes 1 - a \otimes a = \\ &= a - a = 0. \end{aligned} \tag{7}$$

4. Web Service Selection Problem

A large number of web services, developed on various platforms and in various programming languages which provide the same functionality, are accessible on the Internet. When multiple services provide the same functionality they can be grouped into classes. The problem consists of choosing a web service from a given class (*i.e.* the class of services that achieve the desired functionality) on the basis of certain criteria. Often the selection is made on the basis of Quality of Service (QoS) attributes. QoS refers to the non-functional properties of a service such as: performance (measured in terms of throughput, response time, latency *etc.*), security, reliability, availability, scalability, integrity *etc.* (See Ref. 22). Certain relationships very often exist among various QoS attributes.[23] The criteria selected for the following examples are:

Table 2. Selected QoS attributes

QoS Attribute		Description	Unit
Response time	**RT**	Time taken to send a request and receive a response.	millisecond
Availability	**A**	The probability that a service is operating.	percent
Reliability	**R**	Related to the ratio of error messages to total messages.	percent
Security	**S**	The level and kind of security a service provides.	Excellent, Very good, Good, Adequate, Poor
Encryption	**E**	Indicates whether the service provides encryption.	Yes/No

Generally, certain constraints regarding the required QoS attributes are also given. It is assumed that a previous selection of services satisfying these constraints has been made so that only the remaining services are analyzed. The values of the attributes for the remaining services are given in *Table 3*.

Table 3. Values of the selected QoS attributes

	RT	A	R	S	E
WS_1	1000	93	91	Adequate	No
WS_2	2000	98	95	Excellent	No
WS_3	1700	96	98	Poor	Yes

5. Proposed Solution

The main weakness of the weighting technique used in the traditional AHP method, as well as the Fuzzy AHP method, is that it only allows linear relationships among the criteria. Given that certain criteria may influence or be influenced by other criteria as well as the fact that the importance of the criteria may vary based upon the demonstrated level of other criteria, it is necessary to take this into account while choosing the best alternative. Therefore, it is proposed that a logical function is used for defining the importance of the criteria with respect to the goal instead of comparison matrices. The logical function, which takes into account the correlation among the criteria and the trade-offs the decision maker is willing to make, should be defined within the Boolean frame.[24] In other words, the main goal of Logical Aggregation is to combine the initial criteria into a single global criterion using a logical function as a logical aggregation operator. GBP in logical aggregation has the role of a logical combined element.[21] The proposed Logical Aggregation approach can be applied to both the traditional AHP method (based on crisp numbers) and the Fuzzy AHP method — where the preferences are fuzzy numbers (Refs. 23 and 25–28) or else the values of the selected QoS attributes are formalized as fuzzy sets (Refs. 29 and 30).

The proposed solution will be illustrated on two examples. The first is a simple case when only the goal is a logical demand. The second is a more complex one, where the criteria and subcriteria also represent logical demands and two different approaches for calculating the global priorities will be presented and compared.

5.1. *Case 1*

Following the traditional AHP method the first step is to create a hierarchy model. In the simplest case, the hierarchy only contains three levels: the goal at the top, the relevant criteria in the middle and the possible alternatives at the bottom level. The goal is to achieve the best QoS, the criteria are the chosen QoS attributes (Response time, Availability and Reliability) and the alternatives are the three possible web services (*Fig. 1.*).

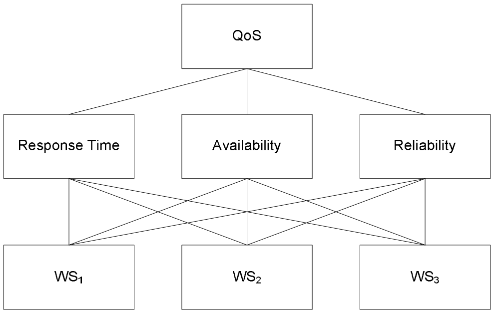

Fig. 1. Hierarchical model for web service selection when only the goal is a logical demand.

Next, the comparison matrices representing the relative importance of the alternatives regarding each criterion are constructed (*Table 4.*).

Table 4. Comparison matrices for Case 1.

	Response Time			Availability			Reliability		
	WS_1	WS_2	WS_3	WS_1	WS_2	WS_3	WS_1	WS_2	WS_3
WS_1	1	1/9	1/4	1	1/7	1/3	1	1/5	1/7
WS_2	9	1	2	7	1	2	5	1	½
WS_3	4	1/2	1	3	1/2	1	7	2	1

The matrices are then processed and the principal right eigenvector of each comparison matrix is calculated (*Table 5.*).

Table 5. Eigenvectors and rankings for Case 1

	Response Time		Availability		Reliability	
WS_1	0.0724	3	0.0926	3	0.0755	3
WS_2	0.6263	**1**	0.6150	**1**	0.3338	2
WS_3	0.3013	2	0.2924	2	0.5907	**1**

It is necessary to evaluate the consistency of the decision maker's judgments (*Table 6.*). Since all of the Consistency Ratios (CR) are well below 10% the judgments can be treated as reliable and it could be said that in this example the decision maker has been almost perfectly consistent.

Table 6. Consistency evaluation for Case 1

	Response Time	Availability	Reliability
λ_{max}	3.002	3.004	3.020
CI	0.001	0.002	0.010
CR	0.20%	0.32%	1.70%

The next step in the traditional AHP would be to repeat the same procedure for the criteria with respect to the goal and finally calculate the composite vector.

However, a decision maker might want to trade off one attribute against another *e.g.* Availability (**A**) is typically related to Reliability (**R**) so this should be taken into consideration: if a service has a high level of **A** then it may be more important to take into consideration the value of the Response Time (**RT**) and if it is low then **R** is more important. This request can only be expressed by a logical function:

$$\left(A \wedge RT\right) \vee \left(\neg A \wedge R\right). \tag{8}$$

This logical function could be evaluated by applying the rules of conventional fuzzy logic (*Eq. (9)*) and the results are given in *Table 7*.

$$\left(A\times RT\right)+\left(\left(1-A\right)\times R\right)-\left(A\times RT\times(1-A)\times R\right). \tag{9}$$

Nevertheless, the proposed approach prefers the use of consistent fuzzy logic for reasons previously explained in Section 3.1. To transform a Boolean function into a GBP the first step is to assess its structure. A detailed description of this transformation is given in Ref. 20. In this particular case the following transformation steps have been taken:

$$
\begin{aligned}
&\left(\left(A\wedge RT\right)\vee\left(\neg A\wedge R\right)\right)^{\otimes}=\\
&=\left(A\wedge RT\right)^{\otimes}+\left(\neg A\wedge R\right)^{\otimes}-\left(\left(A\wedge RT\right)\wedge\left(\neg A\wedge R\right)\right)^{\otimes}=\\
&=A\otimes RT+\left(\left(1-A\right)\wedge R\right)^{\otimes}-\left(A\wedge RT\right)^{\otimes}\otimes\left(\neg A\wedge R\right)^{\otimes}=\\
&=A\otimes RT+\left(1-A\right)\otimes R-A\otimes RT\otimes\left(\left(1-A\right)\otimes R\right)=\\
&=A\otimes RT+R-A\otimes R-A\otimes RT\otimes R+A\otimes RT\otimes A\otimes R=\\
&=A\otimes RT+R-A\otimes R. \qquad (10)
\end{aligned}
$$

After the transformation has been accomplished focus is transferred to the value level by choosing the standard product as an adequate operator for the generalized product and then inputting the values (which have already been normalized as a result of the previous AHP steps). *Table 7* depicts the results.

For clarification purposes, the values in *Table 7 e.g.* for WS_1 are calculated as follows:

- for Consistent Fuzzy Logic: `0.0752 = 0.0926*0.0724+0.0755-0.0926*0.0755`.
- for Conventional Fuzzy Logic: `0.0747 = 0.0926*0.0724 + (1-0.0926)*0.0755 -0.0926*0.0724*(1-0.0926)*0.0755`.

As expected the results of these two approaches differ. WS_2 is obviously the better choice regarding the defined requirements since it outranked WS_3 in two out of three criteria.

Table 7. Result comparison for Case 1

	Consistent Fuzzy Logic		Conventional Fuzzy Logic	
WS_1	0.0752	3	0.0747	3
WS_2	**0.5137**	**1**	0.4642	2
WS_3	0.5061	2	**0.4693**	**1**

5.2. *Case 2*

When the decision should be made on the basis of several criteria, possibly complex, the problem could be decomposed into a set of hierarchically organized sub-problems. Therefore, the hierarchy model would contain several levels corresponding to the goal, the criteria, the subcriteria and the possible alternatives. For example, in addition to the previous Logical demand (subsequently referred to as **LD$_1$**) regarding the Response time, Availability and Reliability the decision maker might also want to take into account the attributes related to the security level of the web service (namely, the Security (**S**) and Encryption (**E**) attributes). If the decision maker is willing to trade off these two attributes the logical demand could be stated as follows: a high level of either **S** or **E** indicates that the particular service is a secure one.

This logical demand, subsequently be referred to as LD2, can be expressed as:

$$S\vee E. \qquad (11)$$

The hierarchy model for this problem is given in *Fig. 2*.

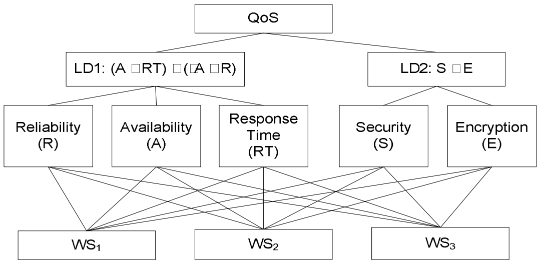

Fig. 2. Hierarchical model for web service selection when both the goal and the criteria are logical demands.

The comparison matrices representing the relative importance of the alternatives for the new attributes are given in *Table 8*.

Table 8. Comparison matrices for Case 2

	Security			Encryption		
	WS_1	WS_2	WS_3	WS_1	WS_2	WS_3
WS_1	1	1/5	2	1	1	1/7
WS_2	5	1	9	1	1	1/7
WS_3	1/2	1/9	1	7	7	1

The principal right eigenvectors of the comparison matrixes are calculated and given in *Table 9* along with the ranks of the services.

Table 9. Eigenvectors and rankings for Case 2

	Security		Encryption	
WS_1	0.1577	2	0.1111	3
WS_2	0.7606	**1**	0.1111	3
WS_3	0.0817	3	0.7778	**1**

Table 10 confirms that the decision maker has once again been consistent in his judgments.

Table 10. Consistency evaluation for Case 2

	Security	Encryption
λ_{max}	3.002	3
CI	0.001	0
CR	0.19%	0%

As previously, logical function (*11*) is evaluated by applying the rules of Boolean consistent fuzzy logic (with the standard product as the generalized product):

$$\left(S \vee E\right)^{\otimes} = S + E - \left(S \wedge E\right)^{\otimes} = \\ = S + E - S \otimes E. \qquad (12)$$

The next step in the traditional AHP method would be to repeat the same procedure for the criteria (LD_1 and LD_2) with respect to the goal. When both logical demands are equally important to the decision maker there are two different approaches to how they can be aggregated into a unique goal.

The first approach is to evaluate the relative weights of the criteria with respect to the goal through comparison matrixes which is in accordance with the standard AHP method (*Table 11.*).

Table 11. Comparative matrix, relative weights and rankings of the criteria

	LD_1	LD_2			QoS	
LD_1	1	1	⇒	LD_1	0.5	1
LD_2	1	1		LD_2	0.5	1

The global priorities of the web services with respect to the goal are then obtained through the aggregation of the local priorities of every hierarchy element in all paths from the alternative to the goal using the additive aggregation method.

However, a problem arises from the fact that by a judicious choice of preferences one can make an alternative that is dominant on even one criterion, no matter how unimportant that criterion may be, have the largest value after weighting and adding and thus turn out to be the most preferred.[15] In other words, when both criteria should be equally important the assignment of equal weights to both of them does not adequately reflect the actual logical demand ($LD_1 \wedge LD_2$). For example, for two alternatives (a very good one and a very poor one) if the good alternative is much more intense then the poor assigning equal weights to each of them one could eliminate the negative impact of the poor alternative. In this situation it would make more sense to choose two average alternatives and this can only be accomplished by the use of logical functions. Thereby, the choice will be based on the values of both demands equally.

Therefore, the second approach to obtaining global priorities is to use the same proposed logical function technique for evaluating the criteria preferences instead of using comparison matrixes. The global priorities will be obtained as a result of this logical aggregation. The results of both approaches are presented in *Table 12.*

Table 12. Result comparison for Case 2

	SAW		Conventional Fuzzy Logic	
WS_1	0.1632	3	0.0189	3
WS_2	0.6505	2	**0.4044**	**1**
WS_3	**0.6510**	**1**	0.4028	2

In accordance with the previous discussion the results show that these two approaches do not lead to the same choice.

6. Related Work

The approach proposed in this paper is envisaged to be applicable in any area in which it is necessary to make a decision on the basis of several criteria which can be interrelated, conflicting or traded-off.

Among the numerous approaches for solving MCDM problems (See Refs. 13 and 31 for a detailed survey) AHP is one of the most widely used and it has been successfully applied in a number of different problem areas.

At the same time various approaches have also been proposed for expressing interrelation and trade-offs among the criteria in a wide range of different problem areas. Due to heterogeneity of problem areas as well as the different MCDM approaches on which they are based it would be impossible to synthesize the related work within the space constraints of the paper. Therefore, this section will only focus on the different approaches for solving the problem presented in this paper, namely the web service selection problem modeled as a MCDM problem. This does in no way imply that the proposed solution is only applicable to this problem.

The approach presented in Ref. 32 is the closest to the one presented in this paper since it is also based on AHP but it does not take into account the correlation that might exist among the attributes or the trade-offs that the decision maker might wish to make. In most of the existing approaches these trade-offs are usually limited to a certain strategy for assigning scores to services, usually weighted, and weighing the relative importance of the attribute.[29]

However, some approaches have considered the use of fuzzy logic for defining the decision maker's preferences and the trade-offs among QoS attributes. In the approach presented in Ref. 29 fuzzy rules are automatically generated from the decision maker's preferences and used in a fuzzy inference process that ranks the web services. The premises of the fuzzy rules specify possible combinations of values for the attributes, and the corresponding conclusion specifies the degree of acceptability for that web service. In the approach presented in Ref. 25 the trade-offs among QoS attributes are given by fuzzy expressions, but the problem is modeled as an optimization problem. A combination of first order logic inference and hierarchical fuzzy logic evaluation has been used to model the service selection problem in Ref. 26. In Ref. 30 the decision maker's preferences are modeled by fuzzy IF-THEN rules expressing the acceptance degree for different combinations of attributes. A formal policy language is defined in Ref. 33 and the paper shows how the concepts of utility function policies can be used to define cardinal preferences over functional as well as non-functional properties of a web service.

It should be noted that the approaches presented in Refs. 25 and 30 were used for solving the web service composition problem which is a different problem from the one regarded in this paper.

7. Conclusions

When choosing the best alternative based on a set of attributes the decision maker has selected for representing the goal (the criteria) using the AHP method, the fact that the criteria may be interrelated, conflicting or traded-off should be taken into account. Since, these relationships among the criteria are usually expressed by verbal statements is only natural to use logical functions for expressing such logical demands.

It is proposed that the traditional AHP method, which lacks support for this type of problem, could be extended to cover this situation by applying fuzzy logic when defining the goal or criteria. Two different application scenarios are given showing that the proposed approach can be used at different levels of the AHP hierarchy model.

Even though, conventional fuzzy logic could be applied to this problem it is shown (Case 1) that, in certain cases, it could lead to the choice of a worse alternative (the ranking: $WS_3 \succ WS_2 \succ WS_1$ instead of the ranking: $WS_2 \succ WS_3 \succ WS_1$ which is the result of the Boolean consistent fuzzy approach). This stems from the fact that no conventional fuzzy set theory is in the Boolean frame. Foremost, because negation is treated differently in these two approaches, but also because the Boolean consistent approach requires that a set of structural transformations be executed before the values can be introduced.

Logical functions (*i.e.* Logical Aggregation) result in a new structure of the components as opposed to the weighted sum approach and it is shown that this characteristic could result in a different ranking of alternatives (Case 2).

Further work would be aimed at the application of the proposed approach using fuzzy preferences instead of crisp ones.

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