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Maintainability Estimation of Component Based Software Development Using Fuzzy AHP

Author
Sengar Dipti
School of Computing Science, Galgotias University
Greater Noida (U.P.)-India
Email: *sengardipti@gmail.com*

Abstract

The analytic hierarchy process (AHP) is a popular method for solving multicriteria analysis (MA) problems involving qualitative data. However, this method is often criticized due to its use of an unbalanced scale of judgements and its inability to adequately handle the inherent products enter the maintenance phase due to the growing application of information systems. Software maintenance is the modification of a software product after delivery to correct faults and improve its overall performance and quality. Easily maintainable software saves large costs and effort involved in developing the uncertainty and imprecision of the pairwise comparison process. A large number of software software. This paper presents a fuzzy approach for estimating maintainability of CBSD in a simple and straightforward manner. The result shows that the approach developed is simple and comprehensible in concept, efficient in computation, and robust in modeling human evaluation processes which make it of general use for solving practical applications.

Keywords:Analytical Hierarchy Process , Fuzzy logic ,Maintainabilty , quality attributes

Introduction

A software product requires a number of measures to be taken into account for its designing. Among all the quality criteria, software maintainability is broadly accepted as a highly signif-icant quality criterion in the economic success of engineering systems and products. There is a need for software engineers to understand how various components of a design interact in order to maintain and enhance the reliability of software dur-ing maintenance. Maintenance of software is one of the most expensive and resource requiring phase of the software devel-opment process. Thus maintainability evaluation is an essential component of modern software development life cycle. Evaluation of software maintainability, if done accurately, can be useful in aiding decision making related to the software, efficiency of the maintenance process, comparing productivity and costs among different projects, allocation of resource and staff, and so on. This minimizes the future maintenance effort [4].Assessing maintainability of a system is a difficult process as many contradictory criteria must be considered in order to reach a decision [5]. Hence a layered approach is used to eva-luate software maintainability [6]. In this approach, fuzzy eval-uation method in combination with Analytic Hierarchy Process (AHP) is utilized to handle problems involving multiple indices based on quantitative procedural information to get the qualita-tive results. AHP [7] is used since it helps to capture both sub-jective and objective evaluation measures, providing a useful mechanism for checking the consistency of the evaluation measures and suggested alternatives thus reducing bias in deci-sion making.The study has been conducted in component based software paradigm. Main aim of CBSD is to construct software by integrating components rather than developing software.For CBSD, there is CBSE(component based software engineering) which is based on design and construction of component based software using Reusable software component and relies on software reuse and emerged from the failure of object oriented development which in turn helps in assessing software qualities such as software defects, testing, and maintenance effort [11]. Hence the main objective of this paper is to evaluate software maintainability by using fuzzy layered evaluation method in combination with Analytic Hie-rarchy Process (AHP).

Literature Survey

Several studies have been conducted to assess maintainability using fuzzy approach. K.K. Aggarwal et al. [12] proposed an integrated measure of software maintainability based of fuzzy theory utilizing three important aspects of software- Readability of Source Code (RSC), Documentation Quality (DOQ), and Understandability of Software (UOS). The analytic hierarchy process (AHP) of Saaty [14, 15] is a popular method for maintainability estimation involving qualitative data, and has successfully been applied to many actual decision situations

Pair wise comparison is used in the decision-making process to form a reciprocal decision matrix, thus transforming qualitative data to crisp ratios and making the process simple and easy

to handle. An eigenvector method is used to solve the reciprocal matrix for determining the criteria importance and alternative performance. The simple additive weighting (SAW) method [4,9] is used to calculate the utility for each alternative across all criteria. However this method is often criticized because of (a) its use of an unbalanced scale of estimations and (b) its inability to

Adequately handle the uncertainty and imprecision associated with the mapping of the DM's perception to a crisp number [5,13].

Buckley [2] and Laarhoven and Pedrycz [12] extend Saaty's AHP to deal with the imprecision and subjectiveness in the pair wise comparison process. Triangular or trapezoidal fuzzy numbers are used to express the DM's assessments on alternatives with respect to each criterion. After the criteria are weighted, the overall utilities of alternatives, known as fuzzy utilities (represented by fuzzy numbers), are aggregated by fuzzy arithmetic [11] using the method. To prioritize the alternatives, their fuzzy utilities need to be compared and ranked. However this comparison process can be quite complex may produce unreliable results due to (a) considerable computations required, (b) inconsistent ranking outcomes with different ranking approaches, And (c) counter-intuitive ranking outcomes under some circumstances [1, 4, 6, and 23]. To facilitate the pair wise comparison process and to avoid the complex and unreliable process of comparing fuzzy utilities, this paper presents an MA approach for effectively solving MA problems involving qualitative data. Triangular fuzzy numbers are used in the pair wise comparison process to express the DMÕs subjective assessments. The concept of fuzzy extent analysis is applied to solve the fuzzy reciprocal matrix for determining the criteria importance and alternative Performance. The concept of fuzzy extent analysis is applied to solve the fuzzy reciprocal matrix for determining the criteria importance and alternative performance. To avoid the complex and unreliable process of comparing fuzzy utilities, the a-cut concept is used to transform the fuzzy performance matrix representing the overall performance of all alternatives with respect to each criterion into an interval performance matrix.

Software Maintainability

According to IEEE standard glossary of Software Engineering, maintainability is ―the ease with which a software system or component can be modified to correct faults, improve performance or other attributes, or adapt to a changed environment [23]. The ISO/IEC-9126 standard [24] describes a model for software product quality that dissects the overall notion of quality into 6 main characteristics: functionality, reliability, usability, efficiency, maintainability, and portability. These characteristics are further subdivided into 27 sub-characteristics.

Maintainability is one of the main criteria, characteristics or contributing attributes towards quality. It is the capability of the software to be modified [24]. It is characterized by the following sub-criteria:

1. Document quality- It is the capability of software to be diagnosed for deficiencies or causes of failures in the software or for identification of parts requiring modification.
2. Changeability- It is the capability of software to enable a specified modification to be implemented.
3. Coupling- It is the indication of strength of interconnection between program units.
4. Testability- It is the ability of software to validate modified software.

Analytical Hierarchy Process

AHP, as proposed by Saaty in 1980, is a multi-criteria decision making method for complicated and unstructured problems and it is also an approach that uses a hierarchical model having levels of goal, criteria, possible sub-criteria, and alterna-tives [25]. With AHP, the decision maker selects the alternative that best meets his or her decision criteria developing a numerical score to rank each decision alternative based on how well each alternative meets them. In other words, it is an approach that is suitable for dealing with complex systems where both qualitative and quantitative aspects need to be considered.

AHP process has been applied to software selection in [32], [33], [34]. A model for bank performance evaluation and rating highlighting CAMEL rating [35] was based

on AHP. AHP has also been utilized in enhancement of financial risk assessment [36]. Data mining along with AHP was used to evaluate a software sys-tem's maintainability according to the ISO/IEC-9126 quality standard in [37]. A fuzzy comprehensive model involving AHP and fuzzy theory for evaluating usability was proposed in [38]. AHP was used in banking crisis resolution in Indonesia [39]. A decision model based on AHP and TOPSIS tech-nique was proposed by [40] in order to help human resources managers in bank and insurance companies in hiring more qualified graduates for their companies. AHP was used in evaluation of software by evaluators with little information technology experience in [41]. A methodology for source code quality and static behavior evaluation of a software system using AHP was proposed by [42]. Application of Excel to cal-culate the weights of software maintainability evaluation based on AHP was recommended in [43]. A multi attributes decision model was recommended to evaluate certain chosen solutions in the case of U.S economic crisis in [44]. AHP was used to examine and evaluate the current e-payment systems in [45]. Furthermore, many applications of AHP developed by various authors can be found in literature.

Methodology

This paper presents a fuzzy MA approach based on the synthesis of the following concepts, including (a) fuzzy set theory, (b) AHP, (c) fuzzy extent analysis, (d) α-cut concept, (e) ideal solution, and (f) vector matching function. As a result, the cognitive burden of the DM is greatly reduced, the subjectiveness and imprecision of the evaluation process are adequately handled, and the complex and unreliable process of

Comparing fuzzy utilities is avoided, resulting in effective decisions being made in solving practical qualitative MA problems.

The ranking procedure starts at the determination of the criteria importance and alternative performance. By using the fuzzy numbers a fuzzy reciprocal judgment matrix for criteria importance (W) or alternative performance with respect to a specific criterion (Cj) can be determined as

$$C_j \text{ or } W = \begin{bmatrix} \bar{a}_{11} & \bar{a}_{12} & \dots & \bar{a}_{1k} \\ \bar{a}_{21} & \bar{a}_{22} & \dots & \bar{a}_{2k} \\ \dots & \dots & \dots & \dots \\ \bar{a}_{k1} & \bar{a}_{k2} & \dots & \bar{a}_{kk} \end{bmatrix},$$

Where,

$$\bar{a}_{ls} = \begin{cases} \bar{1}, \bar{3}, \bar{5}, \bar{9}, & l < s, \\ 1, & l = s, \; l, s = 1, 2, \dots, k; \; k = m \text{ or } n, \\ 1/\bar{a}_{sl}, & l > s. \end{cases}$$

With the application of the fuzzy extent analysis, the corresponding criteria weights (wj) or alternative performance ratings (xij) with respect to a specific criterion Cj can then be determined as

$$x_{ij} \text{ or } w_j = \frac{\sum_{s=1}^{k} \bar{a}_{ls}}{\sum_{l=1}^{k} \sum_{s=1}^{k} \bar{a}_{ls}},$$

Where,
i =1; 2; . . . ; n; j = 1; 2; . . . ;m and k . m or n depending on whether the reciprocal judgments matrix is for assessing the performance ratings of alternatives or the weights of the criteria involved.

As a result, the decision matrix (X) and the weight vector (W) for the MA decision problem can be respectively determined as

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix},$$

$$W = (w_1, w_2, \dots, w_m),$$

Where xij represents the resultant fuzzy performance assessment of alternative Ai .i .= 1; 2; . . . ; n. with respect to criterion Cj and wj is the resultant fuzzy Weight of the criterion Cj .j. =1; 2; . .;m. with respect to the overall objective of the problem. A fuzzy performance matrix Z representing the overall performance of all alternatives with respect to each criterion can therefore be obtained by multiplying the weighting vector by the decision matrix. The arithmetic operations on these fuzzy numbers are based on interval arithmetic [11].

By using an a-cut on the performance matrix, an interval performance matrix can be derived as in , where 0<α<1. The value of a represents the DMOs degree of confidence in his/her fuzzy assessments regarding alternative ratings and criteria weights. A larger a value indicates a more confident DM meaning that the DMO assessments are closer to the most possible value α2 of the triangular fuzzy numbers (a1, a2, a3).

$$Z_\alpha = \begin{bmatrix} [z^\alpha_{11l}, z^\alpha_{11r}] & [z^\alpha_{12l}, z^\alpha_{12r}] & \cdots & [z^\alpha_{1ml}, z^\alpha_{1mr}] \\ [z^\alpha_{21l}, z^\alpha_{21r}] & [z^\alpha_{22l}, z^\alpha_{22r}] & \cdots & [z^\alpha_{2ml}, z^\alpha_{2mr}] \\ \cdots & \cdots & \cdots & \cdots \\ [z^\alpha_{n1l}, z^\alpha_{n1r}] & [z^\alpha_{n2l}, z^\alpha_{n2r}] & \cdots & [z^\alpha_{nml}, z^\alpha_{nmr}] \end{bmatrix}.$$

Incorporated with the DMÕs attitude towards risk using an optimism index

k, an overall crisp performance matrix is calculated as in , where

$$z^{\lambda'}_{ij\alpha} = \lambda z^\alpha_{ijr} + (1-\lambda) z^\alpha_{ijl}, \lambda \in [0, 1].$$

$$Z^{\lambda'}_\alpha = \begin{bmatrix} z^{\lambda'}_{11\alpha} & z^{\lambda'}_{12\alpha} & \cdots & z^{\lambda'}_{1m\alpha} \\ z^{\lambda'}_{21\alpha} & z^{\lambda'}_{22\alpha} & \cdots & z^{\lambda'}_{2m\alpha} \\ \cdots & \cdots & \cdots & \cdots \\ z^{\lambda'}_{n1\alpha} & z^{\lambda'}_{n2\alpha} & \cdots & z^{\lambda'}_{nm\alpha} \end{bmatrix}$$

In practical applications, λ=1, λ=0.5 and.=0 are used to indicate that the DM involved has an optimistic, moderate, or pessimistic view, respectively. An optimistic DM is apt to prefer higher values of his/her fuzzy assessments, while a pessimistic DM tends to favor lower values.

To facilitate the vector matching process, a normalization process in regard to each criterion is applied to , resulting in a normalized performance matrix expressed as :

$$z^\lambda_{ij\alpha} = \frac{z^{\lambda'}_{ij\alpha}}{\sqrt{\sum_{i=1}^{n} (z^{\lambda'}_{ij\alpha})^2}},$$

$$Z^\lambda_\alpha = \begin{bmatrix} z^\lambda_{11\alpha} & z^\lambda_{12\alpha} & \cdots & z^\lambda_{1m\alpha} \\ z^\lambda_{21\alpha} & z^\lambda_{22\alpha} & \cdots & z^\alpha_{2m\alpha} \\ \cdots & \cdots & \cdots & \cdots \\ z^\lambda_{n1\alpha} & z^\lambda_{n2\alpha} & \cdots & z^\lambda_{nm\alpha} \end{bmatrix}.$$

In line with this concept, the positive ideal solution Aα+ and the negative ideal solution Aα-can be determined by selecting the maximum value and the minimum value across all alternatives with respect to each criterion. They respectively represent the best possible and the worst possible results among the alternatives across all criteria.

$$A^{\lambda+}_\alpha = (z^{\lambda+}_{1\alpha}, z^{\lambda+}_{2\alpha}, \ldots, z^{\lambda+}_{m\alpha}),$$
$$A^{\lambda-}_\alpha = (z^{\lambda-}_{1\alpha}, z^{\lambda-}_{2\alpha}, \ldots, z^{\lambda-}_{m\alpha}),$$

where

$$z^{\lambda+}_{j\alpha} = \max(z^\lambda_{1j\alpha}, z^\lambda_{2j\alpha}, \ldots, z^\lambda_{nj\alpha}),$$
$$z^{\lambda-}_{j\alpha} = \min(z^\lambda_{1j\alpha}, z^\lambda_{2j\alpha}, \ldots, z^\lambda_{nj\alpha}).$$

By applying the vector matching function, the degree of similarity between each alternative and the positive ideal solution and the negative ideal solution can be calculated, respectively by

$$S^{\lambda+}_{i\alpha} = \frac{A^\lambda_{i\alpha} A^{\lambda+}_\alpha}{\max(A^\lambda_{i\alpha} A^\lambda_{i\alpha}, A^{\lambda+}_\alpha A^{\lambda+}_\alpha)},$$

$$S^{\lambda-}_{i\alpha} = \frac{A^\lambda_{i\alpha} A^{\lambda-}_\alpha}{\max(A^\lambda_{i\alpha} A^\lambda_{i\alpha}, A^{\lambda-}_\alpha A^{\lambda-}_\alpha)},$$

A preferred alternative should have a higher degree of similarity to the Positive ideal solution, and at the same time a lower degree of similarity to the Negative ideal solution [9,16,19,20,22]. Therefore, an overall performance index for each alternative with the DMO's a level of Confidence in his/her fuzzy assessments and k degree of optimism towards risk can be determined by as

$$P^\lambda_{\alpha i} = \frac{S^{\lambda+}_{i\alpha}}{S^{\lambda+}_{i\alpha} + S^{\lambda-}_{i\alpha}}, \quad i = 1, 2, \ldots, n.$$

The larger the index value, the more preferred the alternative.

The procedure of the AHP for solving these reciprocal matrices is well established [14,15]. Here we only present the overall performance index for each tender and its corresponding ranking. It is clear that tender A1 is the best choice. Same results were obtained with the traditional AHP method and the approach developed.

This would give the DM reasonable assurance in making
Decisions. However in comparison with the traditional AHP method, the approach developed clearly has its advantages. These advantages include (a) better modeling of the uncertainty and
Imprecision associated with the pair wise comparison process, (b) cognitively less demanding on the DM, and (c) adequate rejection of the DMO's attitude toward risk and their degrees of confidence in their subjective assessments.

Conclusion

Although CBSD is increasingly being adopted for software development, but selecting the more appropriate less complex components for CBS to keep its complexity low, is still a difficult task. Thus appropriate evaluation of component maintainability is a critical activity in the component selection process. Hence to improve the AHP method, this paper presents an MA approach using fuzzy pair wise comparison for effectively solving the general MA decision problem involving qualitative data.

The underlying concept of the approach developed is simple and comprehensible, and the computation involved is efficient. In particular, the approach developed can adequately handle the inherent uncertainty and imprecision of the human decision-making process and provide the flexibility and robustness needed for the DM to better understand the decision problem and their decision behaviors. These merits of the approach developed facilitate its use in real situations for making effective decisions.

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