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Algorithm for the evaluation of Free and Open Source Software when the Evaluator is "Uncertain"

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Abstract

Free and Open Source Software is freely available on the Internet and making use of it, could benefit many higher learning institutions in developing countries. However, before adoption, it is necessary to evaluate the software to see if it meets the requirements of the institution. The evaluation of software involves considering the quality attributes of the software, which can either be evaluated objectively or subjectively, depending on whether the attributes are measured directly or indirectly. To handle the subjectivity of qualitative evaluation an algorithm with inherent computational intelligence was developed. The algorithm, Fuzzy Analytic Hierarchy Process incorporates a modified version of extent analysis. It can tolerate fuzziness, ambiguity, imprecision, uncertainty and ill-illustrated judgements. In addition to the improved Fuzzy Analytic Hierarchy Process development, the Group Fuzzy Analytic Hierarchy Process was developed. Using a specially derived set of end-user centric metrics, the algorithm provides the means for evaluating software according to quality attributes. Software developers, to predict end-user requirements, and to more accurately measure end-user satisfaction can use these quality attributes. Soft Systems Methodology was the preferred research methodology in this investigation as it is well suited for fuzzy problems. The algorithm was validated by evaluating Moodle, a free and open source e-learning system, adopted by a University in Tanzania. Students and staff from the university were involved in providing the subjective opinions about the software. The data collected from the subjective evaluation was captured and using Soft System Methodology, the data was analysed cyclically, improving the algorithm with each cycle. The advantages of the proposed final algorithm are: it is efficient, simple to use and cost-effective. It guides the end user to form an informed decision based on the evaluation results of software. The evaluation results determine whether the outlook is pessimistic, moderate or optimistic.

Keyword: software evaluation, free and open source software, e-learning, uncertainty, fuzzy AHP

1. INTRODUCTION

Evaluating software in terms of quality has been investigated by many researchers (Fenton and Neil, 2000; Polancic and Horvat, 2000; Graf and List, 2005; Sanga and Venter, 2007; Shee and Wang, 2008; GoelS and Rana, 2012; Abbeyquaye and Effah, 2013). In order to develop a successful evaluation model, a predefined set of rules and guidelines are required. Evaluation models are complex because decision-making under uncertainty, ambiguity and fuzziness (based on multiple attributes: criteria and sub-criteria) need to be taken into account.

Most evaluation cycles start with the identification of the key attributes of the software quality required. A team of evaluators, which might represent the users from different sections/departments of the organization, then matches the collected attributes of the organization with those mentioned in the literature. Characteristics, sub-characteristics and attributes are hierarchically interrelated and act as a benchmark for the selection and identification process of quality attributes. According to Seffah et al. (2001) IEEE, Boehm, McCall and ISO 9126are examples of software quality models, but these models have some disadvantages:

(i) it is difficult to visualize the relationship between characteristics, sub-characteristics and attributes;
(ii) it is not in a format which can be used by software developers as well as novice users;
(iii) even though different software quality models exist, these are not well incorporated into the software development of Free and Open Source Software (FOSS); and
(iv) it does not take into account the different phases of software development.

The adoption of FOSS is hampered by the fact that the developers develop the software voluntarily and that the user is seldom part of the user requirement elicitation phase. Poor documentation might be the reason why FOSS is often

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considered to be of lesser quality (Nichols and Twidale, 2003) although Scacchi (2007) does not agree with this statement. There is a need of efficient and reliable decision support systems to map the uncertainty associated with the evaluation of FOSS. Such expert system's algorithm should be able to handle the fuzziness associated with FOSS (Zadeh, 1983).

The use and adoption of open source e-learning system in universities of developing countries in Africa has increased in recent years. E-Learning software has become necessary to support the large number of students these universities have to accept - due to the massification of students in higher learning institutions. A further reason for its adoption has been to "catch" the revolution of information communication technologies (ICTs). The revolution was sparked by the landing of submarine optical cables that now provide fast Internet access to most of the developing countries in Africa. Skilled (but also unskilled staff) from these universities were now forced to become involved in the evaluation of software for their use.

Evaluation of software (in terms of software quality and other requirements) is a complex process. The complexity arises from the multiple characteristics, sub-characteristics and attributes of software quality, which needs to be combined and compared as per different software products. It is not possible to obtain complete and comprehensive information about each software quality attribute. Thus, the evaluations are "uncertain".

In Tanzania, open source e-learning systems are in use at the University of Dar es salaam, Sokoine University of Agriculture, Mzumbe University, MUHAS and Open University of Tanzania (Sanga& Venter, 2009). Only a few staff members and students have adopted the systems and are using it. The reason for the failure in uptake of the technology can probably be ascribed to the fact that the e-learning systems (which are in use in these Universities) were not evaluated properly or evaluated in an ad-hoc fashion. There is thus a need for the development of an algorithm to help skilled and unskilled end-users to evaluate software before it is implemented.

Different techniques have been proposed by different researchers to tackle the software evaluation problem (Saaty, 1994; Czogala and Pedrycz, 1981).Traditional methods of evaluating software products involve a heuristic approach using expert judgements. Several experts evaluate the software products and choose one among the many products. Their decisions are then compared and discussed until the experts come to an agreement. This approach is problematic since it depends on how users perceive the software product and hence, software quality is measured from different perspectives. Fenton and Pfleeger (1997) defined measurement theory (Stevens, 1946) which deals with the representation of the measurement of software in terms of software metrics. It models the software phenomena and maps it to a numerical value by means of algebraic expressions.

Basili, Caldeira, and Rombach (1994) proposed a Goal/Question/Metric (GQM) paradigm which is a hierarchical model. The highest level of the GQM hierarchy is the goal or purpose of the measurement followed by a number of questions in subsequent levels, which are divided into metrics (at the lowest levels). Metrics are the entities that are measurable and are either measured objectively or subjectively. The disadvantage of GQM is that it can be used only by the experienced users within a project team, who can define questions relevant to the goals of the business of the organization. The advantage of GQM paradigm is that it allows selecting a few software characteristics of particular interest to the organization. This can also be done by weighted sum model (Graf and List, 2005), which is a multi criteria decision making (MCDM) algorithm. Sanga *et al.* (2007) show that the results obtained using Graf and List model are almost similar to that obtained using AHP.

Koscianski and Costa (1999) argued that software quality models such as ISO 9126, Boehm and McCall should be used in the evaluation of software but these methods measure attributes separately and there was no method for combining their results. Koscianski and Costa (1999) proposed a combination of ISO 9126 and the Analytical Hierarchical Process (AHP) algorithm to address this problem but this solution cannot handle the fuzziness, uncertainty and ambiguity related to evaluation judgements. Procedures for AHP are well described by Finnie *et al*. (1993) and Saaty, (1980). It has the ability to rank choices in the order of their effectiveness in attaining conflicting objectives and it also has the ability to detect inconsistent judgements. According to Cheng *et al*. (1999) AHP has shortcomings: it is used in nearly crisp (non-fuzzy or exact) decision applications; it deals with an unbalanced scale of judgements (1 up to 9);it does not take into account the uncertainty associated with the mapping of a human judgement to a exact number (Tsvetinov & Mikhailov, 2004; Deng, 1999); the ranking of AHP is rather imprecise/vague/inexact; and the subjective judgement, selection and preference of decision makers have great influence on the results of AHP. Further problems with AHP were identified by Wang et al., an increase in the number of criteria used when applying the algorithm increases the number of pairwise comparisons linearly in the form of $\frac{n(n-1)}{2}$, which sometimes can lead the algorithm to fail or to be inconsistent (Wang *et al*., 2008).Another

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disadvantage of AHP is that a change of scale (used in pairwise comparison) changes the result of the algorithm (Sanga & Venter, 2009; Sanga, 2010).

The question thus is: How should an algorithm be designed to deal with the vagueness and imprecision of human cognitive processes (i.e. thinking or reasoning)?

This research was done from a post-positivist perspective. Four cycles of Soft Systems Methodology (SSM) was undertaken. In each of the four cycles the algorithm was refined. In the first cycle the replication experiment was done, in the second cycle AHP was implemented and tested, in the third cycle Fuzzy AHP (with extent analysis)was implemented and tested and finally, the Group Fuzzy AHP, was implemented.

This paper presents the results of this process to develop a new algorithm called Group Fuzzy AHP, which could be used in the evaluation of FOSS and for the evaluation of closed (commercial) source software (CSS).

In a case study (at a Tanzanian University), the maintainability, usability and deployability characteristics of FOSS–considered to be the most important characteristics that software in a developing country should adhere to–were investigated. These characteristics address problems of developing countries: bandwidth, limited funding, semi-literate users and home languages other than English. It was shown that the new algorithm can handle the subjectivity, uncertainty, fuzziness and ambiguity of evaluator comparison judgements in the form of fuzzy triangular numbers (FTNs). The fuzzy prioritization method was used to compute the prioritisation from fuzzy preferences. Since the aim was to get a crisp value, crisp / exact priorities were derived from the fuzzy comparison matrices. The proposed algorithm was tested for its applicability in enhancing the evaluation of e-learning systems at the University of Tanzania.

2. Research Approaches

This research was mainly from a post-positivist perspective. But, what does this mean? According to Crotty, four questions need to be posed to explain the pivotal issues of the research (Crotty, 1998):

(i) What *method* to use?

The researcher needs to identify the technique or procedures for collecting and analysing data according to the research questions.

(ii) What *methodology* governs the choice and use of the proposed methods?

The methodology is the strategy, plan of action or design to obtain the desired results.

(iii) What *theoretical perspective* (or approach) is suggested?

Thus, what is the philosophical stance behind the suggested methodology?

(iv) And finally, what *epistemology* informs the suggested theoretical perspective?

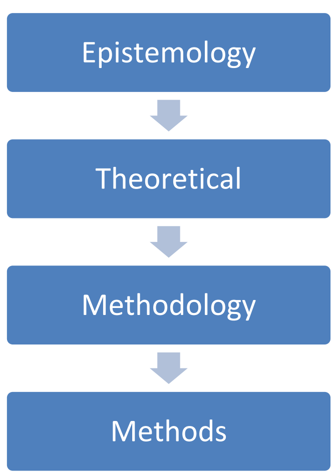

Figure 1: Four elements of the research process

The outline of the research for this paper (using Crotty's model) is represented in Figure 1 and Figure 2.

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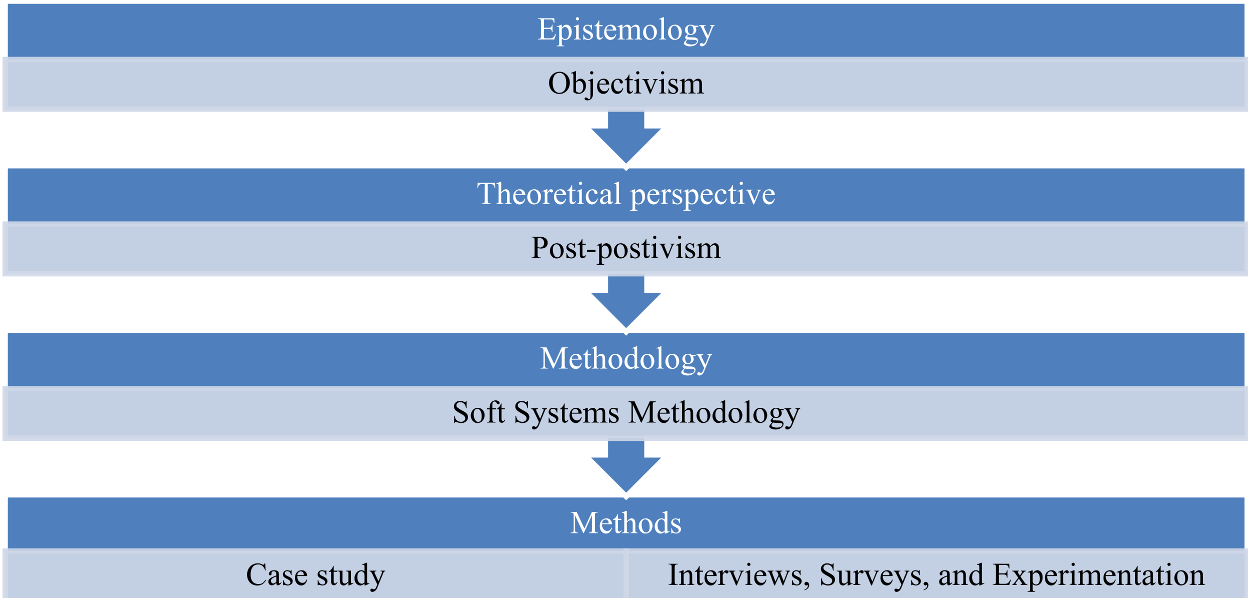

Figure 2: The four elements of research as was used in this paper

How Soft Systems Methodology was used

In this paper, SSM was used to manage the complex data analysis process. According to the Checkland and Scholes, SSM is well suited to solve unstructured, poorly defined and complex problems (Checkland & Scholes, 1990). It is worth noting that SSM allows the researcher to investigate ill-defined (i.e. fuzzy) problem holistically and cyclically.

2.1 What is SSM?

> *"SSM is a methodology that aims to bring about improvement in areas of social concern by activating in the people involved in the situation a learning cycle which is ideally never-ending"*
> *(Checkland & Scholes, 1990, p. 30)*

3. Case study

Twenty-three participants from OUT, who had experience in both ATutor and Moodle, were selected by means of purposive sampling (Van Vuuren & Maree, 1999). The purposive sampling procedure was used because only a limited number of users had the necessary experience and could participate in the study (ibid.). The participants comprised of 20 Second year BSc Information Communication Technology students and 3 IT lecturers (who are involved also in systems administration and maintenance). The participants were given a consent form to complete before taking part in the research to adhere to the ethical standards set for this study.

3.1 Instrument design

To determine what type of questions to ask in the questionnaire and how to ask it, a questionnaire (as instrument for data collection) was developed and refined in a pilot study.

For the three main characteristics (usability, maintainability, and deploy-ability), sub-characteristics were identified as proposed in the literature (Sanga, 2010). For each of these sub-characteristics, the researcher decided on attributes that best describe the selected sub-characteristics. This was done before the pilot testing. The selected attributes were combined with attributes identified in the literature (Sanga, 2010). The combined characteristics, sub-characteristics, and attributes were used in the formulation of a questionnaire; some of the questions were adopted from a Software Usability Measurement Inventory (SUMI) questionnaire (Ryu, 2005: 192). Attributes that were duplicated, were removed from the questionnaire. The aim was to come up with a list of representative attributes, agreed to by all participants. Open-ended questions or probes were designed for the focus group. These

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probes covered some aspects not included in the questionnaire. The questions, in all the instruments used for data collection; were simple, short, precise and to the point.

3.2 Instruments used to collect data

Data was collected between February 2007 and November 2009. Participants were requested to complete the questionnaire and some of the participants were interviewed using probes. Focus groups helped to obtain a wish-list of weights for the characteristics and sub-characteristics of maintainability, usability and deployability. In addition, the researcher took field notes (i.e. participative observation) during the data collection process. This provided rich data, which informed the research process.

The collected data is still relevant today since 40% to 80% of the software development expenditure is spent on the rectifying problems coming from maintenance, usability and deployment of the software (GoelS et al., 2012). Thus, the collected data were meant to be input to the proposed algorithm, which will result into aiding participants in evaluating software per software quality characteristics. Participatory evaluation of software using different stakeholders (i.e. participants) in an organization is useful to minimize the future maintenance efforts. Working towards finding an algorithm to help user in evaluating software as per maintanability, deployability and usability is essential since assessing software according to these software quality characteristics is difficult. It is difficult because maintenance phase in software development life cycle aim at fixing bugs, enhancing usability features, and making sure that the software is deployable and updated to keep pace with changing user (i.e. domain) requirements (GoelS et al., 2012).

3.3 Data preparation

The respondents were required to indicate the level of importance of the software quality characteristics of usability, maintainability and deployability; and their respective sub–characteristics and attributes. The answers the respondent could choose were: extremely important, very important, important, of little importance; or, not important. Different scales were used to convert the user verbal description (i.e. views) (about the comparison of software according to software quality) and responses to the questionnaire into a numerical value. After a number of trials using different types of scales (such as nominal, interval, ordinal and ratio scales), the Saaty scale (Saaty, 1980) was chosen to translate the data into a format that could be used in AHP computations. Mapping software quality phenomena to a numerical value is accepted in measurement theory and software measurement (Fenton and Pfleeger, 1997).

4. How data was analysed

Several cycles of data analysis were undertaken and SSM was used to manage this cyclical data analysis process (see Figure 3).

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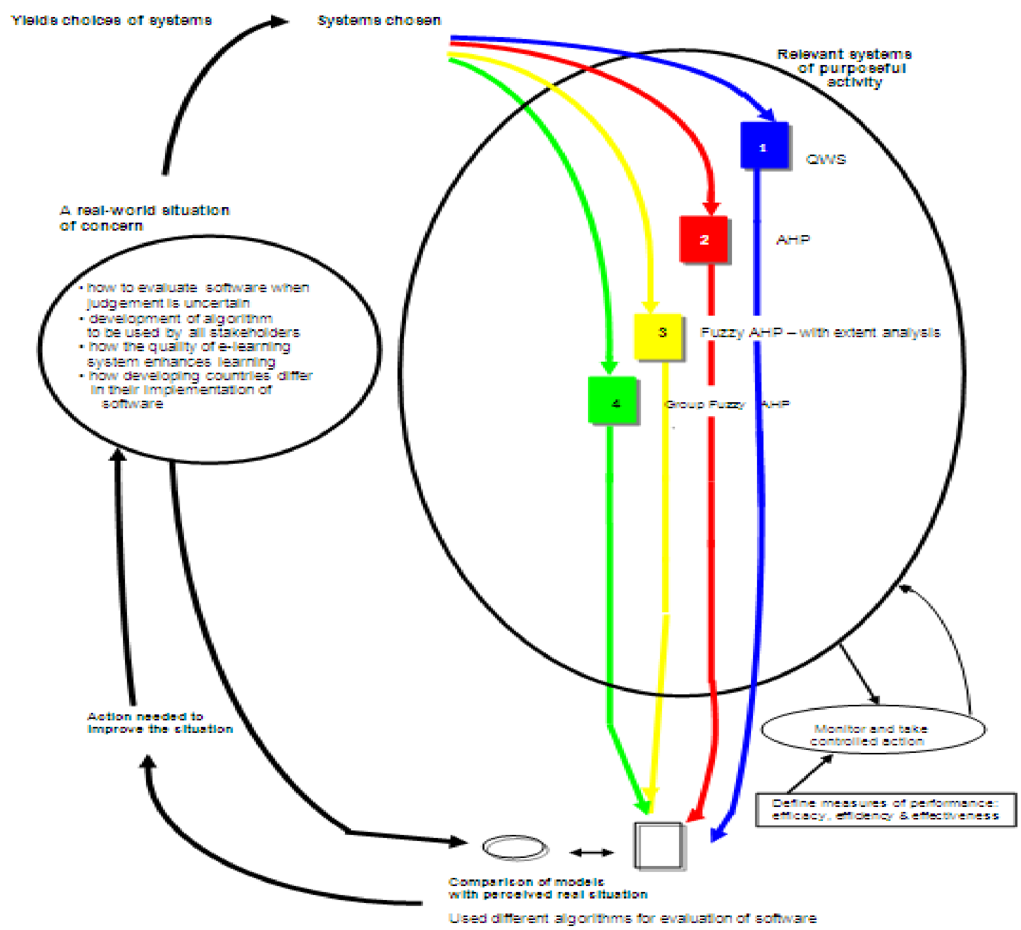

Figure 3: How the SSM was used to manage the research

The cycles of data analysis were undertaken to compare the proposed algorithm with existing algorithms and to validate the usefulness of the proposed algorithm. This paper is primarily based on the third and four cycles of the SSM managed research experiment. The first and second cycles were described in previous publications by Sanga *et al.* (2007) and Sanga and Venter (2009), respectively, but are discussed here again briefly to clarify the motivation for cycles three and four.

4.1 First cycle of SSM: Replication experiment

The aim of this investigation was to determine whether the results of an empirical QWS evaluation could be confirmed using a different evaluation algorithm, namely AHP. In this experiment, the Qualitative Weight and Sum approach (QWS) used by the researchers Graf and List (2005) to evaluate several free and open source e-learning software platforms, were studied and replicated with AHP. It was found that the ranking of the e-learning platforms with AHP differs slightly from the outcome of QWS. However, with AHP it is possible to determine the consistency of the evaluation evaluators' judgements. Both QWS and AHP were useful to evaluate software but it is easier to rank software using AHP (Sanga, Venter, and Agbinya, 2007).

4.2 Second cycle of SSM: Implementation of AHP

The objective of this part of the experiment (see 2 in Figure 3) was to determine whether AHP would be suitable for the evaluation of software by evaluators with little IT experience. It was felt that AHP would be useful to determine evaluation preferences by a group of users, however; its weakness is that it cannot deal with uncertainty of user

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judgement (Sanga and Venter, 2009). Thus, in order to deal with uncertainty during evaluation there is a need for an algorithm, which can cope with this reality.

4.3 Third cycle of SSM: Implementation of Fuzzy AHP (with extent analysis)

The objective of this experiment (see 3 in Figure 3) was to extend the multi-criteria evaluation algorithm, AHP, which is applicable for managing "certain" evaluation judgements, and to imitate the way humans' reason and judge. Human reasoning and judgement during the evaluation of software is subjective and could be said to be "uncertain". Thus, algorithms that could deal with the uncertainty of human judgements would be an improvement on AHP. It was felt that fuzzy logic combined with the AHP algorithm, could compensate for the weakness of AHP. The algorithm was developed and implemented and the results of the Fuzzy AHP (with extent analysis) and that of AHP were compared. The developed Fuzzy AHP (with extent analysis) does not discard priority weights (of the characteristics, sub-characteristics and attributes) with low numerical values (i.e. ratings). It novel characteristic is that it includes the decision analysis in the final stages of the algorithm (Sanga, 2010).

In the next sections the new algorithm which consists of Fuzzy AHP (4.3.1) and extent analysis (4.3.2) are presented.

4.3.1 Fuzzy AHP

The central part for any MCDA (Multi-Criteria Decision Algorithm) such as AHP, is computing the priority weight. Different approaches have been used to compute prioritization weight. The approaches differ according to whether they apply crisp values or fuzzy values. Saaty (1980) who invented AHP used eigenvalue method for crisp value estimation. Other methods for crisp values are distance functions least squares, weighted least squares method, logarithmic least squares and logarithmic least squares absolute values (Golany and Kress, 1993) and the goal programming method (Wang *et al*., 2008). Mikhailov (2003) used a fuzzy preference programming method for fuzzy judgements after noticing that weakness of other methods in fuzzy AHP, namely: (i) all derive priorities from fuzzy comparison matrices (ii) after fuzzy priorities are obtained then, the final fuzzy scores obtained are also fuzzy (iii) after different kinds of operations in the defuzzification the final fuzzy scores need to be ranked using different methods which could result into different outcomes (Bortolan and Degani, 1985). Srdjevic (2005) proposed a combined method for prioritization which combines methods for AHP and Fuzzy AHP. The only weakness of Srdjevic's method is that the extent analysis method was not included in the combined method.

The study by Leung and Cao (2000) provides a good outline of how consistency and ranking is addressed when using fuzzy AHP. They indicated that is necessary to test for consistency. Saaty and Tran (2007) felt that all judgements before being fuzzified are already fuzzy and they doubted that fuzzification might make judgements more inconsistent.

Fuzzy problem structuring

It is similar to the way it is done in traditional AHP: the unstructured problem and the goal/objectives and the intended outcomes/results are clearly stated. After the problem has been structured into a hierarchy of characteristics, sub-characteristics, attributes and alternatives; the next step is to derive pairwise comparison at each level. AHP does this by crisp pairwise comparisons (i.e. by giving exact value for comparisons) but since it is difficult to capture the vagueness and uncertainty of human evaluations, fuzzy AHP addresses this by using a fuzzy comparison matrix.

The calculation for local priorities must take into account the vagueness nature of human thinking (Mikhailov and Tsvetinov, 2004) therefore, to express the comparison between any two elements at the same level of hierarchy, fuzzy set theory (Zadeh, 1965) or fuzzy numbers are introduced to handle the fuzziness/imprecision/uncertainty of evaluation comparison judgements (Buckely and Pedrycz, 1985).

The fuzzy set is characterized by a membership function, which assigns a value that ranges from 0 and 1to each object (Zadeh, 1965). It differs from a traditional set which defines that an element either belongs or does not belong to a set. The fuzzy triangular membership function defines sets in terms of the centre (b which is a point of maximum membership equivalent to 1) of the triangle and the width of the set. It is formed by two gradients$\left(\frac{\Delta y}{\Delta x}\right)$; *a, b*and *c*, which are equivalent to $(x-a)/(b-a)$ and $(c-x)/(c-b)$ respectively; where *b,a,* and *c* are the mean, the lower bounds and upper bounds, respectively. The fuzzy triangular membership function gives the foundation for defining other types of membership functions such as general triangular function, right-angled triangular function

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and trapezoidal function. For example when *a*=*b*, we can get a right-angled triangular function such as (1, 1, 3) (Csutora and Buckley, 2001) (see Table 1)

Table 1: Membership function for a fuzzy number

Fuzzy number	Membership function
$\tilde{1}$	(1,1,3)
$\tilde{x}$	(x-2,x,x+2) for x = 3, 5, 7
$\tilde{9}$	(7,9,9)

The user compares the characteristics or sub-characteristics or attributes, which are on the same level of the hierarchy, using a crisp value. The inherent subjectivity of the evaluation necessitates the algorithm to change the crisp value the user allocated, to a set of triangular fuzzy numbers (TFNs). By doing so the uncertainty (Zadeh, 1983) of the evaluation judgement from the user (i.e. evaluator) is taken into account. Normal arithmetic operations (like addition, multiplication, division and inverse) can be done on triangular fuzzy numbers **(**Dubois and Prade, 1979; Zhu *et al*., 1999**;** Mikhailov, 2002; Srdjevic, 2005; Bozdag *et al*., 2003, Mikhailov and Tsvetinov, 2004; Mikhailov, 2003).Table 1gives the definitions of the triangular fuzzy numbers of the Saaty scale (1 to 9).The triangular fuzzy numbers are used to make fuzzy judgement matrix (Kwong and Bai, 2002) in order to solve the problem associated with exactor crisp scale used in AHP.

Table 2: Mapping a fuzzy number to a membership function

Linguistic term	Fuzzy number	Membership function
Very poor	$\tilde{1}$	(1,1,3)
Poor	$\tilde{3}$	(1,3,5)
Ordinary	$\tilde{5}$	(3,5,7)
Excellent	$\tilde{7}$	(5,7,9)
Very excellent	$\tilde{9}$	(7,9,9)

To get the membership function of the scale for a triangular fuzzy number is to assume that it is the difference between two consecutive mid-value elements (see Figure 4and Table 2).

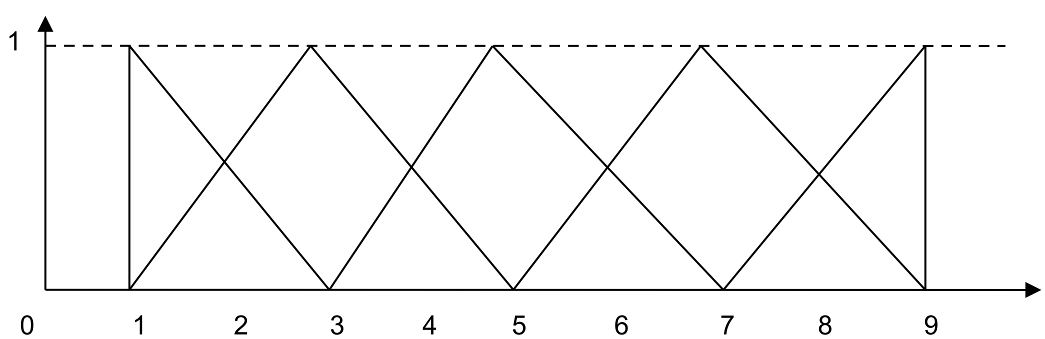

Figure 4: The membership function plot for Table 2

An alternative method is to assume that the difference is 1 (see Table 3 and Figure 5).

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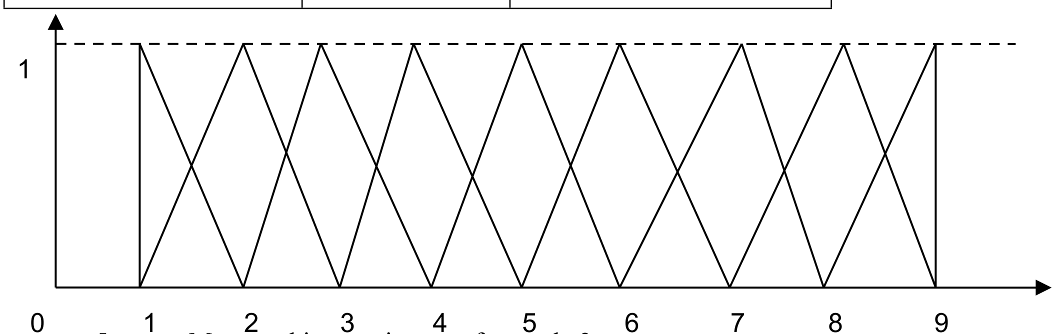
Table 3: Membership function

Linguistic term	Fuzzy number	Membership function
Equally important	$\tilde{1}$	(1,1,2)
Intermediate	$\tilde{2}$	(1,2,3)
Moderately important	$\tilde{3}$	(2,3,4)
Intermediate	$\tilde{4}$	(3,4,5)
Important	$\tilde{5}$	(4,5,6)
Intermediate	$\tilde{6}$	(5,6,7)
Very important	$\tilde{7}$	(6,7,8)
Intermediate	$\tilde{8}$	(7,8,9)
Extremely important	$\tilde{9}$	(8,9,9)



ure 5: Me rship ctior t for le 3

Table 4 shows the conversion of crisp pairwise comparison to a fuzzy pairwise comparison.

Table 4: Mapping crisp pairwise comparisons to fuzzy pairwise comparisons

Crisp (fuzzy singleton) pairwise comparison	Fuzzy pairwise comparison	Crisp (fuzzy singleton) pairwise comparison	Fuzzy pairwise comparison
1	(1,1,3)	1	(1/3,1,1)
3	(1,3,5)	1/3	(1/5,1/3,1)
5	(3,5,7)	1/5	(1/7,1/5,1/3)
7	(5,7,9)	1/7	(1/9,1/7,1/5)
9	(7,9,9)	1/9	(1/9,1/9,1/7)

The conversion scale chosen in mapping exact or crisp scale to fuzzy scale depends on the characteristics of the data.

4.3.2 Fuzzy extent calculation

The basic procedures for fuzzy extent are adopted from Zhu *et al*. (1999).

Let x= $\{x_1, x_2, \ldots, x_n\}$ an object set

G= $\{g_1, g_2, \ldots, g_n\}$ be a goal

M extent analysis on each object is taken

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$M_{gi}^{1}, M_{gi}^{2}, M_{gi}^{3}, \ldots, M_{gi}^{n}$ where i=1,2,3,…,n

Where M_{gi}^{j} (j=1, 2, 3,…, m) all are triangular fuzzy numbers

First procedure: The value of fuzzy synthetic extent with respect to the *i* th object is defined as

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \quad (3)$$

To obtain $\sum_{j=1}^{m} M_{gi}^{j}$, perform the fuzzy addition operation of m extent analysis values for a particular matrix such that:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j , \sum_{j=1}^{m} m_j , \sum_{j=1}^{m} u_j \right) \quad (4)$$

and to obtain $\left[\sum_{j=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1}$, perform the fuzzy addition operation of M^{j}_{gi}*(j = 1, 2, ...,m)* values such that

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i , \sum_{i=1}^{n} m_i , \sum_{i=1}^{n} u_i \right) \quad (5)$$

and then compute the inverse of the vector above, such that:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \quad (6)$$

Second procedure*:* layer simple sequencing

Pair by pair comparison of each block towards the overall goal is done. This gives the sequencing weight vector for each block. This method has a disadvantage of eliminating some useful judgements from user.

According to Bozdag *et al*. (2003) as $\tilde{M}_1 = (l_1, m_1, u_1)$ and $\tilde{M}_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ defined as:

$$V\left(\tilde{M}_2 \geq \tilde{M}_1\right) = \begin{cases} 1, & if \quad m_2 \geq m_1 \\ 0, & if \quad l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \quad (7)$$

This method has a disadvantage of eliminating some useful judgements from user especially when $V\left(\tilde{M}_2 \geq \tilde{M}_1\right) = 0$. But this might be an important feature for the case of researchers who want to isolate some data from a chunk of data in a database.

Third procedure*:* is to normalize the sequencing vector obtained in the above procedure. The result is non-fuzzy number (Zhu *et al*., 1999).

Therefore fuzzy weight performance weight becomes

$$p_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \otimes w_i \tag{8}$$

Then the value of p must be defuzzified for final ranking. There are many methods for this purpose such as the centre of gravity method, the dominance measure method, the alpha cut with synthesis method and the total integral value method. In this study, the total integral value method by Liou and Wang (1992) was adopted.

For example, if the performance matrix is in form of triangular fuzzy numbers (TFNs) $A = (l_1, m_1, u_1)$, the total integral value is defined as:

$$I_T^{\lambda}(A) = (1/2)\big(\lambda u_1 + m_1 + (1-\lambda) l_1\big), \text{ where } \lambda \in (0,1) \tag{9}$$

This expression indicates an optimism index, which expresses the judgement subjectivity (it might be pessimistic, moderate and optimistic views of the evaluator).

Computing Fuzzy Prioritization

Wang and Chin (2008), Zhu *et al*. (1999), Da-Yong Chang (1996) and Bozdag *et al*. (2003) all suggested that fuzzy AHP with extent analysis should be used for the purpose of prioritizing fuzzy judgements. Mikhailov (2003) argued that using extent analysis has drawbacks and suggested that fuzzy preference programming should be used to compute fuzzy prioritization. The characteristics of the method proposed by Mikhailov are: (i) it allows for prioritization from an incomplete set (ii) it is not necessary to construct fuzzy comparison matrices of skewed reciprocal elements; (iii) it uses a max–min optimisation approach; (iv) it can derive crisp priorities no additional ranking procedure is needed; and (v) it can be applied to group decision-making.

The prioritization method used by Srdjevic (2005) was a combination of the traditional AHP and fuzzy AHP methods. Additive normalization, eigenvalue, weight least squares, logarithmic least squares and logarithmic goal programming are the methods used when applying conventional AHP to determine prioritization, while fuzzy preference programming is used in fuzzy AHP. Srdjevic felt that either of these methods could be used for prioritization since the results are almost similar.

The method proposed by Srdjevic (2005) has three steps similar to the normal AHP algorithm, the only difference is the computation of the priority vector. In computation of priority, different prioritization methods are applied and then the comparison between the obtained results is done in order to establish the estimation error (in case of inconsistency judgement matrix). The estimation error shows the deviation of the priority vector from the actual priority vector.

Computing global priorities

The prioritization of aggregated assessments is required in order to rank the alternatives. The commonly used methods for aggregates are the mean, max, min, median, and mixed operators. Instead of computing the geometric mean: the *(a,c)* can be computed. The mean of the fuzzy triangular numbers is where: *c*=Max: maximum of the lower bound in the fuzzy triangular number and *a*=Min: minimum of the lower bound in the fuzzy triangular number.

Chen and Klein (1997) showed methods, which can be used in this procedure, namely: (i)Centre of gravity method;(ii)The dominance measure method; (iii)The $\alpha - cut$ interval synthesis method; and (iv)the total integral value. One of these procedures must be chosen and applied to an evaluation problem to obtain the global priorities, which are used to determine ranking.

The steps of AHP involve first structuring the problem into hierarchy; secondly computing the pairwise comparison matrix to obtain the weight or priority vector and lastly, the overall priority vector is computed (Sanga & Venter, 2009).

The triangular fuzzy numbers (TFNs)take care of the problem of unbalanced scales used in traditional AHP and are used for the fuzzification of the fuzzy crisp pairwise comparison. Fuzzy extent analysis is used to obtain the criteria importance and alternative performances (Zhu *et al*., 1999) and leads to the fuzzy weights. The global priorities, in Fuzzy AHP it is called the integrated fuzzy weight, which is converted into crisp output through defuzzification.

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4.3.3 The implementation of Fuzzy AHP (with extent analysis)

Let the fuzzy pairwise comparison be equal to $\tilde{A}$

$$\tilde{A} = \begin{bmatrix} (a_{11l} a_{11m} a_{11u})(a_{12l} a_{12m} a_{12u}) & \cdots & (a_{1nl} a_{1nm} a_{1nu}) \\ \vdots & \ddots & \vdots \\ (a_{m1l} a_{m1m} a_{m1u})(a_{12l} a_{11m} a_{12u}) & \cdots & (a_{mnl} a_{mnm} a_{mnu}) \end{bmatrix} \quad (1)$$

Fuzzy extent analysis is applied on $\tilde{A}$.

$$x_i or w_j = \frac{\sum_{j=1}^{k} \tilde{a}_i}{\sum_{i=1}^{k} \sum_{j=1}^{k} \tilde{a}_{ij}} \quad (2)$$

where i=1,2,3,…,k

p=1, 2, 3,…, q and k=q

$$x_i = \begin{bmatrix} (a_{11l} a_{11m} a_{11u}) \\ \vdots \\ (a_{i1l} a_{ijm} a_{iju}) \end{bmatrix}$$ where j= number of sub-criteria and number of criteria in the other upper level

$x_i = [(w_{1l} w_{1m} w_{1u})(w_{2l} w_{2m} w_{2u}) \cdots (w_{nl} w_{nm} w_{nu})]$ where n = number of sub-criteria or sub-criteria

Thus a fuzzy weighted performance matrix (p) can be obtained by multiplying the weight vector with the decision matrix

$p = x_i \times w$ where $x_i = s_i$

4.4 Fourth cycle of SSM: Implementation of the proposed algorithm, Group Fuzzy AHP

In the fourth cycle, Group Fuzzy AHP (see 4 in Figure 3) was developed and applied to see if this algorithm could address the concerns of the researcher namely "how to evaluate software efficiently when a group of users does the evaluation and user judgement is uncertain".

Here you need to add the explanation of how the new algorithm (namely Group Fuzzy AHP) was developed.

The Group Fuzzy AHP work similar to Fuzzy AHP (with extent analysis except it has an additional step called 'final assessment'. In it, the results obtained from initial steps are subjected to further testing to measure their pessimistic, moderate and optimistic. This helped to restrict that the fuzzy scale taken as input result into findings which belong to fuzzy value rather than crisp value (GoelS and Rana, 2012). The aim is to find the subjective of the results from the user judgement.

5. RESULTS

The work presented in this paper is a continuation of the paper by Sanga and Venter (2009). In their paper, the AHP was used to aid selection and evaluation of software under certain situation. The results that represented in this paper extend the previous work in evaluation of software under uncertain situation. The basis is how the proposed algorithm could be used in selecting a software product for *usability* and its sub-characteristics (See Figure 4). The software quality characteristics: *maintanability* and *deployability that were also considered in the research* will not be discussed here, but their respective sub-characteristics and attributes can be calculated in a similar fashion.

The evaluators were required to indicate the level of importance of usability and its respective sub–characteristics and attributes and could choose from categories such as: extremely important; very important; important; of little importance; and not important. Different scales were used to convert the user verbal descriptions into numerical values. After a number of trials using different types of scales (such as nominal, interval, ordinal and ratio scales), the Saaty scale (Saaty, 1980) was chosen to translate the data into a format that could be used in the AHP and Fuzzy AHP computations.

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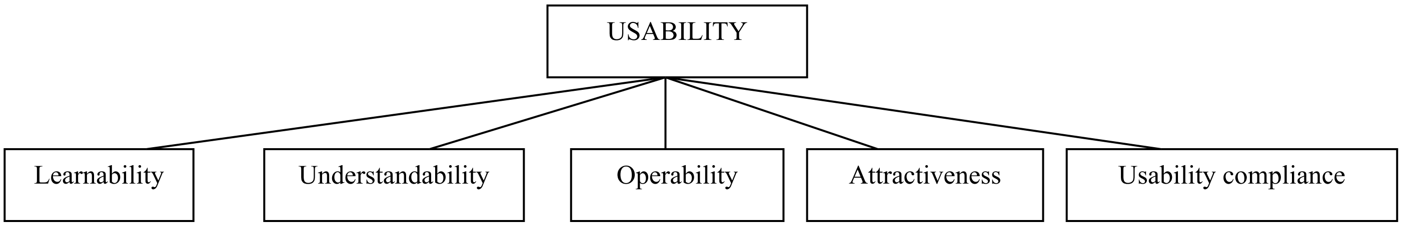

Figure 6: Hierarchical problem structuring of the characteristic: *usability*

5.1 The results of the implementation of Fuzzy AHP (with extent analysis) (Cycle 3 of Figure 3)

5.1.1 The calculation of the pairwise comparison matrix

Saaty scale was used to compare the relative contribution of each sub-characteristic toward the *usability* characteristic.The Saaty expression (Saaty, 1980) was used to get the pairwise comparison table, Table 5).

Table 5: Pairwise comparison matrix

Usability	**Learnability**	**Understandability**	**Operability**	**Attractiveness**	**Usability compliance**
Learnability	1	2	5	3	2
Understandability	0.5000	1	7.0000	3.0000	3.0000
Operability	0.2000	0.1429	1	0.2000	0.2000
Attractiveness	0.3333	0.3333	5.0000	1	3.0000
Usability compliance	0.5000	0.3333	5.0000	0.3333	1

5.1.2 Calculating the normalised pairwise comparison matrix and the weight/priority vector

The normalization matrix was obtained by dividing each element of pairwise comparison matrix by the summation of the column of matrix (see Table 6). The priority vector/weight vector/eigenvector was obtained by computing the row average of the normalized matrix. Saaty expressions (Saaty, 1980) were used.

Table 6: Priority vector

Sub-characteristic	Priority vector
Learnability	0.350549908
Understandability	0.297706658

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Operability	0.041642686
Attractiveness	0.179060114
Usability compliance	0.131040633

5.1.3 Checking for consistency

In traditional AHP, the judgements made by the user are normally checked to find out if they are consistent in order to decide if the priority vector can be accepted. Saaty expressions (Saaty, 1980) were used to calculate the consistency index (CI) which was 0.10819278 and since CI was not equal to zero its consistency ratio (CR) had to be computed (Saaty, 1980).

The CR was found to be 0.096600697, which is less or equal to 0.1 and thus the evaluation judgement is consistent. In practice, if the CR is greater than 0.1 the evaluation judgements must be revised (Finnie *et al*., 1993; Saaty, 1980) - either the calculations must be revisited or the data collection must be done afresh.

5.1.4 Introducing Fuzzy AHP (with extent analysis)

In order to use the proposed fuzzy algorithm, each crisp value shown in the pairwise comparison (Table 5) had to be fuzzified by introducing TFNs (depending on the definitions of the TFNs (see Table 1 to Table 4)).

Table 7: Conversion from crisp values to TFNs

	Learnability	**Under-standability**	**Operability**	**Attractive-ness**	**Usability compliance**
Learnability	(1,1,2)	(1,2,3)	(4,5,6)	(2,3,4)	(1,2,3)
Under-standability	(1/3,1/2,1)	(1,1,2)	(6,7,8)	(2,3,4)	(2,3,4)
Operability	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(1,1,2)	(1/6,1/5,1/4)	(1/6,1/5,1/4)
Attractiveness	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/5,1/6)	(1,1,2)	(2,3,4)
Usability compliance	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/4,1/5,1/6)	(1/4,1/3,1/2)	(1,1,2)

Table 7 shows the results of the fuzzification of crisp judgements using the TFNs (triangular fuzzy numbers) of Table 2 (Zadeh, 1983).

5.1.5 Calculating the Fuzzy Pairwise comparison matrix

In order to obtain the fuzzy pairwise comparison matrix (using the fuzzy extent analysis method), equations1, 2, 3, 4,5, and 6 were applied (Table 8).

Table 8: Fuzzy pairwise comparison

	Lower bound	Mid- value	Upper bound
S1=	9	13	18
S2=	11.333333	14.5	19
S3=	1.625	1.742857143	2.91666667
S4=	3.75	4.866666667	7.16666667
S5=	2.0833333	2.366666667	4.16666667

The pairwise comparison matrix (a, b, c) (see Table 9), is the summation of the elements of Table 8.

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Table 9: Determination of boundary

Lower bound	Mid-value	Upper bound
27.791667	36.47619048	51.25
The reciprocal of the above values are:		
A	B	C
0.0195122	0.027415144	0.03598201

5.1.6 Determining the fuzzy judgement matrix

The pair by pair comparison of the sequencing index, using equation 6, gave the results as depicted in Table 10.

Table 10: Extent analysis

Product of reciprocal and pairwise matrix

	Lower bound	Mid-value	Upper bound
S1	0.1756098	0.356396867	0.64767616
S2	0.2211382	0.397519582	0.68365817
S3	0.0317073	0.047780679	0.10494753
S4	0.0731707	0.133420366	0.25787106
S5	0.0406504	0.064882507	0.14992504

The pair by pair comparison of the sequencing index, using equation 7,gave the Table 11.The table obtained by testing $V\left(\tilde{M}_2 \geq \tilde{M}_1\right)$as per equation 7 and the first column titled comparison was filled. The minimum value in each block (*s1, s2, s3 and s4*) was computed and we got value for the minimum column. After that we calculated the normalization of the four values. The resultant of this process gave the priority vector.

Table 11: Decision analysis

	Comparison	Minimum in each block (weight vector)	Normalization
s1>s2	0.9120672		
s1>s3	1		
s1>s4	1		
s1>s5	1	0.9120672	0.448373
s2>s1	1		
s2>s3	1		
s2>s4	1		
s2>s5	1	1	0.491601
s3>s1	0		
s3>s2	0		
s3>s4	0.2706332		
s3>s5	0.7899011	0	0
s4>s1	0.2694991		
s4>s2	0.1221042		
s4>s3	1		
s4>s5	**1**	0.12210418	0.060026
s5>s1	0		
s5>s2	0		

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s5>s3	1		
s5>s4	0.5282756	0	0

5.1.7 Ranking

AHP ranking using Saaty expressions (Saaty, 1980) (see Table 1).

Table 12: AHP ranking

Sub-characteristic	Priority vector	Ranking
Learnability	0.350549908	1
Understandability	0.297706658	2
Operability	0.041642686	5
Attractiveness	0.179060114	3
Usability compliance	0.131040633	4

Fuzzy AHP (with extent analysis) ranking (see Table 13) was obtained from the decision analysis table (Table 11)

Table 13: Fuzzy AHP (with extent analysis) ranking

Sub-characteristic	Priority vector	Ranking
Learnability	0.448373	2
Understandability	0.491601	1
Operability	0	
Attractiveness	0.060026	3
Usability compliance	0	

The fuzzy extent analysis method for finding the priority/weight vector was criticized by Wang *et al*. (2008), thus to improve the algorithm, the mid value of the fuzzy judgement matrix was used (see Table 14). It was obtained by taking the mid – value of extent analysis of Table 10.

Table 14: Fuzzy judgement

Sub-characteristic	Priority vector	Ranking
Learnability	0.356396867	2
Understandability	0.397519582	1
Operability	0.047780679	5
Attractiveness	0.133420366	3
Usability compliance	0.064882507	4

5.2 The results of the implementation of Group Fuzzy AHP (Cycle 4 of SSM in Figure 3)

The final assessment calculated from the mid-value was determined by applying the total integral of the mid value (equation 9) (Table 15) by adhering to the principle of using a fuzzy number to calculate the assessment. The resultant value is a bell-shaped fuzzy set or convex fuzzy set (Dubois and Prade, 1979). The assessment is a fuzzy sub set and its membership function is clustered around the mean value (or mid value).

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Table 15: Final assessment

Priority vector		
Pessimistic	Moderate	Optimistic
λ =0	λ =0.5	λ = 1
0.266003	0.38402	0.502037
0.309329	0.424959	0.540589
0.039744	0.058054	0.076364
0.103296	0.149471	0.195646
0.052766	0.080085	0.107404

The results presented in Table 15, is an improvement on the results that were obtained by Wang *et al*., (2008) using the mean of the fuzzy judgement. When using the mean, the result in some cases deviates from the real value.

6. DISCUSSION AND CONCLUSION

6.1 Third cycle of SSM: Implementation of Fuzzy AHP (with extent analysis)

The objective of this experiment (see 3 in Figure 3) was to extend the multi-criteria evaluation algorithm, AHP, which is applicable for managing "certain" evaluation judgements, and to imitate the way humans' reason and judge. Human reasoning and judgement during the evaluation of software is subjective and could be said to be "uncertain". Thus, algorithms that could deal with the uncertainty of human judgements would be an improvement on AHP. It was felt that fuzzy logic combined with the AHP algorithm, could compensate for the weakness of AHP. The algorithm was developed and implemented and the findings of the Fuzzy AHP (with extent analysis) and the findings of AHP, were compared. The developed Fuzzy AHP (with extent analysis) does not discard priority weights (of the characteristics, sub-characteristics and attributes) with low numerical values (i.e. ratings).

Although the results were almost similar, it was felt that Group Fuzzy AHP would be an improvement on Fuzzy AHP (with extent analysis) since it is simple and has less computations. Apart from these mentioned advantages, Group Fuzzy AHP has those advantages of AHP (Sanga & Venter, 2009). The reason for this is that Group Fuzzy AHP is based on principles of AHP. Thus the advantages of Group Fuzzy AHP includes: it is easily understood and flexible, it integrates deductive approaches, it acknowledges interdependence of elements of software systems, it has a hierarchical structure, measures intangibles, tracks logical consistency, gives an overall estimation, consider relative priorities and improve judgements.

6.2 Fourth cycle of SSM: Implementation of the proposed algorithm, Group Fuzzy AHP

In the fourth cycle, Group Fuzzy AHP (see 4 in Figure 3) was developed and applied to see if this algorithm could address the concerns of the researcher namely "how to evaluate software efficiently when a group of users does the evaluation and user judgement is uncertain".

The results of Fuzzy AHP with extent analysis are quite different from that of conventional AHP. But if the mid – value of fuzzy judgement matrix is taken, the ranking obtained is almost similar to that of Fuzzy AHP. The sum of the medium values equals to 1 and thus, it has reduced uncertainty in evaluation judgements.

The above results show the strength of the proposed algorithm but in future studies more analysis of it is needed. This will make the authors to be in a position of stating whether the algorithm is different, new, or better than the existing one.

Currently, it has been found to be simple to use, efficient, and reduces number of pairwise comparisons needed. Therefore it is feasible for even large number of criteria (where other algorithms have difficulties as observed by Wang *et al*., 2008). With the proposed algorithm, more research work is needed in future studies to detect inconsistent judgement. It seems there is preservation of rank that is to say if sensitivity analysis is done by changing the weight there is a possibility of preserving the rank.

Another noble characteristic of the proposed algorithm is the use of total integral value (Table 15 and equation 9) to assess the ranking of global priorities. This concurs with the observation by Somerville (2001, p. 522) who concluded in his algorithmic cost estimation model under uncertainty that

> *"the estimator should develop a range of estimates (worst, expected and best) rather than a single estimate".*

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Algorithmic cost estimation model predicts cost of software during development, which exhibits this similar feature to the proposed algorithm.

The proposed algorithm adds knowledge to the field of computational intelligence and software metrics. The study contributes to the theory, methodology and application of computational intelligence. The application of the proposed algorithm is in the development of intelligent decision support systems (DSS) for software evaluations in "uncertain" situations.

Further cycles of the experiment (see Figure 3) could be added to address the weakness of Group Fuzzy AHP by comparing it with other algorithms as recommended by Levitin and Saaty (Levitin, 2003; Saaty, 1980). The comparison should be in terms of the followingfeatures, namely: (i) consistency checking, (ii) comparing the correctness of the outcome, (iii) comparison of the time efficiency (or time complexity) of the algorithms, (iv)comparison of space efficiency, (v) determining its simplicity, and (vi) generalising the algorithms. This is one of the areas proposed for future study.

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