



A fuzzy group analytical hierarchy process approach for software quality assurance management: Fuzzy logarithmic least squares method

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ABSTRACT

This paper proposes a Fuzzy Group Analytical Hierarchy Process approach for assessing the quality of software, with judgments by a group of experts at different levels. The international standard of software quality attributes, ISO/IEC 9126-1:2001 which comprises of 6 criteria with 27 subcriteria, is applied as the attributes of software quality. Regarding the prioritization method, the modified fuzzy Logarithmic Least Squares Method (LLSM) is applied to derive the importance weight vectors. The Fuzzy Prioritization Programming for Direct Rating Scales (FPP-DRS) on the basis of the modified fuzzy LLSM and the rescaling functions is proposed to design the direct rating scales in fuzzy number. The Fuzzy Synthesis Programming for Absolute Measurement (FSPAM) including Integrated Fuzzy Scores of Individual Expert (IFSIE) and Group Integrated Fuzzy Score (GIFS) is proposed to aggregate the criteria values from various experts. The proposed approach can help a group of various experts including developers, testers and purchasers, to measure the level of the software quality of the in-house development or the third party development.

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1. Introduction

A high quality software system is one of the essential attributes of high confidence computer systems. Any malfunctions of the software systems can cause great inconvenience, even a disaster to the users. A high confidence system is a system which meets the standard of software quality. Software quality assurance plays an essential role in the development of such software systems.

Measurement of the software quality includes the measurement of in-house developments and a selection of vendors' products. SQA takes the responsibility to make the "go/not go" decision in this matter. If the quality of the product released or purchased is below standard, the company will suffer a significant loss. If the product development is behind schedule, the company also loses a lot. As it is difficult to build a perfect or error free software system or to purchase highly compatible software components, SQA must apply comprehensive techniques to determine whether the systems reach the right level of quality. These techniques include the clear definition of quality attributes, measurement tools, and the integration framework.

To determine software quality, quality metric models have been studied by many researchers. This research selects six attributes with 27 subcriteria in ISO/IEC 9126-1 (2001), which is the revision

of 1991 version (ISO/IEC 9126, 1991), for the development of the proposed fuzzy group analytical hierarchy process.

ISO/IEC 9126-1 defines terms for the software quality characteristics and how these characteristics are decomposed into subcharacteristics. The details of this are given in Section 5. ISO/IEC 9126-1, however, does not describe how any of these subcharacteristics could be measured. To address this issue, three more parts are extended: ISO/IEC 9126-2 (2003), ISO/IEC 9126-3 (2003), ISO/IEC 9126-4 (2003). ISO/IEC 9126-2 (2003) defines external metrics which measure the behaviours of the computer-based system that includes the software. ISO/IEC 9126-3 (2003) defines internal metrics which measure the software itself. ISO/IEC 9126-4 defines quality in use metrics which measure the effects of using the software in a specific context of use. However, a drawback of the existing international standards is that they provide very general quality models and guidelines, but are very difficult to apply specific domain (Bertoa, Troya, & Vallecillo, 2006). Expert judgments using the proposed fuzzy group analytical hierarchy process (FGAHP) can be the ideal solution, especially for some subcriteria which are less computable.

Regarding measurement tools and the integration framework including aggregation techniques and synthesis approaches, the analytic hierarchy process (AHP) (Saaty, 1980, 1990, 2005) is the popular approach which enables the user to make decisions to address these issues. The software development of AHP can be found in various researches (e.g. Ossadnik & Lange, 1999; Zhu, Aurum, Gorton, & Jeffery, 2005). The limitation is that the measurement

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scales for the value of the utility function, which is basically numerical and probabilistically judgmental, induce difficulties when making the evaluation. This can be solved by applying linguistic labels, represented by fuzzy numbers, as the scales for the software metrics. Studies in fuzzy AHP (e.g. Boender, de Graan, & Lootsma, 1989; Buyukozkan, Kahraman, & Ruan, 2004; Chang, 1996; Chang, Wu, & Lin, 2008; Chen, Tzeng, & Ding, 2008; Laarhoven & Pedrycz, 1983; Mikehailov & Tsvetinov, 2004; Wang, Elhag, & Hua, 2006, 2008) can be applied to address this limitation.

The outline of this paper is as follows. Section 2 reviews the related works. Section 3 presents the foundations of fuzzy theory. Section 4 presents the generic managerial process of FGAHP. Sections 5–9 illustrate the details of the generic process. Section 5 presents the (ISO/IEC 9126-1, 2001) software quality model which consists of six criteria with 27 subcriteria. Section 6 presents the rating scale schema. Section 7 presents the prioritization methods for deriving fuzzy importance and fuzzy metric scales of the hierarchical criteria using a modified fuzzy LLSM model. Section 8 illustrates the synthesis method to integrate the evaluation scores and importance of the hierarchical criteria. Section 9 shows the case study demonstrating the proposed approach and discussion of the applicability of the proposed model. The Conclusion is in Section 10. The notation summary is shown in the Appendix.

2. Related works

Related research about FGAHP in software quality measurement is rarely found in the literature. Two articles (Buyukozkan et al., 2004; Chang et al., 2008) which are identified address the selection problems.

Buyukozkan et al. (2004) developed a fuzzy AHP approach for the selection of software development strategy. The main problem is that the research used the extent analysis method (EAM) (Chang, 1996) in fuzzy AHP, which has been used in many studies as it is regarded as less complex than other methods. However, the recent research from Wang, Luo, & Hua (2008) pointed out that EAM was problematic. Wang et al. (2006, 2008) proposed a Modified Fuzzy Logarithmic Least Squares Method (MF-LLSM) as the appropriate alternative (Boender et al., 1989; Laarhoven & Pedrycz, 1983). The modified fuzzy LLSM is applied in this paper.

Chang et al. (2008) proposed fuzzy AHP for the selection of software projects using 21 subcriteria only (there should be 27 according to the document) in ISO 9126-1:2001. However, firstly, their paper just used ratio relative measurement with its limitations that several projects should be compared, so that the best one among them can be chosen. This paper applies absolute measurement. The advantage of this is that the project is evaluated by itself without any influence from other projects as there is no need to compare among alternatives; but there is a need to understand the performance of the project that is being measured. Secondly, the prioritization method is not determined. Users have to define the two parametric values $\alpha, \beta \in [0, 1]$ to convert the fuzzy numbers into crisp values, and next to integrate the crisp inputs. However, the choices of α and β are infinite. The approach proposed in this paper does not take care of this parametric process as fuzzy aggregation by modified fuzzy LLSM is applied. Thirdly, their output values are not of fuzzy number. The output value of a fuzzy number suggests the reasonable interval for the decision maker. Usually the lower boundary of the fuzzy number is a pessimistic estimation of the quality measurement, the upper boundary is the opposite, and the modal value is the adoptive value. This is the beauty of a fuzzy number. Finally, the two studies (Buyukozkan et al., 2004; Chang et al., 2008) did not include group judgment capability as the aggregation methods appeared not to support this function. Conversely, algorithms of this new approach support group judgments.

3. Fuzzy theory foundations

FGAHP applies fuzzy linguistic labels. A fuzzy linguistic label can be represented by a fuzzy number which is represented by a fuzzy set (Zadeh, 1965, 1975, 1996). Fuzzy sets capture the ability to handle uncertainty by approximate methods. A triangular fuzzy number (TFN) is applied mostly in fuzzy theories and applications. The details are as follows:

If X is a universal set (or universal of discourse) of elements x 's, then a fuzzy set α in X is a set of ordered pairs, i.e. $\alpha = \{(x, \mu_\alpha(x)) : x \in X\}$. μ_α is called the membership function or the grade of membership which defined as $\mu_\alpha : X \rightarrow [0, 1]$.

A TFN is represented by 3-tuple (l, m, u) , and its membership has the form:

$$\mu_\alpha(x) = \begin{cases} \frac{x-l}{m-l}, & l \leq x \leq m \\ \frac{u-x}{u-m}, & m \leq x \leq u, \quad l \leq m \leq u, \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

l is the fuzzy up boundary, and u is the fuzzy low boundary and m is the modal value.

Consider two TFNs $\alpha_1 = (l_1, m_1, u_1)$ and $\alpha_2 = (l_2, m_2, u_2)$. Some of the operational axioms are as follows:

Addition:

$$\begin{aligned} \alpha_1 + \alpha_2 &= (l_1, m_1, u_1) + (l_2, m_2, u_2) \\ &= (l_1 + l_2, m_1 + m_2, u_1 + u_2) \end{aligned} \quad (2)$$

Subtraction:

$$\begin{aligned} \alpha_1 - \alpha_2 &= (l_1, m_1, u_1) - (l_2, m_2, u_2) \\ &= (l_1 - l_2, m_1 - m_2, u_1 - u_2) \end{aligned} \quad (3)$$

Multiplication:

$$\alpha_1 \cdot \alpha_2 = (l_1, m_1, u_1) \cdot (l_2, m_2, u_2) = (l_1 \cdot l_2, m_1 \cdot m_2, u_1 \cdot u_2) \quad (4)$$

Division:

$$\alpha_1 / \alpha_2 = (l_1, m_1, u_1) / (l_2, m_2, u_2) = (l_1 / l_2, m_1 / m_2, u_1 / u_2) \quad (5)$$

Inversion:

$$(l_1, m_1, u_1)^{-1} = (1/(u_1 \cup l_1), 1/m_1, 1/(u_1 \cap l_1)). \quad (6)$$

Eq. (6) is used for fuzzy reciprocal scales which will be discussed in Section 6.

Example 1. Let $\alpha_1 = (5, 6, 7)$, $\alpha_2 = (\frac{1}{4}, \frac{1}{3}, \frac{1}{2})$. Then their memberships are:

$$\mu_{\alpha_1}(x) = \begin{cases} x - 5, & 5 \leq x \leq 6 \\ 7 - x, & 6 \leq x \leq 7, \\ 0, & \text{otherwise} \end{cases} \quad \mu_{\alpha_2}(x) = \begin{cases} 12x - 3, & \frac{1}{4} \leq x \leq \frac{1}{3} \\ 3 - 6x, & \frac{1}{3} \leq x \leq \frac{1}{2} \\ 0, & \text{otherwise} \end{cases}$$

Addition of both is $\alpha_1 + \alpha_2 = (\frac{21}{4}, \frac{19}{3}, \frac{15}{2})$, subtraction of both is $\alpha_1 - \alpha_2 = (\frac{19}{4}, \frac{17}{3}, \frac{13}{2})$, multiplication of both is $\alpha_1 \cdot \alpha_2 = (\frac{5}{4}, 2, \frac{7}{2})$, and division of both is $\frac{\alpha_1}{\alpha_2} = (20, 18, 14)$. Inversions of both are $\alpha_1^{-1} = (\frac{1}{7}, \frac{1}{6}, \frac{1}{5})$ and $\alpha_2^{-1} = (2, 3, 4)$.

4. Overview of FGAHP

The FGAHP Approach is associated with the following five steps:
Step 1: Problem definition analysis:

In this step a hierarchy structure to solve the domain problem is built. The structure includes an objective, single or multiple level(s) of criteria, rating scales for all criteria, and corresponding ex-

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