IJCSE International Journal of Computer Sciences and Engineering Open Access
Research Paper Vol.-7, Issue-4, April 2019 E-ISSN: 2347-2693

Software Dependability Estimation: Implementation through Fuzzy AHP

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DOI: https://doi.org/10.26438/ijcse/v7i4.18 | Available online at: www.ijcseonline.org

Accepted: 11/Apr/2019, Published: 30/Apr/2019

***Abstract* -** Achieving dependability has always been a challenging task for the software developers. Ensuring the selection of suitable dependability attributes for the software development is crucial for the development of dependable software and to maintain trust among software developers. For multi criteria decision making a very helpful tool is identified called Fuzzy Analytic Hierarchy Process (FAHP). For the comparison of different factors and sub-factors (attributes) and to know the impact of one factor over the other the FAHP has been identified by researchers. The main objective of this paper is to implementation of Fuzzy Analytic Hierarchy Process for the estimation of software dependability, By which we can identify the most suitable dependability attributes and ranked them as per their weight-ages. The Fuzzy Analytic Hierarchy Process uses a defined range of values rather than a single crisp value to vanish the decision maker's uncertainty. Using the definite range of values, the decision makers can choose the value that shows his confidence and also they can specify their stance like optimistic, pessimistic or moderate. This paper reveals the implementation of Fuzzy AHP technique to calculate the weight-ages of dependability attributes and ranked them. This study can be a guide of the methodology to be implemented by software developers for the selection of appropriate dependability factors and sub-factors for the development of dependable software.

Keywords: Software Dependability; Dependability Factors; Dependability Sub-Factors (Attributes); AHP; FAHP.

I.INTRODUCTION

The approach for the selection of software dependability factors and sub-factors has been a critical matter in the research of software engineering for a long time, and it is mainly because of the importance of dependability in software development [1]. The consideration of dependability and its different factors and sub-factors is required, at the same time in most of the software design and development problems and it is depend on the individual judgments made by experts in the field of software engineering [2]. For the selection of suitable factor according to the problem, the analytic hierarchy process (AHP) technique is widely used and accepted in cases of decision-making from 1980, when Thomas Saaty introduced this technique [3]. After the evolution of fuzzy set theory, a derivative of AHP known as Fuzzy AHP which is drived by combining the principles of fuzzy set theory with the AHP technique. The aim behind the development of fuzzy AHP is to deal with the uncertainty and fuzziness, which arises when the decision makers select a value from a given fundamental scale of 1 to 9 [4], [5].

To reflect the improbability, the judgment makers require more supple scales by using fuzzy functions and variables, e.g. good ,poor or moderate, rather than using a single crisp values [6]. Similarly as conventional AHP technique, this technique has also been applied to the many areas of the engineering industry [7]. As per our literature survey, it is found that, the fuzzy AHP was never been used in the area of software dependability and we choose fuzzy AHP among all other multi criteria decision making techniques due to the fact that it is more advantageous to provide flexible scales from fuzzy membership functions [8]. The method has been implemented successfully to calculate priority weights in various decision-making problems [9].

Although after the increasing popularity of the fuzzy AHP, a little research has been performed with respect to the software dependability, for calculating priority weight of factors and sub-factors by this approach, called fuzzy AHP [10],[11]. Therefore, the main focus of this paper is on the calculation of weight-ages of factors and sub-factors of software dependability. The results of priority weights obtained from this empirical study would show the path to the professionals associated with software design and development by which they can give priorities to the factors and sub-factors as per the requirement of the project. In this paper we use the fuzzy AHP for the implementation of software dependability estimation.

II. METHODOLOGY

The problem should be expressed clearly and the hierarchy of problem must be defined. The structure can be determined using any of appropriate method. In this paper we put the problem at the top which is dependability estimation [12], the software dependability factors and the sub factors at the base. Sub factors are the attributes of software dependability and the factors are the nature of dependability attributes.

A. Hierarchy for Software Dependability:

The construction of the problem hierarchy is a crucial phase, which is common to both FAHP and AHP techniques. The construction of the hierarchy is very helpful for the researches to understand the problem.

The hierarchy for the priority evaluation of the software dependability attributes (sub factors) is structured as per the three factors which are preventive, behavioral and functional [1].

Figure 1 describes the hierarchy of this problem in which the objective is at the top followed by the factors and then the sub factors for the estimation of priorities. The present hierarchy has a top to bottom flow.

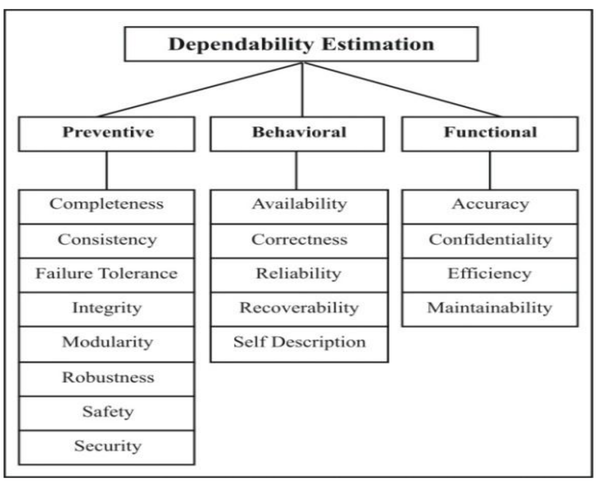

Figure 1: Detail hierarchy of the dependability estimation

As we discussed in the above sections that, the decision making process is relatively more explicitly defined by the fuzzy AHP. That is the reason why, the fuzzy AHP approach given by [13],[14] is used in this paper and all the major steps are discussed below:

B. Establishing Triangular Fuzzy Numbers (TFN):

As per the definition a triplet (L, M, S) is known as Triangular Fuzzy Number, where "L" represents largest likely value, "M" represent the most probable value, and "S" represent the smallest possible value, that describes the fuzzy number set. The triangular fuzzy numbers T_{ij} are calculated using following formula:

$T_{ij} = (L_{ij}, M_{ij}, S_{ij})$

$S_{ij} \leq M_{ij} \leq L_{ij}$ and $L_{ij}, M_{ij}, S_{ij} € [9, 1/9]$

S_{ij}= min (Jije);

$$M_{ij} = \sqrt[n]{\prod_{e=1}^{n} J_{ije}}$$

S_{ij}= max (Jije)

Here Jije represents the judgment of experts e.

C. Establishing Fuzzy Pair-Wise Comparison Matrix and Defuzzification:

Here we adopted the defuzzification method derived by Liou and Wang [15], to express the fuzzy perception the following formula is given:

$u_{\alpha,\beta} (\tilde{a}_{ij}) = [\beta.f_\alpha (S_{ij}) +(1- \beta).f_\alpha (L_{ij})],\ 0 \leq \beta \leq 1,\ 0 \leq \alpha \leq 1$

where left – end value of α- cut for ãij is represented by

$f_\alpha (S_{ij}) = (M_{ij} - S_{ij}) . \alpha + S_{ij}$

and right– end value of α- cut for ãij is represented by

$f_\alpha (L_{ij}) = L_{ij} - (L_{ij} - M_{ij}) . \alpha$

$u_{\alpha,\beta} (\tilde{a}_{ji}) = 1/ {}_{g\alpha,\beta} (\tilde{a}_{ij}),\ 0 \leq \beta \leq 1,\ 0 \leq \alpha \leq 1,\ i > j.$

$u_{\alpha,\beta} (\breve{A}) = g_{\alpha,\beta} ([\tilde{a}_{ij}]) =$

$$\begin{array}{c} C_1 \\ C_2 \\ . \\ . \\ C_n \end{array} \begin{pmatrix} 1 & u_{\alpha,\beta}(\tilde{a}_{12}) & \dots & u_{\alpha,\beta}(\tilde{a}_{1n}) \\ 1/ u_{\alpha,\beta}(\tilde{a}_{12}) & 1 & \dots & u_{\alpha,\beta}(\tilde{a}_{2n}) \\ . & . & & . \\ . & . & & . \\ 1/u_{\alpha,\beta}(\tilde{a}_{1n}) & 1/ u_{\alpha,\beta}(\tilde{a}_{2n}) & \dots & 1 \end{pmatrix}$$

D. Step to Determine Eigen Vectors:

Eigen Value of the single pair-wise comparison matrix

uα,β is defined by **λ**_max .

uα, β (Ă).W= **λ**_max V

and [(uα, β (Ă) -**λ**_maxI]V=0

where V denotes the eigen vector of uα, β (Ă), $0 \leq \alpha \leq 1,\ 0 \leq \beta \leq 1$

E. Step for Consistency Test:

The consistency index (C.I) and consistency ratio (C.R.) proposed by [3] are defined below to verify the consistency of comparison matrix

C.I. = (**λ**_max – n) / n - 1

C.R. = C.I. / R.I.
Where R.I. = average consistency index.
If C.R.< 0.1, the estimate is accepted; else, a new comparison matrix is to be find until C.R.<0.1.

III. IMPLEMENTATION

A. Fuzzy Analytic hierarchy process (FAHP) for dependability factors (D)

Through the expert's opinions (21 expert's), we Aggregate TFN Values of D1 as:
{(4,5,6)⊗(6,7,8)⊗(7,8,9)⊗(1/3,½,1)⊗ (1/4,1/3,1/2)⊗(4,5,6)⊗(1/6,1/5,1/4)⊗(2,3,4)⊗(2,3,4)⊗(3,4,5)⊗(7,8,9)⊗(4,5,6)⊗(1/6,1/5,1/4)⊗(7,8,9)⊗(6,7,8)⊗(1/8,1/7,1/6)⊗(1/6,1/5,1/4)⊗(1/3,1/2,1)⊗(1/8,1/7,1/6)⊗(6,7,8)⊗(7,8,9)}/21={1.38, 1.72, 2.18}

In this section the three dependability factors are calculated to form TFN values shown in table 1. After that the Fuzzy pair-wise comparison matrix is formed and the defuzzification has been done which shown in table 2. After that pair-wise matrix is formed of all the factors and their weight-ages were concluded as present in table 3.

Table: 1 Aggregate TFN Values

Dependability Factors	(D1)	(D2)	(D3)
Preventive (D1)	1	1.38, 1.72, 2.18	1.07, 1.53, 1.99
Behavioral (D2)	-	1	0.34, 0.43, 0.57
Functional (D3)	-	-	1

Calculation of Defuzzification is shown as follows:
Impact of Factor 1 to Factor 2= (S_{12}, M_{12}, L_{12}) = (1.38, 1.72, 2.18)
then,
$f_{0.5}(S_{12}) = (M_{12} - S_{12}).0.5 + S_{12}$
$f_{0.5}(S_{12}) = (1.72 - 1.38) \times 0.5 + 1.38 = 1.55$
$f_{0.5}(L_{12}) = L_{12} - (L_{12} - M_{12}).\ 0.5$
$f_{0.5}(L_{12}) = 2.18 - (2.18 - 1.72) \times 0.5 = 1.95$
$u_{0.5,\,0.5}(f_{12}) = [0.5\ f_{0.5}(S_{12}) + (1-0.5)\ f_{0.5}(L_{12})]$
$u_{0.5,\,0.5}(f_{12}) = [0.5 \times 1.55 + (1 - 0.5) \times 1.95] = 1.75$
$u_{0.5,\,0.5}(f_{21}) = 1/\ 1.75 = 0.57$

Table 2 : Fuzzy pair-wise comparison matrix and defuzzification

Dependability Factors	(D1)	(D2)	(D3)
Preventive (D1)	1	1.75	1.78
Behavioral (D2)	0.57	1	0.69
Functional (D3)	0.56	1.45	1

.

$$[\ u\alpha,\beta(\breve{A}) - \lambda\_maxI]V = \begin{pmatrix} 1 & 1.75 & 1.78 \\ 0.57 & 1 & 0.69 \\ 0.56 & 1.54 & 1 \end{pmatrix}$$

$$\begin{pmatrix} 1 & 1.75 & 1.78 \\ 0.57 & 1 & 0.69 \\ 0.56 & 1.54 & 1 \end{pmatrix} \begin{pmatrix} \text{Preventive} \\ \text{Behavioral} \\ \text{Functional} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}$$

$$\begin{pmatrix} \text{Preventive} \\ \text{Behavioral} \\ \text{Functional} \end{pmatrix} = \begin{pmatrix} 0.48 \\ 0.22 \\ 0.30 \end{pmatrix}$$

Table 3: Priorities of dependability (D) factors.

Dependability Factors	Weightage	Percentage (%)	Rank
Preventive (D1)	0.48	48%	1
Behavioral (D2)	0.22	22%	3
Functional (D3)	0.30	30%	2

The results indicate that, among the three dependability factors, the preventive has been ranked 1 with the highest priority, which is 48%.Similarly other calculation have been done as shown in tables.

B. FAHP for dependability sub factors or attributes (D1)

In this section the three dependability sub factors are calculated to form TFN values shown in table 4. After that the Fuzzy pair-wise comparison matrix is formed and the defuzzification has been done which shown in table 5. After that pairwise matrix is formed of all the factors and their weightages were concluded as present in table 6.

Table 4 : Aggregate TFN Values

Dependability Sub-Factors (D1)	(D1.1)	(D1.2)	(D1.3)	(D1.4)	(D1.5)	(D1.6)	(D1.7)	(D1.8)
Completeness (D1.1)	1	1.06, 1.53, 1.99	0.51, 0.60, 0.86	1.72, 2.31, 2.90	1.69, 2.41, 3.15	1.58, 2.09, 2.61	0.55, 0.64, 0.91	1.29, 1.52, 2.11
Consistency (D1.2)	-	1	1.18, 1.47, 1.87	0.79, 0.96, 1.14	1.46, 1.86, 2.22	1.33, 1.52, 1.80	1.55, 2.20, 2.85	1.73, 2.20, 2.69
Failure Tolerance (D1.3)	-	-	1	1.09, 1.34, 1.87	1.61, 2.34, 3.15	0.34, 0.43, 0.57	1.40, 1.82, 2.45	1.26, 1.86, 2.22
Integrity (D1.4)	-	-	-	1	1.50, 1.93, 2.35	0.95, 1.08, 1.64	1.25, 1.64, 2.03	1.29, 1.59, 2.00
Modularity (D1.5)	-	-	-	-	1	1.19, 1.54, 2.02	1.19, 1.49, 1.90	0.58, 0.73, 0.96
Robustness (D1.6)	-	-	-	-	-	1	0.40, 0.51, 0.66	0.41, 0.54, 0.73
Safety (D1.7)	-	-	-	-	-	-	1	0.68, 0.75, 1.03
Security (D1.8)	-	-	-	-	-	-	-	1

Table 5 : Fuzzy pair-wise comparison matrix and defuzzification.

Dependability Sub-Factors (D1)	(D1.1)	(D1.2)	(D1.3)	(D1.4)	(D1.5)	(D1.6)	(D1.7)	(D1.8)
Completeness (D1.1)	1	1.78	0.89	2.56	2.67	2.34	0.93	1.86
Consistency (D1.2)	0.56	1	1.75	1.21	1.85	1.79	2.42	2.46
Failure Tolerance (D1.3)	1.12	0.57	1	0.99	2.61	0.69	2.12	2.02
Integrity (D1.4)	0.39	0.83	1.01	1	2.18	0.78	1.89	1.00
Modularity (D1.5)	0.38	0.54	0.38	0.46	1	1.82	1.77	1.00
Robustness (D1.6)	0.43	0.56	1.45	1.30	0.55	1	1.44	0.81

Safety (D1.7)	1.07	0.41	0.47	0.53	0.57	0.70	1	1.05
Security (D1.8)	0.538	0.407	0.495	0.999	0.999	1.242	0.951	1

Table 6: Priorities of dependability sub factors or Attributes(D1).

Dependability Sub-Factors (D1)	Weightage	Percentage (%)	Rank
Completeness (D1.1)	0.20	20	1
Consistency (D1.2)	0.17	17	2
Failure Tolerance (D1.3)	0.15	15	3
Integrity (D1.4)	0.12	12	4
Modularity (D1.5)	0.09	09	6
Robustness (D1.6)	0.10	10	5
Safety (D1.7)	0.08	08	8
Security (D1.8)	0.09	09	7

Among the dependability factor (D1) the completeness has been ranked 1 with the highest priority with 19.53%. This shows that in the dependability-factor preventive, the most important dependability attribute is completeness.

C. FAHP for dependability attributes (D2)

In this section the three dependability sub factors are calculated to form TFN values shown in table 7. After that the Fuzzy pair-wise comparison matrix is formed and the defuzzification has been done which shown in table 8. After that pair wise matrix is formed of all the factors and their weight-ages were concluded as present in table 9.

Table 7 : Aggregate TFN Values

Dependability Sub-Factors (D2)	(D2.1)	(D2.2)	(D2.3)	(D2.4)	(D2.5)
Availability (D2.1)	1	1.40, 1.82, 2.45	1.61, 2.34, 3.15	1.09, 1.34, 1.87	1.29, 1.52, 2.11
Correctness (D2.2)	-	1	0.48, 0.61, 0.85	1.19, 1.49, 1.90	0.47, 0.71, 1.25
Reliability(D2.3)	-	-	1	0.20, 0.30, 0.46	0.54, 0.81, 1.28
Recoverability(D2.4)	-	-	-	1	1.18, 1.47, 1.87
Self Description (D2.5)	-	-	-	-	1

Table 8 : Fuzzy pair-wise comparison matrix and defuzzification.

Dependability Sub-Factors (D2)	(D2.1)	(D2.2)	(D2.3)	(D2.4)	(D2.5)
Availability (D2.1)	1	1.86	1.78	1.41	1.86
Correctness (D2.2)	0.54	1	1.77	1.67	1.03
Reliability(D2.3)	0.56	0.56	1	1.13	1.11
Recoverability(D2.4)	0.71	0.60	0.89	1	1.75
Self Description (D2.5)	0.54	0.97	0.90	0.57	1

Table 9: Priorities of dependability sub factors or Attributes(D2).

Dependability Sub-Factors (D2)	Weightage	Percentage (%)	Rank
Availability (D2.1)	**0.30**	30	1
Correctness (D2.2)	**0.22**	21	2
Reliability(D2.3)	**0.16**	16	4
Recoverability(D2.4)	**0.18**	18	3
Self Description (D2.5)	**0.15**	15	5

In the dependability factor (D2) the availability has been ranked 1 with the highest priority with 30%. This shows that in the dependability-factor behavioral, the most important dependability attribute is availability.

D. FAHP for dependability attributes (D3)

In this section the three dependability sub factors are calculated to form TFN values shown in table 10. After that the Fuzzy pair-wise comparison matrix is formed and the defuzzification has been done which shown in table 11. After that pairwise matrix is formed of all the factors and their weight-ages were concluded as present in table 12.

Table 10 : Aggregate TFN Values

Dependability Sub-Factors (D3)	(D3.1)	(D3.2)	(D3.3)	(D3.4)
Accuracy (D3.1)	1	0.79, 0.96, 1.14	1.73, 2.20, 2.69	1.48, 1.86, 2.22
Confidentiality (D3.2)	-	1	1.50, 1.93, 2.35	0.58, 0.73, 0.96
Efficiency (D3.3)	-	-	1	0.95, 1.08, 1.64
Maintainability (D3.4)	-	-	-	1

Table 11 : Fuzzy pair-wise comparison matrix and defuzzification.

Dependability Sub-Factors (D3)	(D3.1)	(D3.2)	(D3.3)	(D3.4)
Accuracy (D3.1)	1	1.21	2.46	1.85
Confidentiality (D3.2)	0.83	1	2.18	1.00
Efficiency (D3.3)	0.41	0.46	1	0.77
Maintainability (D3.4)	0.54	0.10	1.30	1

Table 12: Priorities of dependability sub factors or Attributes(D3).

Dependability Sub-Factors	Weightage	Percentage (%)	Rank
Accuracy (D3.1)	0.36	36	1
Confidentiality (D3.2)	0.27	27	2
Efficiency (D3.3)	0.15	15	4
Maintainability (D3.4)	0.22	22	3

At the last, among the dependability factor (D3) the accuracy has been ranked 1 with the highest priority with 36%. This shows that in the dependability factor functional, the most important dependability attribute is accuracy.

IV. RESULTS AND DISCUSSION

The result shows, the weight-ages of multiple dependability factors and sub-factors (attributes) in the design and development process. The generated ranks of dependability factors and sub-factors may provide a chance to software designers and developers to explore and develop outcome of multiple objectives of dependable software. The implementation of dependability estimation using FAHP outlines the priority weights of identified dependability factors and sub-factors that are present in the hierarchy. With the help of generated priorities we can identify the most important factors and sub-factors of dependability as per the nature of project. The relationship between these factors and sub-factors is very useful for dependability estimation. These comparative values are used as input to the FAHP process, and ranking of dependability factors and sub-factors is summarized in Table 3, 6,9,12. The final priority of the every dependability factor and sub-factor was calculated in the last step of the demonstrated technique. The outcomes show that, among the three dependability factors, the preventive has gain the highest rank and priority which is 48%. This shows that the factor preventive has a great effect on dependability of software. Among the dependability attributes (D1) the completeness has gain the highest rank and the highest priority with 19%. This shows that in the dependability-factor preventive, the most important dependability attribute is completeness. In the dependability attributes (D2) the availability has gain the highest rank and the highest priority with 30%. This shows that in the dependability-factor behavioral, the most important dependability attribute is availability. At the last, among the dependability attributes (D3) the Accuracy has gain the highest rank and the highest priority with 36%. This shows that in the dependability-factor functional, the most important dependability attribute is Accuracy.

V. CONCLUSION AND FUTURE WORK

This paper demonstrates the implementation of the software dependability estimation using Fuzzy AHP and generates the priorities of dependability factors and sub-factors. This may prove to be very important for software designers and developers to achieve new and challenging software dependability requirements. In the frequently changing and challenging work environment the software industry is supposed to revise their development processes to achieve new heights. One of these improvements may include the use of methodologies that can generate better and more accurate results for software dependability estimation. In this work FAHP technique is used which is a famous and widely multi criteria decision making process to calculate priorities of different factors and sub-factors. In the software industry the designers and developers may use the implemented technique to determine the priorities of the dependability factors and sub-factors and can see the probable results and influences. The results shown in this paper would be validated by using other technique in the future.

ACKNOWLEDGEMENT

This work is published with Integral University's research manuscript communication no. IU/R&D/2019-MCN000594.

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