Application of Fuzzy Analytic Hierarchy Method in Software Engineering Scenario

Hota H.S.
Assistant Professor, GGV, Bilaspur (C.G.), India

Sanjay Kumar Singhai, PhD.
Associate Professor Govt. Engineering College Bilaspur (C.G.), India

Ragini Shukla
Assistant Professor, Dr. C.V. Raman University, Kargi Road Kota, Bilaspur (C.G.), India

ABSTRACT

In software engineering scenario, software effort estimation is very uncertain and depends on various external factors .For developing a particular type of software, selection of an optimal and experienced group of developer is essential for software development organization for organizational benefits and is necessary because success and failure of software is highly depends upon experienced team members, but it is not always possible to schedule a suitable team of developer for a specific type of software development from a group of developer ,hence there should be a technique to form a group of developer for specific type of software development for cost effective reason.

In this paper multi criteria decision making (MCDM) based fuzzy analytical hierarchy process is applied for formation or selection of software developer team. Fuzzy AHP is a ranking based optimization technique, which decides ranking among various alternatives based on conflict nature of criteria. Three different criteria from COCOMO effort estimation model are considered to decide ranking of three programmers. This technique can be applied for more number of criteria and alternative in real sense in software development scenario.

Keywords

Fuzzy analytic hierarchy process (FAHP), Analytic hierarchy process, Software Engineering, COCOMO model

1. INTRODUCTION

Most of the software fails during the development and even after development and not delivered in stipulated time period, which may creates problem for software development organization in context of their reputation and reliability in IT industry. Selection of various resources required to develop software in optimal manner is very essential to avoid all these problems. Optimal resource allocation for a specific type of software project is a challenging task to minimize the software development cost and hence to deliver software product to the client well in advance. Many resources like technical resources: hardware, software and most essentially human resources are necessary to assign in optimal manner. These resource allocation may be based on expertise or heuristic manner, which sometimes fails due to uncertainty involved, hence multi criteria decision making(MCDM) based method: Fuzzy AHP can be used for human resource allocation for a particular type of software project.

Very few literatures are available on this topic Santanu ku. Mishra)[1] and et.al has applied fuzzy AHP and byasian technique for programmer selection. However other researchers have applied fuzzy AHP method and other MCDM methods for selection purpose. Sumeet Kaur Mishra and et.al [2] has also used MCDM approach for selection of effort estimation model based on four criteria: reliability, MMRE, percentage prediction and uncertainty for various models suggest by various scientist as alternatives. Results has been compared with AHP and it was found that algorithmic model has highest weight value as compare to other models like expert judgment based model and non algorithmic model.

This paper extends and explores the work all ready done by santanu ku. Mishra [1] and et.al.in special reference to COCOMO’s effort multiplier as criteria of programmers to be selected for forming project team. COCOMO model is one of the very popular effort estimation model based on 17 effort multipliers. These multipliers are quantitative as well qualitative, some of the multiplier are related to technical while other are related to quality of software developer. Quantitative data can be represented well using fuzzy logic, hence fuzzy logic based MCDM method[14]: Fuzzy AHP is well suited for this, Fuzzy AHP method with three different criteria of COCOMO model is considered just for demonstration purpose to select developers from a group of programmer. Work can be extended in real sense in software engineering scenario with more number of alternative and criteria.

2. MULTICRITERIA DECISION MAKING (MCDM) METHOD

Multi criteria decision making is a method to deal with the process of making decision among number of alternatives with conflicting criteria on them . AHP is one of the very popular MCDM method and fuzzy AHP is an extension of original AHP method suggested by saaty[12] to deal with qualitative and quantitative data. We will explain AHP first then fuzzy AHP will be explained in section 2.1 and 2.2 respectively.

2.1 Analytic Hierarchy Process (AHP)

One of the most popular analytical techniques for complex decision-making problem is the analytic hierarchy process(AHP).Analytic Hierarchy Process (AHP) proposed by Saaty(1980,2000)[16], is an approach for decision making that involves structuring multiple choice criteria into a hierarchy, assessing the relative importance of these criteria, comparing alternatives for each criterion, and determining an overall ranking of the alternatives.

An AHP hierarchy can have as many levels as needed to fully characterized particular decision situation. A number of functional characteristics make, AHP a useful methodology.

So the AHP is most highly regarded and widely used decision making method. It can efficiently deal with tangible (i.e. objective) as well as non-tangible (i.e. subjective) attributes[7].

The main procedure of AHP using the radical root method (also called the geometric mean method)is as follows[7]:-

Step *1*: Determine the objective and the evaluation attributes.

Step *2*: Determine the relative importance of different attributes with respect to the goal or objective.

- Construct a pair-wise comparison matrix using a scale of relative importance. The judgments are entered using the fundamental scale of the analytic hierarchy process. An attribute compared with itself is always assigned the value 1, so the main diagonal entries of the pair-wise comparison matrix are all 1 and the rating as based on Saaty's nine point scale shown in table 1.

TABLE 1: SAATY'S NINE POINT SCALE

Compared to 2nd alternative, the 1st alternative is	Numerical rating
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Intermediate judgment between two adjacent judgment	2, 4,6,8

- Assuming M attributes, the pair–wise comparison of attribute *i* with attribute *j* yields a square matrix $B_{M\times M}$ where a_{ij} denotes the comparative importance of attribute *i* with respect to attribute *j*. In the matrix b_{ij}=1 when *i*=*j* and $b_{ji}=\frac{1}{b_{ij}}$.
- Find the relative normalized weight (w_j) of each attribute by -

  (i) Calculating the geo metric mean of the *i-th* row, and

  (ii) Normalizing the geo metric means of rows in the comparison matrix. This can be represented as:-$GM_j = \left[\prod_{i=1}^{M} b_{ij}\right]^{1/M} \ and \ w_j = {GM_j}\Big/{\sum_{i=1}^{M} GM_j}$

- Calculate matrices A3 and A4 such that

  A3=A1×A2 eq (1)

  and A4= A3/A2, eq (2)

  where A2=$[w_1,w_2,\ldots\ldots.,w_i]^T$.

- Determine the maximum Eigen value λ_{max} that is the average of matrix A4.
- Calculate the consistency index CI=${(\lambda_{max} - M)}\Big/{(M-1)}$.
- Obtain the random index (RI) for the number of attributes used in decision making.
- Calculate the consistency ratio CR =CI/RI. Usually, a CR of 0.1 or less is considered as acceptable and is reflects an informed judgment attributable to the knowledge of the analyst regarding the problem understudy.

Step 3: The next step is to compare the alternatives pair-wise with respect to how much better they are in satisfying each of the attributes, i.e., to ascertain how well each alternative serves each attribute.

Step 4: The next step is to obtain the overall or composite performance scores for the alternatives by multiplying the relative normalized weight (wj) of each attribute (obtain in step two) with its corresponding normalized weight value for each alternative (obtain in step three) and summing over the attributes for each alternative.

2.2 Fuzzy Analytic Hierarchy Process (FAHP) Method:

The FAHP[13] method is an advanced analytical method which is developed from the AHP. In spite of the popularity of AHP, this method is often criticized for its inability to adequately handle the inherent uncertainty and imprecision associated with the mapping of the decision-maker's perception to exact numbers. In FAHP method, the fuzzy comparison ratios are used to be able to tolerate vagueness [3]. There is a problem with AHP that in some situations, Decision maker wants to use the uncertainty while performing the comparisons of the alternatives. For taking uncertainties into consider ration fuzzy numbers are used instead of crisp numbers [1].

The method proposed by Chen and Hwang (1992)[7] first converts linguistic terms into fuzzy numbers and then the fuzzy numbers into crisp scores. The method is described as below-

2.2.1 Converting Linguistic terms to fuzzy numbers:- This method systematically converts linguistic term into their corresponding fuzzy numbers. It contains eight conversion scales. The conversion scales were proposed by synthesizing and modifying the works of Wenstop(1976), Bass and Kwakernaak(1977),Efstathiou and Rajkovic (1979),Kerre (1982) and Chen (1988).

2.2.2 Converting Fuzzy Numbers to Crisp Scores:- The method uses a fuzzy scoring approach that is a modification of the fuzzy ranking approaches proposed by Jain(1976) and Chen(1985).The crisp score of fuzzy number 'M' is obtained as follows:

$$\mu_{max}(x) = \begin{cases} x, 0 \le x \le 1 \\ 0, otherwise \end{cases}$$

$$\mu_{min}(x) = \begin{cases} 1-x, 0 \le x \le 1 \\ 0, otherwise \end{cases}$$

The fuzzy max and fuzzy min of fuzzy numbers are defined in a manner such that absolute location of fuzzy numbers can be automatically incorporated in the comparison cases. The right score of each fuzzy number M_i is defined as:-

$$\mu_R(M_1) = Sup[\mu_{max}(x) ^\wedge \mu_{M1}(x)]$$

And the left score is-

$$\mu_L(M_1) = Sup[\mu_{min}(x) ^\wedge \mu_{M1}(x)]$$

The total score of a fuzzy number M_i is defined as:-

$$\mu_T(M_1) = [\mu_R(M_1) + 1 - \mu_L(M_1)]/2$$

2.2.3 Demonstration of the method:- Now, the 5-point scale is considered to demonstrate the conversion of fuzzy number into crisp scores. To demonstrate the method, a 5-point scale having the linguistic terms like low, below average, average, above average and high as shown in figure 1 is considered.

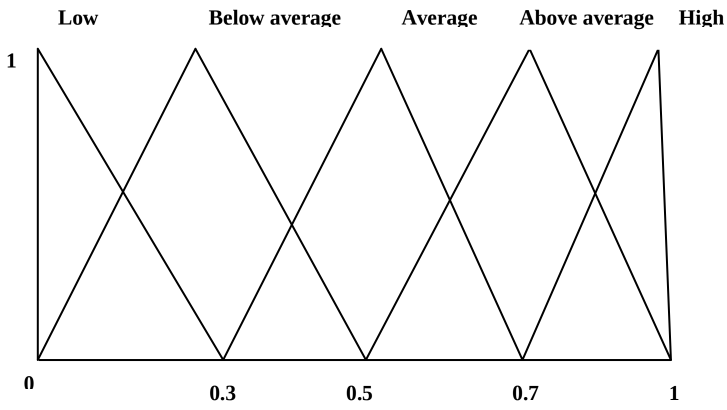

Figure 1:-Fuzzification of linguistic terms to fuzzy numbers conversion

TABLE 2: LINGUISTIC TERMS TO FUZZY NUMBERS CONVERSION

Linguistic Terms	Fuzzy Number
Low	M_1
Below average	M_2
Average	M_3
Above average	M_4
High	M_5

From figure 1,membership function of M_1,M_2,M_3,M_4 and M_5 are written as:

$$\mu_{M1}(x) = \begin{cases} 1, x = 0 \\ \dfrac{(0.3 - x)}{(0.3)}, 0 \le x \le 0.3 \end{cases}$$

$$\mu_{M2}(x) = \begin{cases} \dfrac{(x - 0)}{(0.25)}, 0 \le x \le 0.3 \\ \dfrac{(0.5 - x)}{(0.25)}, 0.25 \le x \le 0.5 \end{cases}$$

$$\mu_{M3}(x) = \begin{cases} \dfrac{(x - 0.3)}{(0.2)}, 0.3 \le x \le 0.5 \\ \dfrac{(0.7 - x)}{0.2}, 0.5 \le x \le 0.7 \end{cases}$$

$$\mu_{M4}(x) = \begin{cases} \dfrac{(x - 0.5)}{(0.25)}, 0.5 \le x \le 0.75 \\ \dfrac{(1.0 - x)}{0.25}, 0.75 \le x \le 1.0 \end{cases}$$

$$\mu_{M5}(x) = \begin{cases} \dfrac{(x - 0.7)}{(0.3)}, 0.7 \le x \le 1.0 \\ 1, x = 1 \end{cases}$$

The right, left and total scores are computed as follows for M_1:-

$$\mu_R(M_1) = Sup[\mu_{max}(x)\wedge \mu_{M1}(x)] = 0.23,$$

$$\mu_L(M_1) = Sup[\mu_{min}(x)\wedge \mu_{M1}(x)] = 1$$

$$\mu_T(M_1) = [\mu_R(M_1) + 1 - \mu_L(M_1)]/2 = 0.115$$

Similarly, the right, left and total scores are computed for M2,M3, M4 and M5 and are tabulated in table 3 and table 4.

TABLE 3: MEMBERSHIP FUNCTION OF M_1,M_2,M_3,M_4,M_5

I	$\mu_R(M_1)$	$\mu_L(M_1)$	$\mu_T(M_1)$
1	0.23	1.0	0.115
2	0.39	0.8	0.295
3	0.58	0.59	0.495
4	0.79	0.4	0.695
5	1.0	0.23	0.895

TABLE 4: LINGUISTIC TERMS WITH THEIR CORRESPONDING CRISP SCORES

Linguistic Term	Fuzzy Number	Crisp Score
Low	M_1	0.115
Below average	M_2	0.295
Average	M_3	0.495
Above average	M_4	0.695
High	M_5	0.895

Instead of assigning arbitrary values for various attributes, this fuzzy method reflects the exact linguistic descriptions in terms of crisp scores. Hence, it gives better approximations that are widely used.

3. SOFTWARE ENGINEERING SCENARIO

The Constructive Cost Model (COCOMO) [10] is a well known model in software engineering scenario. Which is developed by Barry W. Boehm. Effort multipliers for the COCOMO model are considered here for the selection of programmers for software development. Out of 17 multipliers 3 multipliers : APEX-Application Experience, PLEX-Platform Experience, LTEX-Language and tool experience are considered as criteria for the FAHP method[11].

Figure 2 shows hierarchy of programmer selection in which root of the hierarchy is the most general objective (Goal) of the problem such as the objective of making the best decision or selecting the best alternative. Second level of the hierarchy consists: three effort multipliers of COCOMO model as quality of programmer while leaf level represents alternatives.

In order to apply FAHP method for programmer selection for specific software project let us follow the following steps:

Step 1: A decision making matrix(DMM)[15] based on above criteria with three fuzzy linguistic terms as shown in fig.1 with three different alternatives is shown in table 5. Where P1,P2 and P3 represent programmer1,programmer2 programmer3 respectively.

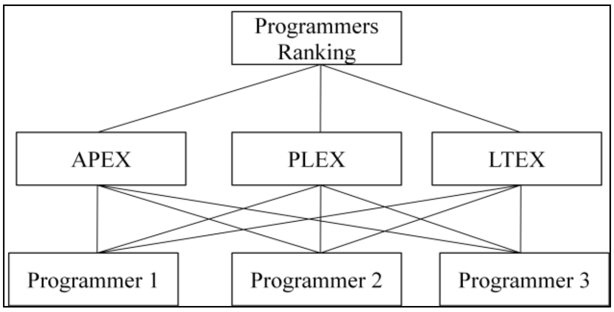

Fig 2:-Hierarchical threshold levels

TABLE 5:DECISION MAKING MATRIX

Programmer	APEX	PLEX	LTEX
P_1	High	Average	Average
P_2	Average	Low	High
P_3	Low	High	Average

Instead of 5-point scale as explained above we have considered here 3-point scale for conversion of fuzzy linguistic term into crisp scores.Here we have used only 3-point scale having the linguistic terms like low, average and high as shown in table 5.

From the above described Chen and Hwang (1992) method :-(From table 4)

TABLE 6 : THE CONVERSION OF LINGUISTIC TERM IN TO CRISP SCORES(3 POINT SCALE):-

Linguistic Term	Fuzzy Number	Crisp Score
Low	M_1	0.115
Average	M_3	0.495
High	M_5	0.895

Fuzzy linguistic term of table 5 in converted into crisp data using 3 point scale as shown in table 6 and depicted in table 7.

TABLE 7:CONVERSION OF FUZZY LINGUISTIC TERM INTO CRISP DATA

Programmers	APEX	PLEX	LTEX
P_1	0.895	0.495	0.495
P_2	0.495	0.115	0.895
P_3	0.115	0.895	0.495

Step 2:- Now in this step we compare criteria with criteria by assigning comparative weights from Saaty's[7] nine point scale as shown in table 1 by applying heuristic knowledge in these domain.

So the Relative Importance Matrix can be written as:-

$$\begin{array}{c} \\ APEX \\ PLEX \\ LTEX \end{array} \begin{bmatrix} APEX & PLEX & LTEX \\ 1 & 5 & 3 \\ 1/5 & 1 & 1/2 \\ 1/3 & 2 & 1 \end{bmatrix}$$

Now calculating Geometric mean (GM) for i^{th} row:- $GM_1=(1\times5\times3)^{1/3}$ = 2.4659 , $GM_2=(1/5\times1\times1/2)^{1/3}$ = 0.4641 and $GM_3=(1/3\times2\times1)^{1/3}$ = 0.873,

Total Geometric mean GM=3.79

Hence the Normalized weights are: W_1 = 2.46/3.79 = 0.649,W_2 = 0.46/3.79 = 0.121 and W_3= 0.87/3.79 = 0.229

Now Consistency checking by using following equations below:

$A_3=A_1\times A_2$

So the $A_3= \begin{bmatrix} 1 & 5 & 3 \\ 1/5 & 1 & 1/2 \\ 1/3 & 2 & 1 \end{bmatrix} \times \begin{bmatrix} 0.649 \\ 0.121 \\ 0.229 \end{bmatrix} = \begin{bmatrix} 1.914 \\ 0.36 \\ 0.678 \end{bmatrix}$

And $A_4 = A_3/A_2$

$A_4 = \begin{bmatrix} 1.914 \\ 0.36 \\ 0.678 \end{bmatrix} \div \begin{bmatrix} 0.649 \\ 0.121 \\ 0.229 \end{bmatrix} = \begin{bmatrix} 2.949 \\ 2.975 \\ 3.0818 \end{bmatrix}$

And maximum value λ_{max} that is the average of matrix A_4 will be

$\lambda_{max} = \frac{2.949+2.975+3.0818}{3}$ = 3.001

Then Consistency Index (CI) = $\frac{(\lambda_{max}-n)}{n-1} = \frac{3.001-3}{2}$ = 0.0005

And Consistency Ratio (CR) = $\frac{CI}{RI} = \frac{0.0005}{0.52}$ = 0.00096<0.1

Hence the weights are consistent.

Step 3:- Now alternatives will be compared with alternatives for all the three criteria known as pair-wise comparison matrix. Three pair-wise comparison matrices are shown below:-

(i) Pair wise comparison matrix for criteria APEX

$$\begin{array}{c} \\ Prog1 \\ Prog2 \\ Prog3 \end{array} \begin{bmatrix} Prog1 & Prog2 & Prog3 \\ 1 & 0.495 & 0.895 \\ 1/0.495 & 1 & 0.895 \\ 1/0.895 & 1/0.895 & 1 \end{bmatrix}$$

Now calculating Geometric mean (GM) for i^{th} row:-
$GM_1=(1\times0.495\times0.895)^{1/3}$=0.7623
,$GM_2=(1/0.495\times1\times0.895)^{1/3}$=1.2182 and
$GM_3=(1/0.895\times1/0.895\times1)^{1/3}$ =1.0767,

Total Geometric mean=3.05

Hence the Normalized weights are: W_1 = 0.7623/3.05 =0.249, W_2 = 1.2182/3.05 = 0.398 and W_3= 1.0767/3.05 = 0.352

Now Consistency checking by using equations (1) and(2) as below:-

So the

$$A_3 = \begin{bmatrix} 1 & 0.495 & 0.895 \\ 1/0.495 & 1 & 0.895 \\ 1/0.895 & 1/0.895 & 1 \end{bmatrix} \times \begin{bmatrix} 0.249 \\ 0.398 \\ 0.352 \end{bmatrix} = \begin{bmatrix} 0.7614 \\ 1.2167 \\ 1.0752 \end{bmatrix}$$

$$\text{And } A_4 = \begin{bmatrix} 0.7614 \\ 1.2167 \\ 1.0752 \end{bmatrix} \div \begin{bmatrix} 0.249 \\ 0.398 \\ 0.352 \end{bmatrix} = \begin{bmatrix} 3.074 \\ 3.005 \\ 3.053 \end{bmatrix}$$

And maximum value λ_{max} that is the average of matrix $A_{4:}$-

$$\lambda_{max} = \frac{3.074+3.005+3.053}{3} = 3.044$$

Then CI = $\frac{(\lambda_{max} - n)}{n-1} = \frac{3.044-3}{2} = 0.022$

And CR = $\frac{CI}{RI} = \frac{0.022}{0.52} = 0.04 < 0.1$

Hence the weights are consistent.

(ii)Pair wise comparison matrix for criteria PLEX

$$\begin{array}{c} Prog1 \\ Prog2 \\ Prog3 \end{array} \begin{bmatrix} Prog1 & Prog2 & Prog3 \\ 1 & 0.895 & 0.115 \\ 1/0.895 & 1 & 0.115 \\ 1/0.115 & 1/0.115 & 1 \end{bmatrix}$$

Now calculating Geometric mean (GM) for i^{th} row:- $GM_1=(1\times0.895\times0.115)^{1/3}$=0.4686, $GM_2=(1/0.895\times1\times0.115)^{1/3}$=0.50464and $GM_3=(1/0.115\times1/0.115\times1)^{1/3}$ =4.2280,

Total Geometric mean=5.2012

Hence the Normalized weights are:W_1 = 0.4686/5.2012=0.090, W_2 = 0.50464/5.2012 = 0.0970 and W_3= 4.2280/5.2012= 0.81288

Now Consistency checking by using equations (1) and (2) as below:-

So the

$$A_3 = \begin{bmatrix} 1 & 0.895 & 0.115 \\ 1/0.895 & 1 & 0.115 \\ 1/0.115 & 1/0.115 & 1 \end{bmatrix} \times \begin{bmatrix} 0.090 \\ 0.0970 \\ 0.812 \end{bmatrix} = \begin{bmatrix} 0.2701 \\ 0.2908 \\ 2.438 \end{bmatrix}$$

$$\text{And } A_4 = \begin{bmatrix} 0.2701 \\ 0.2908 \\ 2.438 \end{bmatrix} \div \begin{bmatrix} 0.090 \\ 0.0970 \\ 0.812 \end{bmatrix} = \begin{bmatrix} 3.001 \\ 2.997 \\ 3.002 \end{bmatrix}$$

And maximum value λ_{max} that is the average of matrix A_4 :-

$$\lambda_{max} = \frac{3.001+2.997+3.002}{3} = 3$$

Then CI = $\frac{(\lambda_{max} - n)}{n-1} = \frac{3-3}{2} = 0$

And CR = $\frac{CI}{RI} = \frac{0}{0.52} = 0 < 0.1$

Hence the weights are consistent.

(iii)Pair wise comparison matrix for criteria LTEX

$$\begin{array}{c} Prog1 \\ Prog2 \\ Prog3 \end{array} \begin{bmatrix} Prog1 & Prog2 & Prog3 \\ 1 & 0.495 & 1 \\ 1/0.495 & 1 & 0.895 \\ 1 & 1/0.895 & 1 \end{bmatrix}$$

Now calculating Geometric mean (GM) for i^{th} row:- $GM_1=(1\times0.495\times1)^{1/3}$=0.7910, $GM_2=(1/0.495\times1\times0.895)^{1/3}$=1.2182 and $GM_3=(1\times1/0.895\times1)^{1/3}$=1.0376,

Total Geometric mean=3.0468

Hence the Normalized weights are:-W_1 = 0.7910/3.0468 = 0.2596, W_2 = 1.2182/3.0468 = 0.3998 and W_3= 1.0376/3.0468 = 0.3406

Now Consistency checking by using equations (1) and (2) as below:-

$$\text{So the } A_3 = \begin{bmatrix} 1 & 0.495 & 1 \\ 1/0.495 & 1 & 0.895 \\ 1 & 1/0.895 & 1 \end{bmatrix} \times \begin{bmatrix} 0.2596 \\ 0.3998 \\ 0.3406 \end{bmatrix} = \begin{bmatrix} 0.7981 \\ 1.229 \\ 1.0469 \end{bmatrix}$$

$$\text{And } A_4 = \begin{bmatrix} 0.7981 \\ 1.229 \\ 1.0469 \end{bmatrix} \div \begin{bmatrix} 0.2596 \\ 0.3998 \\ 0.3406 \end{bmatrix} = \begin{bmatrix} 3.0743 \\ 3.0740 \\ 3.0736 \end{bmatrix}$$

And maximum value λ_{max} that is the average of matrix A_4 :-

$$\lambda_{max} = \frac{3.0743+3.0740+3.0736}{3} = 3.073$$

Then CI = $\frac{(\lambda_{max} - n)}{n-1} = \frac{3.073-3}{2} = 0.036$

And CR = $\frac{CI}{RI} = \frac{0.036}{0.52} = 0.070 < 0.1$

Hence the weights are consistent.

Step 4:-A matrix is formed with the help of obtained weights in case of pair-wise comparison matrix for three different criteria as calculated in step 3 is :-

$$\begin{bmatrix} 0.2493 & 0.090 & 0.2596 \\ 0.3984 & 0.0970 & 0.3998 \\ 0.3521 & 0.8128 & 0.3406 \end{bmatrix}$$

So the final rank can be obtain the overall or composite performance scores for the alternatives are:-

$$\begin{bmatrix} 0.2493 & 0.090 & 0.2596 \\ 0.3984 & 0.0970 & 0.3998 \\ 0.3521 & 0.8128 & 0.3406 \end{bmatrix} \times \begin{bmatrix} 0.649 \\ 0.121 \\ 0.229 \end{bmatrix} = \begin{bmatrix} 0.2319 \\ 0.3617 \\ 0.4047 \end{bmatrix}$$

Deciding the rank according to the higher value of above matrix, hence ranking is P_3, P_2 and P_1.

4. CONCLUSION

Decision making is very necessary for various problems and becomes tedious and difficult if the qualities of the alternatives are conflicting. A suitable method can be applied to deal this type of problem. Multi criteria decision making methods are widely used to solve this type of problem. Criteria of alternatives may be quantitative and qualitative based on these a suitable MCDM method like fuzzy AHP is applied in this piece of research work. This method is applied for selection and to decide ranking of software developer (Programmer) based on COCOMO's effort multiplies as criteria of developers .Experiment is done on sample data set with only three alternatives and three criteria and the ranking decided by FAHP method is P3,P2 and P1.In future FAHP and other fuzzy MCDM methods can be applied for all the multipliers of COCOMO model to stabilize a model for software developer selection in real sense of software engineering scenario.

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