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Application of the Fuzzy AHP Technique for Prioritization of Requirements in Goal Oriented Requirements Elicitation Process

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Abstract*: Prioritizing software requirements could be viewed as a complex multi-criteria decision making technique problem. The analytic hierarchy process (AHP), a multi-criteria decision making technique, is used in weighting the software requirements. Based on the collected customer requirements and engineering requirements of a product or a system that is to be developed, AHP can be applied in the determination of the importance measures. However, customer requirements may contain ambiguity and multiplicity of meaning. The descriptions of customer requirements may be linguistic and vague. In order to model this kind of uncertainty in human preference, fuzzy sets could be incorporated with the pairwise comparison as an extension of AHP. The fuzzy AHP approach allows a more accurate description of the decision-making process, in the cases when the descriptions of requirements are linguistic in nature. In this research paper, a fuzzy AHP approach is used for the prioritization of requirements for an Institute Examination System.

Keywords: Requirements prioritization, Fuzzy set theory, Fuzzy AHP.

I. INTRODUCTION

Requirement Engineering is the branch of science that aims to make system requirements clear and understandable so that they reflect the actual needs of the customers. It is a multi-disciplinary approach which encompasses other fields also like the social and cognitive sciences to endow with theoretical grounds, practical knowledge and techniques for requirements elicitation and analysis. Requirements elicitation is the process through which the customer and the developer of a software system discover, review, articulate, and understand user needs and verifies user requirements through discussion. It is the earliest phase of software development and has the maximum impact on the product in the long run. Hence properly gathered requirements have great influence on the design phase of software development (Sommerville, 2001). In practice, only a limited set of requirements can be implemented in one release, but the product should also meet the stakeholders' expectations.

Goals have long been recognized to be essential components involved in the requirements engineering(RE) process (Ross and Schoman, 1977). Goal-oriented requirements elicitation process is concerned with the use of goals for eliciting, elaborating, structuring, specifying, analyzing, negotiating, documenting, and modifying requirements. This Goal-oriented requirements elicitation process is very important because it helps in defining the main goal and capturing the various objectives that the system under consideration for development must achieve.

Requirements prioritization is a process that helps in identifying the most valuable requirements from the set that contains several requirements (Sommerville and Sawyer, 1997). The process of prioritizing requirements provides support for the stakeholders to decide the core requirements for the system and to plan and select an ordered, optimal set of software requirements for implementation (Karlsson, 1998). The ultimate goal of any software organization is to create systems that meet the stakeholder demands (Wiegers, 1999). Since there are usually more requirements than can be implemented, decision makers must face the problem of selecting the right set of requirements. By selecting a subset of the requirements that are valuable for the customers, and that can be implemented within budget, organizations can become more successful in the market (Yeh, 1992). Requirements prioritization plays an important role in the requirement engineering process. Selecting the right set of requirements for a product release largely depends on how successfully the requirements are prioritized.

II. FUZZY AHP TECHNIQUE

A major contribution of fuzzy set theory is its capability of representing vague data (Erensal et al., 2002). Fuzzy sets and fuzzy logic are powerful mathematical tools for modeling: uncertain systems in industry, nature and humanity; and facilitators for common-sense reasoning in decision making in the absence of complete and precise information (Saaty, 1994). The fuzzy set theory has been introduced by Zadeh and it is oriented towards the rationality of uncertainty due to imprecision or vagueness (Zadeh, 1965).

A fuzzy number is a fuzzy quantity M that represents a generalization of a real number r. Fuzzy numbers is the special classes of fuzzy quantities. Intuitively, M(x) represents a measure of how well M(x) "approximates" r (Zimmermann, 1996 and Nguyen and Walker, 2000 and). A fuzzy number is characterized by a given interval of real numbers, each with a grade of membership between 0 and 1. It is possible to use different fuzzy numbers according to the situation. Generally in practice triangular fuzzy numbers are used (Klir et al., 1995 and Kahraman, 2001). In applications it is often convenient to work with triangular fuzzy numbers (TFNs) because of their computational simplicity, and they are useful in promoting representation and information processing in a fuzzy environment (Kahraman et al., 2002 and Ertugrul et al., 2007). TFNs are defined by three real numbers, expressed as (l, m, u). The parameters l, m, and u, respectively, indicate the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event (Zadeh, 1965 and Klir and Yuan, 1995). There are various operations that can be performed on triangular fuzzy numbers such as addition, subtraction, multiplication etc.

Let $A_1 = (a_1, b_1, c_1)$ and $A_2 = (a_2, b_2, c_2)$ then:

Addition:-

$A_1+A_2 = (a_1+a_2, b_1+b_2, c_1+c_2)$ (1)

Subtraction:-

$A_1-A_2 = (a_1-c_2, b_1-b_2, c_1-a_2)$ (2)

Multiplication:-

$A_1.A_2 = (a_1.a_2, b_1.b_2, c_1.c_2)$ (3)

Division:-

$A_1/A_2 = (a_1/c_2, b_1/b_2, c_1/a_2)$ (4)

Inverse:-

$A_1^{-1} = (1/c_1, 1/b_1, 1/a_1)$ (5)

Negation:-

$A_1 = (-c_1, -b_1, -a_1)$ (6)

Analytic Hierarchy Process (AHP), proposed by Saaty is a powerful decision-making process in order to determine the priorities among different criteria (Saaty, 1980). However, this process is inadequate for dealing with the imprecise or vague nature of linguistic assessment. In FAHP, the pairwise comparisons of both criteria and the alternatives are performed through the linguistic variables. In this approach fuzzy numbers are used for the preferences of one criterion over another and then the synthetic extent value of the pairwise comparison is calculated (Saaty, 1980). Fuzzy Analytic Hierarchy Process embeds the fuzzy theory to Analytic Hierarchy Process. In fuzzy AHP, linguistic statements have been used in the pairwise comparison which can be represented by the fuzzy numbers (Erensal, 2006). The steps of FAHP technique working are described below:-

Step 1: The value of fuzzy synthetic extent with respect to the TFN (M_{gi}^{j}) is defined as-

$Si = \sum_{j=1}^{m} M_{gi}^{j} . [\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}]^{-1}$ (7)

where, $\sum_{j=1}^{m} M_{gi}^{j} = (\sum_{j=1}^{m} a_j , \sum_{j=1}^{m} b_j , \sum_{j=1}^{m} c_j)$ (8)

$[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}]^{-1} = [1/\sum_{i=1}^{n} c_i , 1/\sum_{i=1}^{n} b_i , 1/\sum_{i=1}^{n} a_i]^{-1}$ (9)

Step 2: The degree of possibility of $A_1 = (a_1 , b_1, c_1)$ and $A_2 = (a_2, b_2, c_2)$ is defined as-

V (A_2 >= A_1) = hgt (A_1 ∩ A_2) = μ_{A2} (d) (10)

= 1, if b_2 >= b_1 (10.1)

= 0, if a_1 >= c_2 (10.2)

= (a_1 - c_2)/ ((b_2 - c_2) – (b_1 - a_1)), otherwise (10.3)

Step 3: The degree possibility for a fuzzy number to be greater than equal to k fuzzy numbers A_i (i=1, 2, ..., k) is defined as-

V (A >= A_1 , A_2, …, A_k) = V [(A >= A_1) and (A >= A_2) and, …, (A >= A_k)]

= min V (A >= A_i) (11)

d' (X_i) = min V (A_i >= A_k) (12)

The weight vector is given by-

W' = (d'(X_1), d'(X_2), ..., d'(X_n))^T (13)

Step 4: Via normalization, the normalized weight vectors are defined as-

W = (d (X_1), d (X_2), ..., d (X_n))^T (14)

Step 5: The fuzzy weight matrices with TFNs is defined as-

(p_{1ij} , p_{2ij} , p_{3ij}) = (1/n $\sum_{k=1}^{n} p_{1ij}^{k}$, 1/n $\sum_{k=1}^{n} p_{2ij}^{k}$, 1/n $\sum_{k=1}^{n} p_{3ij}^{k}$) (15)

Step 5.1: The fuzzy ratings with quadratic membership function are aggregated in the form of-

($\lambda_{1ij}, \lambda_{2ij}, \lambda_{3ij}/ d_{ij}/ \Delta_{1ij}, \Delta_{2ij}, \Delta_{3ij}$) (16)

where, λ_{1ij} = (w_{2j} - w_{1j}) (p_{2ij} - p_{1ij}) (17)

λ_{2ij} = w_{1j} (p_{2ij} - p_{1ij}) + p_{1ij} (w_{2j} - w_{1j}) (18)

λ_{1ij} = w_{1j} p_{1ij} (19)

Δ_{1ij} = (w_{3j} - w_{2j}) (p_{3ij} - p_{2ij}) (20)

Δ_{2ij} = w_{3j} (p_{3ij} - p_{2ij}) + p_{3ij} (w_{3j} - w_{2j})(21)

Δ_{3ij} = w_{3j} p_{3ij} (22)

d_{ij} = w_{2j} p_{2ij} (23)

Step 5.2: The requirements are defined by means of extended addition and multiplication for

I = 1, 2, 3 in the form of-

($\lambda_{1i}, \lambda_{2i}, \lambda_{3i}$/ ea_i / $\Delta_{1i}, \Delta_{2i}, \Delta_{3i}$) (24)

where, λ_{Ii} = 1/m $\sum_{j=1}^{m}$ λ_{Iij} (25)

Δ_{Ii} = 1/m $\sum_{j=1}^{m}$ Δ_{Iij} (26)

ea_i = 1/m $\sum_{j=1}^{m}$ d_{ij} (27)

Step 5.3: The ea_i of the requirements are defined in the form of-

($\lambda_1, \lambda_2, \lambda_3$/ sum_ea/ $\Delta_1, \Delta_2, \Delta_3$) (28)

where, λ_I = 1/n $\sum_{i=1}^{n}$ λ_{Ii} (29)

Δ_I = 1/n $\sum_{i=1}^{n}$ Δ_{Ii} (30)

sum_ea = 1/n $\sum_{i=1}^{n}$ ea_i (31)

Step 5.4: The extended difference, ea_i - sum_ea, for each requirement is defined in the form of-

$$((\lambda_{1i} - \Delta_1),(\lambda_{2i} + \Delta_2),(\lambda_{3i} - \Delta_3)/ ea_i - sum\_ea /(\Delta_{1i} - \lambda_1),(-\Delta_{2i} - \lambda_2),(\Delta_{3i} - \lambda_3)) \quad (32)$$

Step 5.5: The ranking value of each requirement (A_i ε R) is defined as-

if ($\lambda_{3i} - \Delta_3$) < 0 , ($\Delta_{3i} - \lambda_3$) >= 0 , ea_i >= sum_ea then

$$rv_i = \mu R (A_i - ea, 0) = \beta^+/ (\beta^+ + \beta^-) \quad (33)$$

else if ($\lambda_{3i} - \Delta_3$) <= 0 , ($\Delta_{3i} - \lambda_3$) > 0 , ea_i <= sum_ea then

$$rv_i = \mu R (A_i - ea, 0) = \gamma^+/ (\gamma^+ + \gamma^-) \quad (34)$$

else if ($\lambda_{3i} - \Delta_3$) = 0 , ($\Delta_{3i} - \lambda_3$) = 0 , ea_i = sum_ea then

$$rv_i = \mu R (A_i - ea, 0) = 0.5 \quad (35)$$

else if ($\lambda_{3i} - \Delta_3$) >= 0 , ($\Delta_{3i} - \lambda_3$) > 0 , ea_i >= sum_ea then

$$rv_i = \mu R (A_i - ea, 0) = 1 \quad (36)$$

else if ($\lambda_{3i} - \Delta_3$) < 0 , ($\Delta_{3i} - \lambda_3$) <= 0 , ea_i <= sum_ea then

$$rv_i = \mu R (A_i - ea, 0) = 0 \quad (37)$$

where,

$$\beta^+ = [1/4(\Delta_{1i} - \lambda_1) - 1/3(\Delta_{2i} + \lambda_2) + 1/2(\Delta_{3i} - \lambda_3)] + [1/4(\lambda_{1i} - \Delta_1)(1 - \mu_1^4) + 1/3(\lambda_{2i} + \Delta_2)(1 - \mu_1^3) + 1/2(\lambda_{3i} - \Delta_3)(1 - \mu_1^2)] \quad (38)$$

$$\beta^- = -[1/4(\lambda_{1i} - \Delta_1)\mu_1^4 + 1/3(\lambda_{2i} + \Delta_2)\mu_1^3 + 1/2(\lambda_{3i} - \Delta_3)\mu_1^2] \quad (39)$$

$$\mu_1 = [-(\lambda_{2i} + \Delta_2) + sqrt\{(\lambda_{2i} + \Delta_2)^2 - 4(\lambda_{1i} - \Delta_1)(\lambda_{3i} - \Delta_3)\}]/[2(\lambda_{1i} - \Delta_1)] \quad (40)$$

$$\gamma^+ = [1/4(\Delta_{1i} - \lambda_1)\mu_2^4 + 1/3(-\Delta_{2i} - \lambda_2)\mu_2^3 + 1/2(\Delta_{3i} - \lambda_3)\mu_2^2] \quad (41)$$

$$\gamma^- = -[1/4(\lambda_{1i} - \Delta_1) + 1/3(\lambda_{2i} + \Delta_2) + 1/2(\lambda_{3i} - \Delta_3)] - [1/4(\Delta_{1i} - \lambda_1)(1 - \mu_2^4) - 1/3(\lambda_{2i} + \lambda_2)(1 - \mu_2^3) + 1/2(\Delta_{3i} - \lambda_3)(1 - \mu_2^2)] \quad (42)$$

$$\mu_2 = [(\Delta_{2i} + \lambda_2) - sqrt\{(-\Delta_{2i} - \lambda_2)^2 - 4(\Delta_{1i} - \lambda_1)(\Delta_{3i} - \lambda_3)\}]/[2(\Delta_{1i} - \lambda_1) \quad (43)$$

Step 6: On the basis of highest to lowest ranking values, the requirements are arranged in the decreasing order of the priority.

III. A NUMERICAL EXAMPLE:

A numerical example is illustrated that implement the Fuzzy AHP technique for requirements prioritization of an Institute Examination System (IES). IES is an efficient, integrated and easy to use system for computerizing total examination work of an institute. The system is robust and able to handle large volume of data. This system is used to provide the facility to submit online examination form, conduct online examination and generate the result of the student. Table1 represent the classification of requirements into functional requirements (FR) and non-functional requirements (NFR). There is an AND decomposition among nfr_1, nfr_2 and nfr_3 but there is an OR decomposition among $nfr_{2\text{-}1}$, $nfr_{2\text{-}2}$ and $nfr_{2\text{-}3}$ given in Table 1. Table 2 represents the classification of functional requirements for IES. Table 3 describes the requirements. Table 4 represents the judgment matrix.

Requirements							
FR			NFR				
FR_1	FR_2	FR_3	nfr_1	nfr_2			nfr_3
				$nfr_{2\text{-}1}$	$nfr_{2\text{-}2}$	$nfr_{2\text{-}3}$	

Table 1: Requirements classification

FR															
FR_1			FR_2				FR_3								
fr_9	fr_{12}	fr_{13}	fr_{16}	fr_3	fr_7	fr_{14}	fr_{15}	fr_1	fr_2	fr_4	fr_5	fr_6	fr_8	fr_{10}	fr_{11}

Table 2: Functional requirements classification

FR_1 :- Student Examination Module.
FR_2 :- System Administrator Module.
FR_3 :- Policy Enforcement Module.
fr_1 :- Document retention that is consistent with departmental policies and contemporaneous with the examination.
fr_2 :- Provision of a set of written instructions that document a routine activity followed by the examination system.
fr_3 :- Online conduction of examination.
fr_4 :- Ensurement of software licensing to all the software used by the system.
fr_5 :- Provision of a working tool that can be used to document technical activities.
fr_6 :- Establishing an event that helps in improving the performance of the data access method.
fr_7 :- Display semester result.
fr_8 :- Investment in a user friendly data management system.
fr_9 :- Online submission of examination fee.
fr_{10} :- Involvement of continuous and comprehensive evaluation scheme.
fr_{11} :- Creation of explicit norms regarding data use at the system and student level.
fr_{12} :- Establishment of guidelines for the online submission of examination form.
fr_{13} :- Generation of complete and accurate examination report for the student.
fr_{14} :- Quick upload of any examination related activities.
fr_{15} :- Entry of internal and external marks.

Table 3: Requirements description. (contd.)

fr_{16} :- Online filling of the examination forms and after successful submission of the forms, system will generate examination hall ticket with the following information related to the student- (a) Name of the student. (b) Father's name of the student. (c) Roll number (d) Enrollment number

(e) Examination name (f) Subject name(s) (g) Subject code(s)
NFR :- Trustworthiness
nfr_1 :- Security
nfr_2 :- Reliability
nfr_3 :- Performance
nfr_{2-1} :- Recoverability
nfr_{2-2} :- Adaptability
nfr_{2-3} :- Flexibility

Table 3: Requirements description.

	nfr_{2-1}	**nfr_{2-3}**	**nfr_{2-3}**
nfr_{2-1}	(1, 1, 1)	(0.3, 2.47, 5)	(1, 5, 5)
nfr_{2-2}	(0.2, 0.993, 3)	(1, 1, 1)	(1, 3.4, 5)
nfr_{2-3}	(0.2, 0.42, 1)	(0.2, 0.4, 1)	(1, 1, 1)

Table 4: Judgment matrix.

By applying formula (7), the values obtained are-

$Snfr_{2-1}$ = (2.3, 8.47, 11).(1/23, 1/15.683, 1/5.9) = (0.1, 0.540, 1.864)

$Snfr_{2-2}$ = (2.2, 5.393, 9).(1/23, 1/15.683, 1/5.9) = (0.096, 0.344, 1.525)

$Snfr_{2-3}$ = (1.4, 1.82, 3).(1/23, 1/15.683, 1/5.9) = (0.061, 0.116, 0.508)

By applying formulae (10), (11), (12), (13) and (14), the values obtained are-

$V(Snfr_{2-1} >= Snfr_{2-2}) = 1$

$V(Snfr_{2-1} >= Snfr_{2-3}) = 1$

$V(Snfr_{2-2} >= Snfr_{2-1}) = 0.879$

$V(Snfr_{2-2} >= Snfr_{2-3}) = 1$

$V(Snfr_{2-3} >= Snfr_{2-1}) = 0.490$

$V(Snfr_{2-3} >= Snfr_{2-2}) = 0.644$

$d'(nfr_{2-1}) = 1$

$d'(nfr_{2-2}) = 0.879$

$d'(nfr_{2-3}) = 0.490$

$W' = (1, 0.879, 0.490)^T$

$W = (0.422, 0.371, 0.207)^T$

Therefore, among the non-functional requirements nfr_{2-1}, nfr_{2-2} and nfr_{2-3}, nfr_{2-1} is the most important and has the first priority, nfr_{2-2} has the second priority and nfr_{2-3} has the third priority.

Table 5 and Table 6 represent the triangular fuzzy number scale of linguistic values for FR and the triangular fuzzy number scale of linguistic values for the relationship between FR and NFR respectively.

S. no.	Linguistic values	Triangular fuzzy number
1	VL (Very low)	(0, 0, 0.25)
2	L (Low)	(0, 0.25, 0.5)
3	M (Middle)	(0.25, 0.5, 0.75)
4	H (High)	(0.5, 0.75, 1)
5	VH (Very High)	(0.75, 1, 1)

Table 5: Triangular fuzzy number scale of linguistic values for FR.

S. no.	Linguistic values	Triangular fuzzy number
1	VW (Very weak)	(2, 2, 4)
2	W (Weak)	(2, 4, 6)
3	M (Medium)	(4, 6, 8)
4	S (Strong)	(6, 8, 10)
5	VS (Very strong)	(8, 10, 10)

Table 6: Triangular fuzzy number scale of linguistic values for the relationship between FR and NFR.

Table 7 and Table 8 represent the linguistic values for NFRs and the linguistic values denoting the relationship between FRs and NFRs respectively.

NFRs	**Linguistic values**									
nfr_1	H	L	VH	VH	H	M	L	M	M	M
nfr_2	VH	H	VH	H	M	L	M	VL	H	VL
nfr_3	M	VH	L	H	VH	H	VH	L	VL	L

Table 7: Linguistic values for NFRs.

FRs	**NFRs**			**FRs**	**NFRs**		
	nfr_1	nfr_2	nfr_3		nfr_1	nfr_2	nfr_3
fr_1	S	VS	W	fr_9	S	S	W
	VS	S	VS		S	VS	S
	W	M	S		VS	W	VS
	S	VW	VW		W	S	S
	M	W	S		VW	VS	VS
fr_2	W	S	VS	fr_{10}	VS	S	M
	S	VS	VW		M	M	S
	M	S	S		W	VW	VS
	S	VS	W		VS	VS	S
	VS	S	S		S	M	S
fr_3	S	S	M	fr_{11}	M	VW	S
	VS	M	M		S	W	M
	W	VS	S		W	M	W
	S	W	VS		VW	S	VW
	S	M	S		S	M	S
fr_4	VS	S	VW	fr_{12}	S	S	VS
	W	W	S		VS	VS	W
	M	VS	VS		S	S	S
	VS	M	M		W	M	M
	VW	VW	S		VS	S	M
fr_5	S	S	VS	fr_{13}	M	VW	S
	VS	VS	W		VS	S	S
	S	S	S		S	M	VW
	M	W	M		M	M	W
	S	VS	M		VS	M	S
fr_6	VW	M	S	fr_{14}	VS	S	M
	W	S	M		W	S	S
	M	W	W		S	W	W
	S	VW	VW		W	S	S
	M	S	S		M	S	S
fr_7	S	VS	M	fr_{15}	S	VS	M
	S	W	S		M	M	S
	W	S	W		VW	W	VS
	S	W	S		VS	VS	S
	S	M	S		M	S	S

Table 8: Linguistic values denoting the relationship between FRs and NFRs. (contd.)

fr_8	VW	M	S	fr_{16}	S	S	W
	S	VS	S		VS	S	S
	M	S	VW		W	VS	VS
	M	M	W		S	W	S
	M	VS	S		VS	VW	VS

Table 8: Linguistic values denoting the relationship between FRs and NFRs.

Table 9 and Table 10 represent the fuzzy weight matrix and the fuzzy relationship between FRs and NFRs respectively. Table 11 denotes the values representation of quadratic membership functions and Table 12 represents the quadratic membership functions.

NFRs	Fuzzy weight
nfr1	(0.35, 0.6, 0.8)
nfr2	(0.3, 0.55, 0.75)
nfr3	(0.35, 0.575, 0.75)

Table 9: Fuzzy weight matrix.

FRs	NFRs		
	nfr_1	nfr_2	nfr_3
fr_1	(5.2, 7.2, 8.8)	(4.4, 6, 7.6)	(4.8, 6.4, 8)
fr_2	(5.2, 7.2, 8.8)	(6.8, 8.8, 10)	(4.8, 6.4, 8)
fr_3	(5.6, 7.6, 9.2)	(4.8, 6.8, 8.4)	(5.6, 7.6, 9.2)
fr_4	(4.8, 6.4, 7.6)	(4.4, 6, 7.6)	(5.2, 6.8, 8.4)
fr_5	(6, 8.4, 9.6)	(6, 8, 9.2)	(4.8, 6.8, 8.4)
fr_6	(3.6, 5.2, 7.2)	(4, 5.6, 7.6)	(4, 5.6, 7.6)
fr_7	(5.2, 7.2, 9.2)	(4.4, 6.4, 8)	(4.8, 6.8, 8.8)
fr_8	(4, 5.6, 7.6)	(6, 8, 9.2)	(4.4, 6, 8)
fr_9	(4.8, 6.4, 8)	(6, 8, 9.2)	(6, 8, 9.2)
fr_{10}	(5.6, 7.6, 8.8)	(4.8, 6.4, 8)	(6, 8, 9.6)
fr_{11}	(4, 5.6, 7.6)	(3.6, 5.2, 7.2)	(4, 5.6, 7.6)
fr_{12}	(6, 8, 9.2)	(6, 8, 9.6)	(4.8, 6.8, 8.4)
fr_{13}	(6, 8, 9.2)	(4, 5.6, 7.6)	(4.4, 6, 8)
fr_{14}	(4.4, 6.4, 8)	(5.2, 7.2, 9.2)	(4.8, 6.8, 8.8)
fr_{15}	(4.8, 6.4, 8)	(5.6, 7.6, 8.8)	(6, 8, 9.6)
fr_{16}	(6, 8, 9.2)	(4.8, 6.4, 8)	(6, 8, 9.2)

Table 10: Fuzzy relationship between FRs and NFRs.

4.32_{QF} = (0.5, 2, 1.82/ 4.32/ 0.32, 3.04, 7.04)
3.3_{QF} = (0.4, 1.58, 1.32/ 3.3/ 0.32, 2.72, 5.7)
3.68_{QF} = (0.36, 1.64, 1.68/ 3.68/ 0.28, 2.6, 6)
4.32_{QF} = (0.5, 2, 1.82/ 4.32/ 0.32, 3.04, 7.04)
4.84_{QF} = (0.5, 2.3, 2.04/ 4.84/ 0.24, 2.9, 7.5)
3.68_{QF} = (0.36, 1.64, 1.68/ 3.68/ 0.28, 2.6, 6)
4.56_{QF} = (0.5, 2.1, 1.96/ 4.56/ 0.32, 3.12, 7.36)
3.74_{QF} = (0.5, 1.8, 1.44/ 3.74/ 0.32, 2.88, 6.3)

4.37_{QF} = (0.45, 1.96, 1.96/ 4.37/ 0.28, 2.81, 6.9)
3.84_{QF} = (0.4, 1.76, 1.68/ 3.84/ 0.24, 2.48, 6.08)
3.3_{QF} = (0.4, 1.58, 1.32/ 3.3/ 0.4, 2.72, 5.7)
3.91_{QF} = (0.36, 1.73, 1.82/ 3.91/0.28, 2.67, 6.3)
5.04_{QF} = (0.6, 2.34, 2.1/ 5.04/ 0.24, 2.88, 2.1)
4.4_{QF} = (0.5, 2.1, 1.8/ 4.4/ 0.24, 2.74, 6.9)
3.91_{QF} = (0.45 1.78, 1.68/ 3.91/ 0.28, 2.67, 6.3)
3.12_{QF} = (0.4, 1.46, 1.26/ 3.12/ 0.4, 5.92, 5.76)
3.08_{QF} = (0.4, 1.48, 1.2/ 3.08/ 0.4, 3.02, 5.7)
3.22_{QF} = (0.36, 1.46, 1.4/ 3.22/ 0.35, 2.83, 5.7)
4.32_{QF} = (0.5, 2, 1.82/ 4.32/ 0.4, 3.44, 7.36)
3.52_{QF} = (0.5, 1.7, 1.32/ 3.52/ 0.32, 2.8, 6)
3.91_{QF} = (0.45, 1.78, 1.68/ 3.91/ 0.35, 3.04, 6.6)
3.36_{QF} = (0.4, 1.56, 1.4/ 3.36/ 0.4, 3.12, 6.08)
4.4_{QF} = (0.5, 2.1, 1.8/ 4.4/ 0.24, 2.74, 6.9)
3.45_{QF} = (0.36, 1.55, 1.54/ 3.45/ 0.35, 2.9, 6)
3.84_{QF} = (0.4, 1.76, 1.68/ 3.84/ 0.32, 2.88, 6.4)
4.4_{QF} = (0.5, 2.1, 1.8/ 4.4/ 0.24, 2.74, 6.9)
4.6_{QF} = (0.45, 2.05, 2.1/ 4.6/ 0.21, 2.51, 6.9)
4.56_{QF} = (0.5, 2.05, 1.96/ 4.56/ 0.24, 2.72, 7.04)
3.52_{QF} = (0.4, 1.68, 1.44/ 3.52/ 0.32, 2.8, 6)
4.6_{QF} = (0.45, 2.05, 2.1/ 4.6/ 0.28, 2.88, 7.2)
3.36_{QF} = (0.4, 1.56, 1.4/ 3.36/ 0.4, 3.12, 6.08)
2.86_{QF} = (0.4, 1.38, 1.08/ 2.86/ 0.4, 2.94, 5.4)
3.22_{QF} = (0.36, 1.46, 1.4/ 3.22/ 0.35, 2.83, 5.7)
4.8_{QF} = (0.5, 2.2, 2.1/ 4.8/ 0.24, 2.8, 7.36)
4.4_{QF} = (0.5, 2.1, 1.8/ 4.4/ 0.32, 3.12, 7.2)
3.91_{QF} = (0.45, 1.78, 1.68/ 3.91/ 0.28, 2.67, 6.3)
4.8_{QF} = (0.5, 2.2, 2.1/ 4.8/ 0.24, 2.8, 7.36)
3.08_{QF} = (0.4, 1.48, 1.2/ 3.08/ 0.4,

3.02, 5.7)

Table 11: Values representation of quadratic membership functions. (contd.)

3.45_{QF} = (0.36, 1.55, 1.54/ 3.45/ 0.35, 2.9, 6)
3.84_{QF} = (0.5, 1.8, 1.54/ 3.84/ 0.32, 2.88, 6.4)
3.96_{QF} = (0.5, 1.9, 1.56/ 3.96/ 0.4, 3.34, 6.9)
3.91_{QF} = (0.45, 1.78, 1.68/ 3.91/ 0.35, 3.04, 6.6)
3.84_{QF} = (0.4, 1.76, 1.68/ 3.84/ 0.32, 2.88, 6.4)
4.18_{QF} = (0.5, 2, 1.68/ 4.18/ 0.24, 2.66, 6.6)
4.6_{QF} = (0.45, 2.05, 2.1/ 4.6/ 0.28, 2.88, 7.2)
4.8_{QF} = (0.5, 2.2, 2.1/ 4.8/ 0.24, 2.8, 7.36)
3.52_{QF} = (0.4, 1.68, 1.44/ 3.52/ 0.32, 2.8, 6)
4.6_{QF} = (0.45, 2.05, 2.1/ 4.6/ 0.21, 2.51, 6.9)

Table 11: Values representation of quadratic membership functions.

FRs	NFRs		
fr_1	4.32_{QF}	3.3_{QF}	3.68_{QF}
fr_2	4.32_{QF}	4.84_{QF}	3.68_{QF}
fr_3	4.56_{QF}	3.74_{QF}	4.37_{QF}
fr_4	3.84_{QF}	3.3_{QF}	3.91_{QF}
fr_5	5.04_{QF}	4.4_{QF}	3.91_{QF}
fr_6	3.12_{QF}	3.08_{QF}	3.22_{QF}
fr_7	4.32_{QF}	3.52_{QF}	3.91_{QF}
fr_8	3.36_{QF}	4.4_{QF}	3.45_{QF}
fr_9	3.84_{QF}	4.4_{QF}	4.6_{QF}
fr_{10}	4.56_{QF}	3.52_{QF}	4.6_{QF}
fr_{11}	3.36_{QF}	2.86_{QF}	3.22_{QF}
fr_{12}	4.8_{QF}	4.4_{QF}	3.91_{QF}
fr_{13}	4.8_{QF}	3.08_{QF}	3.45_{QF}
fr_{14}	3.84_{QF}	3.96_{QF}	3.91_{QF}
fr_{15}	3.84_{QF}	4.18_{QF}	4.6_{QF}
fr_{16}	4.8_{QF}	3.52_{QF}	4.6_{QF}

Table 12: Quadratic membership functions.

After applying the steps 5.2 and 5.3, the ea of requirements is in the form of-

3.963_{QF} = (0.445, 1.834, 1.683/ 3.963/ 0.309, 2.921, 6.400)

After applying the steps 5.4 and 5.5, the requirements ranking values are shown in Table 13.

fr_1	0.465
fr_2	0.779
fr_3	0.599
fr_4	0.438
fr_5	0.219
fr_6	0.200
fr_7	0.516
fr_8	0.461
fr_9	0.611
fr_{10}	0.597
fr_{11}	0.294
fr_{12}	0.635
fr_{13}	0.473
fr_{14}	0.512
fr_{15}	0.593
fr_{16}	0.617

Table 13: Requirements ranking values.

In our case study, fr_2 has the highest priority and fr_6 has the lowest priority. Table 14 represents the ranking values of the requirements arranged in the decreasing order of the priority.

fr_2	0.779
fr_{12}	0.635
fr_{16}	0.617
fr_9	0.611
fr_3	0.599
fr_{10}	0.597
fr_{15}	0.593
fr_7	0.516
fr_{14}	0.512
fr_{13}	0.473
fr_1	0.465
fr_8	0.461
fr_4	0.438
fr_{11}	0.294
fr_5	0.219
fr_6	0.200

Table 14: List of the requirements after prioritization.

IV. CONCLUSION

A software development organization invests resources such as capital and human effort in software product development and expects maximal added value from their investments. This means that the providing value to the stakeholders and end users is a necessity for the business of software development companies. However, providing value requires implementing the prioritized set of requirements within the software product. The Fuzzy AHP (FAHP) is the fuzzy extension of AHP to efficiently handle the fuzziness of the data involved in the decision making. FAHP is an effective requirements prioritization technique that involves comparing all the requirements. Hence, FAHP takes the whole system into account during prioritization of requirements. In further studies, the integration of FAHP with some other requirements prioritization techniques can be used to solve multi attribute decision making problems.

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