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Maintainability Model of Object Oriented Software based on Fuzzy Logic Approach

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Abstract- *Insoftware development life cycle, software maintainability is the most costly phase because it requires more effort as compared to other phases. To minimize the cost of software maintenance, it is necessary to predict software maintainability during the early phases of software development life cycle. Most of the software systems are using Object Oriented approach to enhance the quality of software products. Object Oriented approach also plays an important role to enhance the maintainability of software products. . This paper proposed a fuzzy logic based model for predicting the maintainability of a class. The proposed model is based on the Mamdani's fuzzy inference engine. CK metrics are used as input to the model and the maintainability as output. The value obtained by fuzzy model is validated by using analytical hierarchy processingtechnique.*
Keywords -*Maintainability, AHP, Object Oriented, Fuzzy, CK Metrics.*

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I. Introduction

Software maintenance is the most crucial activity in the software development life cycle. It can consume around 70% of the cost of the entire life cycle [2,3].Thus a good maintainability prediction can reduce the cost of the software product .so evaluation of Maintainability in the early phases of software development life cycle is very essential. Thus if evaluation is done accurately, it can be useful in Taking important decisions related to the software, efficiency of the maintenance process, comparing time effort, productivity and costs among different projects. Metrics are the measures to evaluate maintainability. There are many metrics available to calculate the maintainability factor of a software system. We choose CK metrics for our model because it is the most appropriate metrics to evaluate the maintainability of a software system in Object Oriented environment.Softwaremaintainabilityisacrucial factor to measure as most of the cost of software depends on this factor [6].However we cannot predict the maintainability of a class by using crisp logic i.e. yes or no. Therefore, for flexibility we need fuzzy logic so that we can say maintainability of a class is low, medium or high. Hence, fuzzy logic provides us flexibility to predict the maintainability of a class in the form of low, medium and high rather than crisp logic.

This paper evaluates the maintainability of Object Oriented software systems using fuzzy logic approach. CK metrics are used as input to the model. The value of each metric is fuzzified into one of three values: Low, Medium and High. A total of 729 fuzzy rules were generated, which were used by the fuzzy inference engine. The values obtained from the fuzzy logic system are validated by using AHP technique. AHP [7] is used since it helps to capture both subjective and objective evaluation measures .Hence the main purpose of this paper is to evaluate software maintainability by using fuzzy layered evaluation method and validate it using Analytic HierarchyProcess.

The rest of the paper is divided into three sections. In Section 2, CK metrics and proposed formula to calculate maintainability is explained. Section 3 explains membership functions of CK metrics and rules generation, applies the proposed model to 15 classes and after that validation of maintainability through AHP technique is done. Finally, section 4 explains the conclusions and the future directions referenced to this paper.

II. Ck Metrics

The CK metric suite mainly focuses on complexity of software. The CK metrics are briefly described as follows:

Metrics	Description
WMC	sum of the complexity of the methods of a class
DIT	The maximum length from the node to the root of the tree
NOC	Number of immediate subclasses sub -

	ordinated to a class in the class hierarchy
CBO	count of the number of other classes to which it is coupled
RFC	numbers of methods invoked from a class
LCOM	Dissimilarity of methods in a class via instanced variables

Table 1: CK Metrics

2.1 Proposed Formula

OurapproachistoderiveformulatomeasureMaintainabilityofa classbasedon CK metric suite:

➢ High WMC indicates greater complexity; it has negative impact on maintainability. Therefore,

$M_t \propto 1/WMC$

$M_t = 1/w_1*WMC$ (i)

➢ High DIT means greater design complexity, so take more time to maintain the software system.

$M_t \propto 1/DIT$

$M_t = 1/w_2*DIT$ (ii)

➢ High NOC indicates means more time and effort required for testing and maintainability.

$M_t \propto 1/NOC$

$M_t = 1/w_3*NOC$ (iii)

➢ High CBO means more complex design. Hence more time and effort required to maintain the software system.

$M_t \propto 1/CBO$

$M_t = 1/w_4*CBO$ (iv)

➢ High RFC indicates means more complex design. Hence maintainability is low.

$M_t \propto 1/RFC$

$M_t = 1/w_5*RFC$ (v)

➢ High LCOM indicates class subdivision is not accurate so decrease maintainability of software.

$M_t \propto 1/LCOM$

$M_t = 1/w_6*LCOM$ (vi)

From equation (i) to (vi), we can conclude that maintainability is inversely proportional to all CK metrics as shown below:

$M_t \propto 1 / (LCOM + CBO + WMC + DIT + NOC + RFC)$

M_t 1 / (w1*WMC + w_2*DIT + w_3*NOC + w_4*CBO + w_5*RFC + w_6*LCOM) (vii)

Where the w_1, w_2, w_3, w4, w_5 and w_6 are the weights to be calculated by AHP technique.

III. Proposed model

In this proposed model we have taken complexity, class, coupling, inheritance, number of children, cohesion as inputs to the MFIS (Mamdani's Fuzzy Inference System) and Maintainability as output to using rule base. We have taken 3 terms like Low, Medium, High and 6 values as input to the system so according to formula, 3^6 rules were developed. Hence, a total of 729 rules were made in this MFIS. After fuzzification process is completed, we took the fuzzy sets for output variable that requires defuzzification. For defuzzification the input will be a fuzzy set and output will be a singleton value. Trapezoidal membershipfunction is used to define the values of membership function as Low, Medium and High for each metric as shown in table 2.

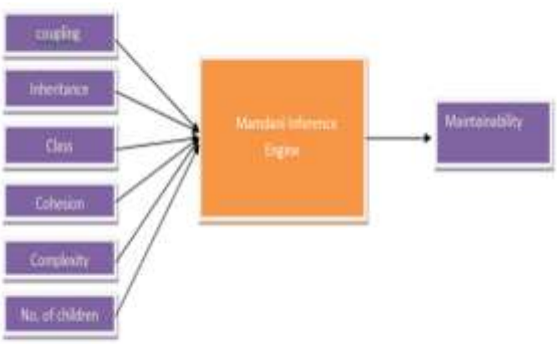

Fig. 1. proposed fuzzy model

3.1 Membership Function for Inputsand Output:

In this paper, three membership functions are defined as –low, medium and high for CK metrics as input. In this MFIS, we have considered six inputs named complexity, class, coupling, and inheritance, number of children, cohesion and maintainability as output. These are shown in figure 3, 4, 5, 6, 7, 8, 9. Table 2 explains the range of membership functions for CK metrics and figure 2 shows the fuzzy logic model in which CK metrics are taken as input and maintainability as output.

Table2. Membership Functions and their Range

Input/ output	Low(mf1)	Medium(mf2)	High(mf3)	Range
WMC	[0 0 5 10]	[5 10 15 20]	[15 20 30 30]	[0 -30]
DIT	[0 0 1 3]	[1 3 4 6]	[4 6 10 10]	[0-10]
NOC	[0 0 2 4]	[2 4 6 8]	[6 8 12 12]	[0-12]
RFC	[0 0 10 20]	[10 20 30 40]	[30 40 60 60]	[0-60]
CBO	[0 0 2 4]	[2 4 5 7]	[5 7 10 10]	[0-10]
LCOM	[0 0 1 3]	[1 3 4 6]	[4 6 10 10]	[0-10]
M_t	[0 0 0.2 0.4]	[0.2 0.4 0.6 0.8]	[0.6 0.8 1 1]	[0-1]

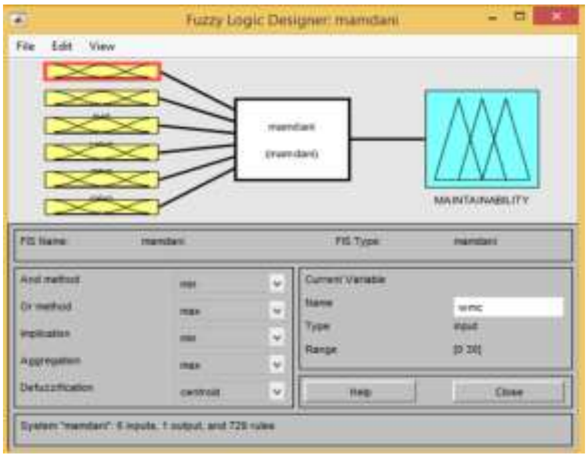

Fig. 2: Mamdani's Fuzzy Inference System

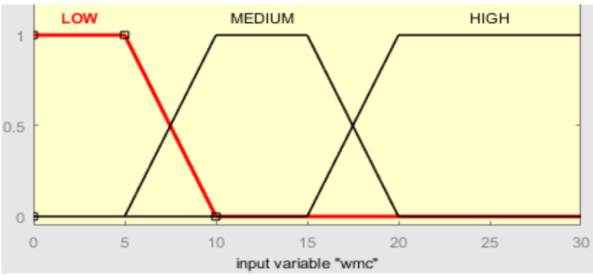

Fig**. 3** : Membership functions of WMC

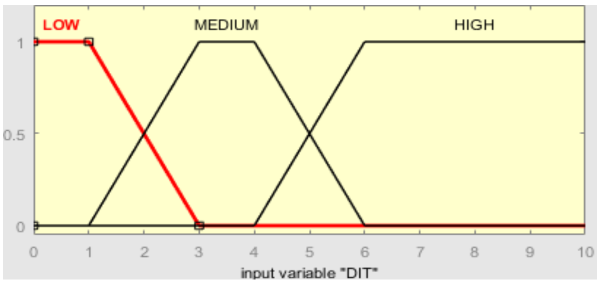

Fig. 4: Membership functions of DIT

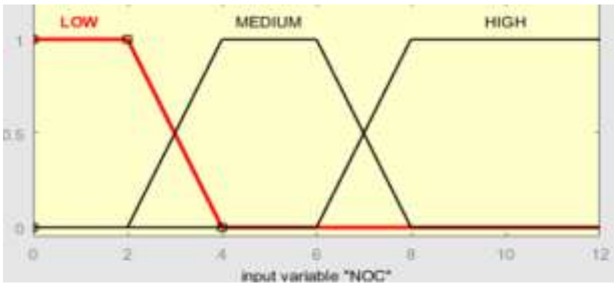

Fig. 5: Membership functions of NOC

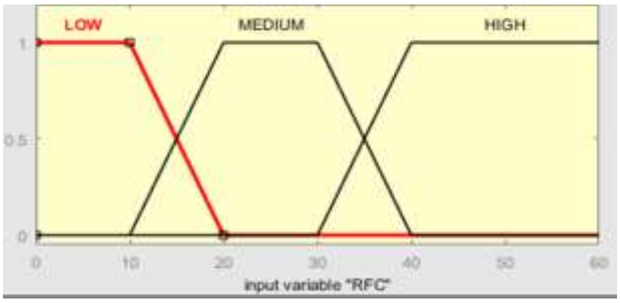

Fig. 6: Membership functions of RFC

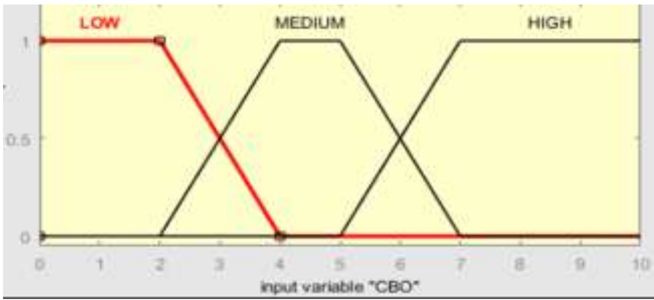

Fig. 7: Membership functions of CBO

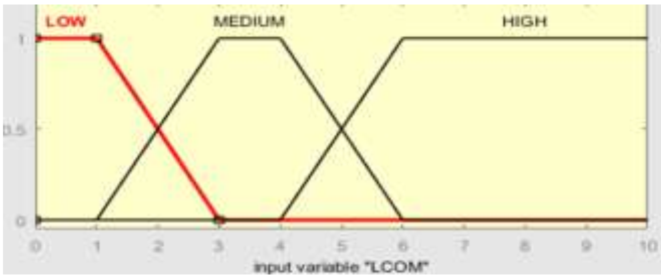

Fig. 8: Membership functions of LCOM

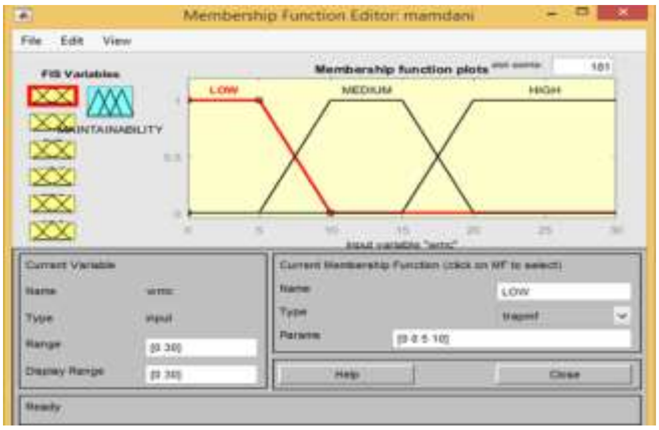

Fig. 9: Membership function of Maintainability

3.2 Rule Base

In this proposed model, we have taken 3 terms for membership function as Low, medium, high and 6 inputs therefore, 3^6 rules were generated. So there are 729 rules were developed. The rules format is shown in table 3. Table 3 shows 20 rules out of 729 rules considering the 20 different types of inputs and corresponding output. In Table 3,M is written for Medium.

Table 3: Rules format

S. NO.	WMC	DIT	NOC	RFC	CBO	LCOM	M_t
1	M	LOW	LOW	LOW	LOW	M	HIGH
2	HIGH	LOW	LOW	M	M	M	M
3	HIGH	HIGH	LOW	M	LOW	LOW	LOW
4	LOW	LOW	LOW	LOW	LOW	M	HIGH
5	LOW	LOW	LOW	LOW	LOW	LOW	HIGH
6	HIGH	HIGH	LOW	HIGH	LOW	M	LOW
7	LOW	LOW	LOW	LOW	M	LOW	HIGH
8	LOW	M	LOW	LOW	LOW	LOW	HIGH
9	M	LOW	LOW	LOW	LOW	LOW	HIGH
10	M	M	M	M	M	M	M
11	M	LOW	LOW	HIGH	HIGH	LOW	LOW
12	HIGH	M	LOW	LOW	LOW	LOW	M
13	HIGH	HIGH	M	M	M	M	LOW
14	HIGH	M	LOW	HIGH	M	LOW	LOW
15	M	M	LOW	LOW	M	M	M
16	HIGH	HIGH	LOW	LOW	LOW	LOW	M
17	LOW	LOW	HIGH	HIGH	M	M	LOW
18	LOW	HIGH	M	M	LOW	LOW	M
19	HIGH	HIGH	HIGH	LOW	M	M	LOW
20	LOW	LOW	M	LOW	LOW	LOW	HIGH

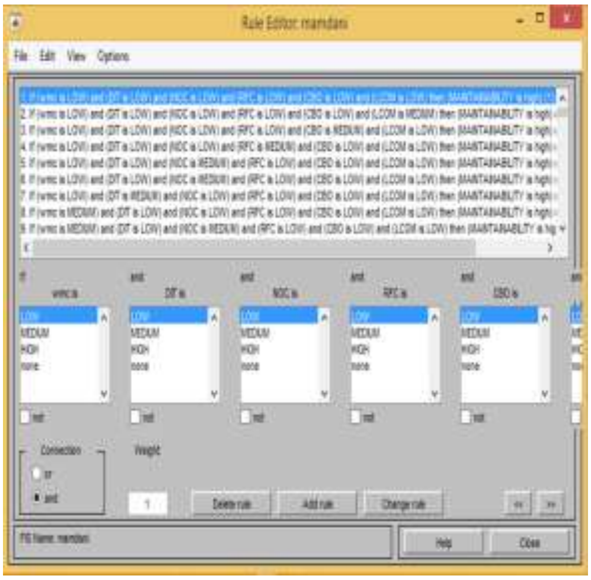

Fig. 10: Rule Editor

Fig. 11: Rule viewer

3.3 Measuring Class Maintainability

The proposed model was applied to 15 classes and based on the values of CK metrics, maintainability of classes is calculated.The results are shown in Table 4.

Table 4: Maintainability of classes

Class	**WMC**	**DIT**	**NOC**	**RFC**	**CBO**	**LCOM**	**Maintainability**
C1	17	0	0	9	0	5	0.63
C2	21	3	0	32	5	5	0.44
C3	28	7	0	36	0	0	0.5
C4	6	3	1	12	3	4	0.63
C5	6	0	0	7	1	0	0.84
C6	25	7	0	46	0	5	0.5
C7	8	3	1	12	1	0	0.60
C8	9	5	0	8	1	2	0.63
C9	12	0	1	18	1	0	0.84
C10	7	0	0	5	1	0	0.83
C11	12	0	0	6	0	0	0.85
C12	26	4	0	30	0	0	0.5
C13	3	0	0	9	3	0	0.83
C14	27	4	2	50	6	1	0.38
C15	15	2	0	25	6	5	0.5

3.4 Validation of ProposedModel

The proposed model is validated using standard AHP (Analytic Hierarchy Process) technique given by Saaty [18]. In table 5,we calculated the values of 6 factors as complexity (C_p), class (Class), coupling (Coup), inheritance (I_h) and Number of children(NOC) and cohesion(c_h).if the value of consistency index is less than 0.1 then the decision value of 6 factors is accepted otherwise it's rejected.

Table 5.values Using AHP Technique

	C_p	Class	Coup	I_h	NOC	C_h	Eigen Vector (w)
C_p	1	1/3	1/3	1/7	1	1/3	0.044
Class	3	1	3	1/7	3	3	0.158
Coupling	3	1/3	1	1/9	2	2	0.092
I_h	7	7	9	1	7	9	0.585
NOC	1	1/3	½	1/7	1	1/3	0.047
C_h	3	1/3	½	1/9	3	1	0.078
Total							1.000

Consistency Index (CI) = (λmax –n)/(n-1) where n=6.
= (6.53-6)/5 = 0.088
Consistency Ratio (CR) = 0.088/1.24 = 0.070 < 0.1 for n=6 index of consistency=1.24 [18].
Hence, decision values are accepted.

The various metrics values of 15 classes is multiplied by their corresponding weight values calculated in table 5, obtained by AHP to get the maintainability of the various classes by putting in equation (vii) In table 6,we compared values obtained from proposed model and AHP technique by putting in proposed formula then relative error and relative root square error is calculated. We got maintainability of different classes almost same to the proposed model as shown in chart 1 below Which shows that proposed model is able to evaluate maintainability of Object Oriented software system and can be used by application developers.

Table 6. Comparison of Proposed Model and AHP values

class	Fuzzy M_t	AHP	RE	RRSE
C1	0.63	0.64	0.01	0.0001
C2	0.44	0.11	0.33	0.108
C3	0.5	0.09	0.41	0.168
C4	0.63	0.20	0.43	0.18
C5	0.84	0.68	0.16	0.025
C6	0.5	0.07	0.43	0.18
C7	0.60	0.25	0.35	0.122
C8	0.63	0.20	0.43	0.18
C9	0.84	0.25	0.59	0.34
C10	0.83	0.84	0.01	0.0001
C11	0.85	0.68	0.17	0.028
C12	0.5	0.12	0.38	0.155
C13	0.83	0.54	0.29	0.084
C14	0.38	0.07	0.31	0.096
C15	0.5	0.14	0.36	0.129

$$\mathrm{MAE} = \frac{1}{n}\sum_{j=1}^{n}|y_j - \hat{y}_j|$$ =0.31 (Mean Absolute Error)

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(y_j - \hat{y}_j)^2}$$ =0.33(Root Mean Square Error)

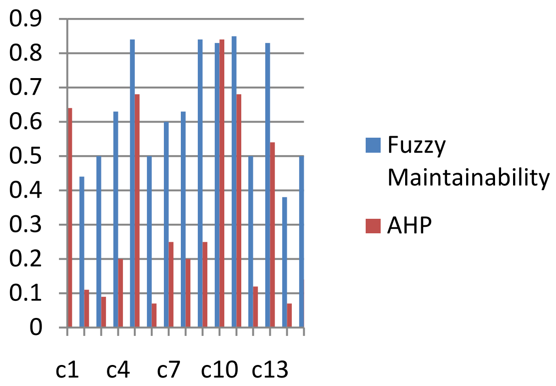

Fig. 12: Fuzzy Maintainability V/S AHP

IV. Conclusion

This paper proposed a MFIS to measure the maintainability of Object Oriented software systems. The inputs for the proposed model are complexity, class, coupling, inheritance, number of children and cohesion and output is maintainability. We proposed a formula based on these inputs to evaluate the maintainability factor using AHP technique. A total of 729 rules were generated for evaluating Object Oriented software systems. The proposed model calculated the maintainability of 15 classes. The results are validated by using AHP technique. The results we obtained from fuzzy model and AHP technique are almost same for all the 15 classes. So, it validates the proposed model. This model is helpful for the software industry to predict the maintainability of Object Oriented software systems in advance. That would be very beneficial for developers too in reference to cost benefits. In future the model will be more refined by taking consideration of other Object Oriented metrics and more number ofprojects. In this paper we have taken only 15 classes, so more work can be done by taking large projects so that maintainability of a project can be calculated easily in advance.

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