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Software Reliability Apportionment using Fuzzy Logic

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Abstract

Objectives: This paper presents software reliability apportionment using fuzzy logic. **Methods/Statistical Analysis:** The proposed methodology attempts to allocate target reliability to its modules. For calculation of reliability, the first step is to aggregate the opinion of all team members of ith module. Second step is to calculate proportionality factor of the software system. Defuzzify the Fuzzy Proportionality Factor by using defuzzification formula. After obtaining crisp values, we have to calculate weightage of each module. Based on weightage, reliability of each module is calculated. **Findings:** Operational Profile is one of the main parameters for making effective testing and improved reliability by testing most used functions in first phase and lesser used function in next phase. Comparing with the previous result, reliability has been improved. **Application/Improvements:** It helps to allocate reliability to all modules before the actual system is built. Also it considers Operational Profile as a parameter in proportionality factor, which helps to allocate reliability to most used modules, therefore making reliability apportionment beneficial for every module.

Keywords: Fuzzy Logic and Operational Profile, Proportionality Factor, Reliability Allocation, Reliability Apportionment

1. Introduction

With the increase of human dependency over computer software, considerable effort should be given to assign reliability. Reliability is defined as “probability of failure free operation for a specified time in a given environment”. However, it is difficult to allocate as number of factors have to consider during design process[1] and system reliability is affected by its module reliability. Therefore, reliability apportionment becomes critical requirement during early phase[23]. Reliability apportionment is an important part of reliability allocation. Once the overall reliability is specified, the next step is to assign reliability to its modules. If module reliability requirement is fulfilled, then overall system reliability can be achieved. There are number of reliability apportionment approaches available in literature. The first method introduced was equal apportionment, which assigns target reliability to its subsystems[2]. Other methods include Advisory Group on reliability of Electronic Equipment (AGREE)[4] and cost Minimization etc.[3] has presented reliability apportionment of a software module by considering user opinion. However, these methods do not consider the many of reliability factors like complexity, maintainability, Time of Operation etc. considers all these factors and various mathematics calculations to derive proportionality factors. In this paper experts used scale based measurement for various factors. However, it becomes very difficult to obtain a final crisp value by considering all opinions, because every expert will possess different opinion. Also this paper does not consider early reliability allocation by considering subjective opinions of experts. Recently, in few years, concept of fuzzy logic has been used for reliability allocation by various researchers. In[5] has given the way of reliability allocation using Fuzzy Logic and Analytical Hierarchy Process. He has considered expert judgment and risk index for selecting control factor and their weight. In[6,7] also discussed fuzzy based allocation. In[5] proposed fuzzy reliability allocation for engine based on multi-field expert opinion. In[8] proposed fuzzy reliability allocation and risk evaluation by considering multi-domain experts opinion. However, there are various

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reliability allocation approaches available in literature but there are less number of works is done for software reliability apportionment. For a software system, to work properly, it is required to allocate reliability to its entire module, in order to achieve overall system reliability goal. So, this paper proposes reliability apportionment to all modules of a system by considering various engineering factor[4] including Operational Profile[9,10] also. There is no mention of Operational Profile consideration. However, it is very important criteria for reliability allocation from user's point of view. Therefore, the proposed methodology considers factors like module complexity, maintenance effort, operational profile, module severity, time of operation and state of the art. Experts are used to provide fuzzy rating based on scaling measurement, to various factors mentioned above. System proportionality factor is calculated by considering all factors, which will provide weightage of each module further. Reliability allocation is done based on weightage of each module.

Rest of paper is organized as follows: Section 2 describes the review of reliability allocation method based on certain engineering factors. Section 3 will describe some fuzzy arithmetic operations. Section 4 will discuss proposed methodology. Section 5 will discuss the case study and results. Conclusion for this study is given in Section 7.

2. Review of Reliability Allocation Method based on Various Factors

The previous reliability allocation method has given a relationship between target reliability and reliability of all modules, which is given below:

$$R_{mi} = (R_g)^{W_{mi}} \quad (1)$$

Where R_{mi}- Reliability of module i, R_g- Reliability of target system W_{mi}- weightage of ith module

Weightage of a module can be calculated by proportionality factor and proportionality factor can be defined on the basis of relationship among various factors, that can affect software reliability and it is given below.

$$W_{mi} = \frac{Zi}{\sum zi} \quad (2)$$

Where Z_i- proportionality factor.

Now, a brief description about all the factors will be discussed below:

2.1 Complexity

Baisley defines complexity as a measure of the resources expended by a system while interacting with a piece of software (Baisley). However, complexity factor can be different for different modules. And there is a relation between reliability and complexity. Therefore different complexity modules have different reliability. Cyclomatic complexity is one of the metric to measure complexity and it has been found that high complexity module will have lowest reliability because they tend to produce very abrupt code which is difficult to change or apply. However, failure rate of a highly complex module will be high. Therefore failure rate of a module is directly proportional to its complexity. If failure rate is denoted by Z and complexity is denoted by then this relation can be mathematically shown as in Equation (3).

$$Z \propto C_{mi} \quad (3)$$

2.2 Cost

Cost is considered an important factor in reliability allocation process. A module or component can be either in-house product or it will be Commercial Off the shelf product. So, if a system consists of 4 in-house product and 2 COTS product, then its cost will be high. However, it is known that there is relation between cost and reliability. Therefore the module having high cost, should get lesser reliability, because the higher will be cost, so less attention will be given to that module. So there will be more chance to have faulty module with high cost. Its mathematical Equation can be shown in Equation (4).

$$Z \propto CO_{mi} \quad (4)$$

2.3 Maintainability

It is other important factor for reliability allocation. Module, which is checked or repaired on regular basis, will have high availability. So, highly maintained software tends to have lower reliability value and having higher failure rate. Its mathematical Equation can be shown in Equation (5).

$$Z \propto M_{mi} \quad (5)$$

2.4 Criticality

Criticality is other important factor in reliability allocation. Suppose if we have an airplane operation that is very infrequent but highly critical and it is related to human lives also. Therefore, high reliability will be provided to this functionally critical module. It means a highly critical module will have high reliability and low failure rate. Its mathematical Equation can be shown in Equation (6).

$$Z \,\alpha\, \frac{1}{CRmi} \tag{6}$$

2.5 Operational Profile

Operational Profile is considered as an important factor for reliability allocation. Operational Profile is defined as “quantitative representation of how a system will be used” or it is the set of number of operations with their occurrence probability. Modules based on Operational Profile based testing have most used operations among others. Therefore, module with high Operational Profile will get higher reliability and less failure rate. Its mathematical Equation can be shown using Equation (7).

$$Z \,\alpha\, \frac{1}{OPmi} \tag{7}$$

2.6 Time of Operation

Time of operation is also related to reliability in some manner. Suppose there are n modules in a system, out of which (n-3) modules have high time of operation than the rest modules. It means they will execute more and therefore should get high reliability. High reliable module will have less failure rate. Its mathematical Equation can be shown in Equation (8).

$$Z \,\alpha\, \frac{1}{Tmi} \tag{8}$$

2.7 Reusability

Module reusability is also an important factor considered for reliability allocation. In computer science and software engineering, “reusability is the use of existing assets in some form within the software product development process”. Therefore, a highly reusable module will have high reliability and lower failure rate. Its mathematical Equation can be found in Equation (9).

$$Z \,\alpha\, \frac{1}{Rmi} \tag{9}$$

2.8 Redundancy Introduction

It is suggested that possibility of redundancy introduction should also find a place in reliability allocation. A stage, where it is feasible to use redundant module can offer itself for higher reliability allocation. Its mathematical Equation can be found below:

$$Z \propto RI\mathbf{mi}$$

The above mentioned factors can be used successfully for reliability allocation by incorporating this allocation method. This methodology can be applied to any software system, which needs to perform reliability apportionment for its modules.

By considering all above factors, formula for proportionality factor can be expressed by Equation (10).

$$Z = \frac{Cmi * COmi * Mmi * RI\mathrm{mi}}{CRmi * OPmi * Tmi * Rmi} \tag{10}$$

3. Fuzzy Numbers and Arithmetic

Fuzzy numbers are fuzzy subsets of sets on real number satisfying some additional condition. Fuzzy numbers allow us to model non-probabilistic uncertainties in an easy way. Triangular and trapezoidal fuzzy numbers are commonly used. Therefore, here we will discuss about these two numbers only. Triangular and trapezoidal fuzzy numbers can be represented by (a, b, c) and (a, b, c, d) respectively. Triangular fuzzy numbers are the special case of trapezoidal fuzzy numbers, when b equals c. Let A and B be two triangular fuzzy numbers, parameterized by (a1, a2, a3) and (b1, b2, b3). Their arithmetic can be described following:

A+B = (a1+b1, a2+b2, a3+b3) A-B = (a1-b3, a2-b2, a3-b1)
A*B = (a1b1, a2b2, a3b3) A/B = (a1/b3, a2/b2, a3/b1)

Let A and B be two triangular fuzzy numbers, parameterized by (a1, a2, a3, a4) and (b1, b2, b3, b4). Their arithmetic can be described following:
A+B = (a1+b1, a2+b2, a3+b3, a4+b4) A-B = (a1-b4, a2-b3, a3-b2, a4-b1)
A*B = (a1b1, a2b2, a3b3, a4b4) A/B = (a1/b4, a2/b3, a3/b2, a4/b1)

These are the operations performed on fuzzy numbers. However, these values need to be mapped to real values for further comparisons. Process of converting fuzzy numbers into crisp numbers is called defuzzification. Defuzzification is required, as we cannot compare fuzzy numbers in real worlds. Formula has been already given by[11] for performing defuzzification operations on triangular and trapezoidal fuzzy numbers. These formulas are given below:

Let A (a1, a2, a3) and B (b1, b2, b3) are two triangular fuzzy numbers. Their defuzzification formula is given below:

$$Ca = \frac{1}{3(a+b+d)} \qquad (11)$$

Let A (a1, a2, a3, a4) and B (b1, b2, b3, b4) are two trapezoidal fuzzy numbers. Their defuzzification formula is given below:

$$Ca = \frac{c2 + d2\ cd - a2 - b2 - ab}{3(c+d-a-b)} \qquad (12)$$

Now, it is observed by many researchers[12,13] that the addition and subtraction of the parameterized fuzzy numbers resulted in closed form, but it does not work in case of multiplication and division. Therefore, a method based on linear programming for triangular and trapezoidal fuzzy number division method has been proposed by[13,14].

First, triangular fuzzy division method will be discussed. Let A and B are two parameterized fuzzy numbers represented by (l1, c1, r1) and (l2, c2, r2), where l1, l2, c1, c2, r1, r2 are left end points, center point and right end points respectively. So division of two fuzzy numbers can be expressed as:

$C = \frac{A}{B}$ Where C (C_l, C_c, C_r) is a fuzzy number.

The linear problem that has to be solved is follows:

Max f(c) = C_r - C_l

Subject to

$$Cl \geq \frac{c1}{c2} - \frac{c1 - l1}{c2 - l2} \qquad (13)$$

$$Cr \leq \frac{c1}{c2} + \frac{r1 - c1}{r2 - c2} \qquad (14)$$

$$Cl \leq \frac{c1}{c2} \qquad (15)$$

$$Cr \geq \frac{c1}{c2} \qquad (16)$$

In the same fashion fuzzy division of trapezoidal number is also shown. Let A and B are two parameterized fuzzy numbers represented by (l1, c1, c11, r1) and (l2, c2, c22, r2), where l1, l2, c1, c2, c11, c22, r1, r2 are left end points, left center point, right center point and right end points respectively. So division of two fuzzy numbers can be expressed as:

$C = \frac{A}{B}$ Where C (C_l, C_{c1}, $C_{c2}C_r$) is a fuzzy number.

The linear problem that has to be solved is follows:

Max f(c) = C_r- C_l

Subject to

$$Cl \geq \frac{c1}{c2} - \frac{c1 - l1}{c2 - l2} \qquad (17)$$

$$Cr \leq \frac{c11}{c22} + \frac{r1 - c11}{r2 - c22} \qquad (18)$$

$$Cl \leq \frac{c1}{c22} \qquad (19)$$

$$Cr \geq \frac{c11}{c2} \qquad (20)$$

4. Proposed Methodology

The proposed methodology attempts to allocate target reliability[13,14] to its modules. For calculation of reliability, the first step is to calculate proportionality factor of the software system. However, it is not easy to calculate proportionality factor. In[15,16] discussed similar kind of problem in Failure Mode Effect and Criticality Analysis, while evaluating risk factor using fuzzy logic. The proposed methodology will follow the same effort for proportionality factor evaluation. A scale measurement has been given for all allocation factors, which is consistent with traditional allocation method, which is shown in Table 1. However, these numbers are treated as fuzzy numbers, because ambiguity exists in estimation. We will apply our methodology for trapezoidal numbers. Suppose there are k_i modules and software managers and programmers consisting of m team members for evaluation. As mentioned above, that all allocation factors will be treated as trapezoidal fuzzy numbers, So Module's fuzzy rating can be represented as trapezoidal fuzzy number, which is shown below:

$C_{ij} = (C_{ijl}, C_{ijc1}, C_{ijc2}, C_{ijr})$.

i = (1…4) j = (1..3) l, c1, c2, r are left end point, left center point, right center point, right end point.

$CO_{ij} = (CO_{ijl}, CO_{ijc1,} CO_{ijc2} CO_{ijr})$.
i = (1…4) j = (1..3) l, c1, c2, r are left end point, left center point, right center point, right end point.
$M_{ij} = (M_{ijl}, M_{ijc1,} M_{ijc2} M_{ijr})$.
i = (1…4) j = (1..3) l, c1, c2, r are left end point, left center point, right center point, right end point.
$Cr_{ij} = (Cr_{ijl}, Cr_{ijc1}, Cr_{ijc2} Cr_{ijr})$.
i = (1…4) j = (1..3) l, c1, c2, r are left end point, left center point, right center point, right end point.
$OP_{ij} = (OP_{ijl}, OP_{ijc1,} OP_{ijc2} OP_{ijr})$.
i = (1…4) j = (1..3) l, c1, c2, r are left end point, left center point, right center point, right end point.
$T_{ij} = (T_{ijl}, T_{ijc1,} T_{ijc2} T_{ijr})$.
i = (1…4) j = (1..3) l, c1, c2, r are left end point, left center point, right center point, right end point.
$R_{ij} = (R_{ijl}, R_{ijc1,} R_{ijc2} R_{ijr})$.
i = (1…4) j = (1..3) l, c1, c2, r are left end point, left center point, right center point, right end point.
$RI_{ij} = (RI_{ijl}, RI_{ijc1,} RI_{ijc2} RI_{ijr})$.
i = (1…4) j = (1..3) l, c1, c2, r are left end point, left center point, right center point, right end point.

The above mentioned values are the fuzzy rating of ith module by jth expert and hj be the weight given to team members. Base on these assumptions, we will now explain the steps of proposed methodology.

Step 1: Aggregate the opinion of all team members for ith module where i =1..4, by using the following Equations

$$\tilde{\tilde{Ci}} = \sum_{j=1}^{m} hj\,\tilde{\tilde{Cij}} = \left(\sum_{j=1}^{m} hjCijl, \sum_{j=1}^{m} hjCijc1, \sum_{j=1}^{m} hjCijc2 \sum_{j=1}^{m} hjCijr\right) \quad (21)$$

$$\tilde{\tilde{COi}} = \sum_{j=1}^{m} hj\,\tilde{\tilde{COij}} = \left(\sum_{j=1}^{m} hjCOijl, \sum_{j=1}^{m} hjCOijc1, \sum_{j=1}^{m} hjCOijc2 \sum_{j=1}^{m} hjCOijr\right) \quad (22)$$

$$\tilde{\tilde{Mi}} = \sum_{j=1}^{m} hj\,\tilde{\tilde{Mij}} = \left(\sum_{j=1}^{m} hjMijl, \sum_{j=1}^{m} hjMijc1, \sum_{j=1}^{m} hjMijc2 \sum_{j=1}^{m} hjMijr\right) \quad (23)$$

$$\tilde{\tilde{Cri}} = \sum_{j=1}^{m} hj\,\tilde{\tilde{Crij}} = \left(\sum_{j=1}^{m} hjCrijl, \sum_{j=1}^{m} hjCrijc1, \sum_{j=1}^{m} hjCrijc2 \sum_{j=1}^{m} hjCrijr\right) \quad (24)$$

$$\tilde{\tilde{Ri}} = \sum_{j=1}^{m} hj\,\tilde{\tilde{Rij}} = \left(\sum_{j=1}^{m} hjRijl, \sum_{j=1}^{m} hjRijc1, \sum_{j=1}^{m} hjRijc2 \sum_{j=1}^{m} hjRijr\right) \quad (25)$$

$$\tilde{\tilde{Ti}} = \sum_{j=1}^{m} hj\,\tilde{\tilde{Tij}} = \left(\sum_{j=1}^{m} hjTijl, \sum_{j=1}^{m} hjTijc1, \sum_{j=1}^{m} hjTijc2 \sum_{j=1}^{m} hjTijr\right) \quad (26)$$

$$\tilde{\tilde{OPi}} = \sum_{j=1}^{m} hj\,\tilde{\tilde{OPij}} = \left(\sum_{j=1}^{m} hjOPijl, \sum_{j=1}^{m} hjOPijc1, \sum_{j=1}^{m} hjOPijc2 \sum_{j=1}^{m} hjOPijr\right) \quad (27)$$

$$\tilde{\tilde{RIi}} = \sum_{j=1}^{m} hj\,\tilde{\tilde{RIij}} = \left(\sum_{j=1}^{m} hjRIijl, \sum_{j=1}^{m} hjRIijc1, \sum_{j=1}^{m} hjRIijc2 \sum_{j=1}^{m} hjRIijr\right) \quad (28)$$

Step 2: For each module, compute the Fuzzy Proportionality Factor.

Step 3: Defuzzify the Fuzzy Proportionality Factor by using defuzzification formula for trapezoidal numbers by using Equation (12)[17].

Step 4: Calculate the weightage of each module by using Equation (2).

Step 5: Calculate the reliability of each module by using Equation (1).

5. Case Study and Results

In this section, we will provide a numerical example. Here, our work is to apportion software reliability to its modules. Therefore we will take an example of a modular smart phone, having different modules. Our work will focus that how much reliability a module should be given. Software programmer and manager consist of a team of three team members. Data has been taken from[18]. Here we will talk about a modular smart phone, consisting of 16 modules. However, this work considers the 4 critical module of this software system and applies in the proposed methodology, in order to apportion target reliability to its module. Membership function for fuzzy rating for allocation factor is shown in Figure 1. Reliability specification requires modular smart phone to operate 48 h with a probability of 0.875. The team members have used the linguistic terms defined in Table 1 for the evaluating allocation factors. The allocation information for four modules by three team member is given in Tables 2 and 3. However, different experts can have different opinions. Therefore, every team member has been given a weight, to reflect their opinion. TM1, TM2 and TM3 have 45%, 25% and 30% weights respectively. Now, it is required to combine theses opinion into a single value. Equations (21)-(28) have been used to aggregate the opinions of all team members. Table 4 presents the aggregated fuzzy evolution information for four modules. Now, next step is to find the system proportionality factor. However, fuzzy numbers are used for allocation of modules. Therefore, fuzzy multiplication and division is performed, for evaluating fuzzy proportionality factor and is shown in Table 5. Next step is to defuzzify FZ of all modules, which is then used to calculate weightage of each module. In the last step, reliability allocation is calculated for each module (Table 6).

6. Analysis

This paper has presented software reliability apportionment technique using fuzzy logic. Various factors like complexity, cost, maintenance, redundancy introduction, criticality, reusability, time of operation and Operational Profile are given in order to calculate the proportionality factor for software system. Presently, Operational Profile is seen as an important aspect for software reliability. Operational Profile is defined as "how a system will be used". It is the set of all operations with their occurrence probability. Consideration of Operational Profile is important, because it gives the most used operation with their occurrence probability. Therefore by considering this factor, we can find out that out of all modules, which module could get high reliability value.

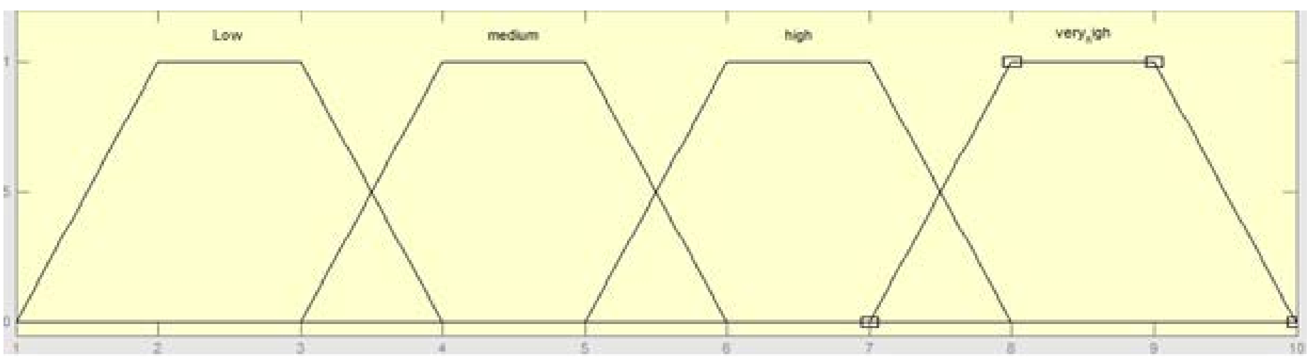

Figure 1. Fuzzy rating for allocation factors.

Table 1. Fuzzy rating for reliability allocation factors

Scale	Complex-ity	Cost	Mainte-nance	Redundancy introduction	Critical-ity	Operation-al Profile	Time of operation	Reusability
(7,8,9)	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high
(5,6,7)	High	High	High	High	High	High	High	High
(3,4 5)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
(1,2,3)	Low	Low	Low	Low	Low	Low	Low	Low

Table 2. Allocation information for modules

Modules	Team Members	C	M	CO	RI	Cr	R	T	OP
Sennheiser HQ audio module	TM1(45%)	VH	VH	H	H	H	M	VH	VH
	TM2(25%)	H	H	VH	VH	H	H	VH	VH
	TM3(30%)	VH	H	M	M	M	L	H	H
Solid energy battery module	TM1(45%)	H	H	VH	VH	M	H	H	H
	TM2(25%)	M	VH	M	M	H	M	VH	VH
	TM3(30%)	H	M	H	H	H	H	H	H
Biosensor module	TM1(45%)	H	VH	H	H	H	M	VH	VH
	TM2(25%)	M	H	M	M	M	L	H	H
	TM3(30%)	H	M	VH	VH	L	H	H	H
Radiation sensor module	TM1(45%)	L	H	H	H	VH	L	VH	VH
	TM2(25%)	L	M	M	M	H	M	VH	VH
	TM3(30%)	M	VH	H	H	M	M	H	H

Table 3. Allocation information for modules

Modules	Team Members	C	M	CO	RI	Cr	R	T	OP
Sennheiser HQ audio module	TM1(45%)	(7,8,9, 10)	(7,8,9, 10)	(5,6,7, 8)	(5,6,7, 8)	(5,6,7, 8)	(3,4,5,6)	(7,8,9,10)	(7,8,9,10)
	TM2(25%)	(5,6,7, 8)	(5,6,7, 8)	(7,8,9, 10)	(7,8,9, 10)	(5,6,7, 8)	(5,6,7,8)	(7,8,9,10)	(7,8,9,10)
	TM3(30%)	(7,8,9, 10)	(5,6,7, 8)	(3,4,5, 6)	(3,4,5, 6)	(3,4,5, 6)	(1,2,3,4)	(5,6,7,8)	(5,6,7,8)
Solid energy battery module	TM1(45%)	(5,6,7, 8)	(5,6,7, 8)	(7,8,9, 10)	(7,8,9, 10)	(3,4,5, 6)	(5,6,7,8)	(5,6,7,8)	(5,6,7,8)
	TM2(25%)	(3,4,5, 6)	(7,8,9, 10)	(3,4,5, 6)	(3,4,5, 6)	(5,6,7, 8)	(3,4,5,6)	(7,8,9,10)	(7,8,9,10)
	TM3(30%)	(5,6,7, 8)	(3,4,5, 6)	(5,6,7, 8)	(5,6,7, 8)	(5,6,7, 8)	(5,6,7,8)	(5,6,7,8)	(5,6,7,8)
Biosensor module	TM1(45%)	(5,6,7, 8)	(7,8,9, 10)	(5,6,7, 8)	(5,6,7, 8)	(5,6,7, 8)	(3,4,5,6)	(7,8,9,10)	(7,8,9,10)
	TM2(25%)	(3,4,5, 6)	(5,6,7, 8)	(3,4,5, 6)	(3,4,5, 6)	(3,4,5, 6)	(1,2,3,4)	(5,6,7,8)	(5,6,7,8)
	TM3(30%)	(5,6,7, 8)	(3,4,5, 6)	(7,8,9, 10)	(7,8,9, 10)	(1,2,3, 4)	(5,6,7,8)	(5,6,7,8)	(5,6,7,8)
Radiation sensor module	TM1(45%)	(1,2,3, 4)	(5,6,7, 8)	(5,6,7, 8)	(5,6,7, 8)	(7,8,9, 10)	(1,2,3,4)	(7,8,9,10)	(7,8,9,10)
	TM2(25%)	(1,2,3, 4)	(3,4,5, 6)	(3,4,5, 6)	(3,4,5, 6)	(5,6,7, 8)	(3,4,5, 6)	(7,8,9,10)	(7,8,9,10)
	TM3(30%)	(3,4,5, 6)	(7,8,9, 10)	(5,6,7, 8)	(5,6,7, 8)	(3,4,5, 6)	(3,4,5, 6)	(5,6,7,8)	(5,6,7,8)

Table 4. Aggregated fuzzy evolution information for modules

C	CO	RI	R	T	Cr	OP
(6.5,7.5,8.5,9.5)	(4.9,5.9,6.9, 7.9)	(4.9,5.9,6.9, 7.9)	(2.9,3.9,4.9, 5.9)	(6.4,7.4,8.4, 9.4)	(4.4,5.4,6.4, 7.4)	(6.4,7.4,8.4, 9.4)
(4.5,5.5,6.5, 7.5)	(5.4,6.4,7.4, 8.4)	(5.4,6.4,7.4, 7.4)	(4.5,5.5,6.5, 7.5)	(5.5,6.5,7.5, 8.5)	(4.1,5.1,6.1, 7.1)	(5.5,6.5,7.5, 8.5)
(4.5,5.5,6.5, 7.5)	(5.1,6.1,7.1, 8.1)	(5.1,6.1,7.1, 8.1)	(3.1,4.1,5.1, 6.1)	(5.9,6.9,7.9, 8.9)	(3.3,4.3,5.3, 6.3)	(5.9,6.9,7.9, 8.9)
(1.6,2.6,3.6, 4.6)	(4.5,5.5,6.5, 7.5)	(4.5,5.5,6.5, 7.5)	(2.1,3.1,4.1, 5.1)	(6.4,7.4,8.4, 9.4)	(5.3,6.3,7.3, 8.3)	(6.4,7.4,8.4, 9.4)

Table 5. Evaluation result of the proportionality factor for each module

Modules	C*M*CO*RI	R*T*Cr*OP	Fuzzy Proportionality factor
Sennheiser HQ audio module	920.783,1801.417, 3197.01, 5276.76	522.649, 1153.245, 2212.76, 3857.79	0.19694, 0.81410, 2.70218, 2.77906
Solid energy battery module	600.112, 1256.65, 2342.63, 4013.45	558.112, 1185.112, 2230.31, 3847.31	0.0132, 0.56344, 1.97671, 2.08364
Biosensor module	620.338, 1289.32, 2391.95, 4084.22	356.21, 839.36, 1686.94, 3044.04	0.15145, 0.7642, 2.6497, 2.66487
Radiation sensor module	165.24, 479.76, 1080.56, 2095.87	455.88, 1069.46, 2111.8, 3740.27	0, 0.22718, 1.0103, 1.13515

Table 6. Reliability apportionment of each module

Modules	Defuzzified (FZ)	Weightage	Allocated reliability
Sennheiser HQ audio module	1.6360	0.32521	0.95750
Solid energy battery module	1.15223	0.22904	0.96987
Biosensor module	1.6507	0.32813	0.95713
Radiation sensor module	0.59155	0.11759	0.984420

7. Conclusion

This paper proposes fuzzy based reliability allocation to software modules and takes linguistic variables for calculating the allocation information of software modules by three team members. Finally, weightage of all modules is calculated. Based on the weightage of each module and target reliability, reliability apportionment of each module is performed.

8. References

1. Aggarwal KK. Reliability engineering. 3rd ed. Netherlands: Kluwar Academic Publisher; 2007.
2. Ebeling CE. An introduction to reliability and maintainability engineering. 10th ed. New Delhi, India: Tata McGraw-Hill Publishing Company Limited; 2008.
3. Aggarwal KK, Singh Y. Software reliability apportionment using analytical hierarchy process. ACM SIGSOFT Software Engineering Notes. 1995; 20(5):56–61.
4. Dhillon BS. Reliability apportionment/allocation: A survey. Microelectronics Reliability. 1986; 26(6):1121–9.
5. Gu YK, Huang KQ. A fuzzy reliability allocation method for engine based on the experts' knowledge. Journal of Aerospace Power. 2009; 2005–9.
6. Hong-bin Z, Zhi-xin J. Complex system reliability allocation based on fuzzy decision method. Proceedings of the IEEE international workshop on intelligent systems and applications; 2009. p. 1–4.
7. Mahapatra GS, Mahapatra BS. Redundancy optimization using intuitionist fuzzy multi-objective programming. International Journal of Performability Engineering. 2011; 7(2):155–64.
8. Yingkui G, Shuyun T. A fuzzy reliability allocation method for the product based on the knowledge. Proceedings of the IEEE International Conference on Measuring Technology and Mechatronics Automation. 2010; 2010:101–4.
9. Yadav DKA. Operational Profile based software test case allocation. Proceedings of 2nd International Conference on Computing for Sustainable Development; New Delhi. 2015. p. 1775–9.
10. Yadav DKA. A novel method for allocating software test cases. Proceedings of International Conference on Recent Trends in Computing; 2015. p. 131–8.
11. Gargama H, Chaturvedi SK. Criticality assessment models for failure mode effects and criticality analysis using fuzzy logic. IEEE Transactions on Reliability. 2011; 60(1):102–10.
12. Liu H, Liu L, Liu N. Risk evaluation approaches in failure mode and effects analysis: A literature review. Expert Systems with Applications. 2013; 40(2):828–38.
13. Molani M, Ghaffari A, Jafarian A. A new approach to software project cost estimation using a hybrid model of radial basis function neural network and Genetic Algorithm. Indian Journal of Science and Technology. 2014; 7(6):838–43.
14. Gayathry G, Selvi RT. Classification of software reliability models to improve the reliability of software. Indian Journal of Science and Technology. 2015; 8(29):1–5.
15. Giachetti RE, Young RE. Analysis of the error in the standard approximation used for multiplication of triangular and trapezoidal fuzzy numbers and the development of a new approximation. Fuzzy Sets and Systems. 1997; 91(1):1–13.
16. Basaran MA, Aladag CH, Kadilar C. Conducting fuzzy division by using linear programming. WSEAS Transactions on Information Science and Applications. 2008; 5(6):923–8.
17. Wang YM, Yanga JB, Xua DL, Chin KS. On the centroids of fuzzy numbers. Fuzzy Sets and Systems. 2006; 157(7):919–26.
18. Sriramdas V, Chaturvedi SK, Gargama H. Fuzzy arithmetic based reliability allocation approach during early design and development. Expert Systems and Applications. 2014; 41(7):3444–9.