An Evaluation of Requirements Prioritisation Methods

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Requirements prioritization method is an essential activity in software development to identify most important functionalities of the project within limited resources. This work evaluates various requirements prioritization methods with respect to a number of parameters viz. size of the project, feasibility measure, conflicts resolution, complexity analysis and keeps the developer focused on most suitable prioritization method. To comprehend the needs of stakeholders, this work captures the fuzzy requirements from stakeholders and employs a Multi-Criteria Decision-Making approach to yield a rapid selection of an appropriate prioritization method.

Keywords*: Requirements Prioritisation; MAS (Multi-Agent System); Multi-Criteria Decision-Making method (MCDM)*

I. INTRODUCTION

Requirements prioritization has been emerging as a critical and essential but challenging activity in software development. Budgetary and time constraints often require stakeholders to cautiously prioritize requirements. Requirements prioritization involves identifying most important requirements from the exhaustive list of requirements, both significant and insignificant [21].In case of a small project, industry may fine-tune with any of the informal technique for requirements prioritization. But for large projects, thousands of requirements with hundred of stakeholders may require a formal and well defined requirements prioritization method. This should accommodate a number of issues such as size of the project, negotiation of requirements, feasibility measure, fuzzy concerns of stakeholders and multiple criteria viz. cost, performance, risk etc.[16], [26].This work captures the fuzzy requirements from stakeholders and proposes a Multi-Criteria Decision-Making approach to scrutinize an appropriate prioritization method.

Various requirements negotiation and prioritization techniques reported in [2], [12], [16], [17], [23], [31], [32] possess their salient features. Relationship matrix based prioritization method contemplates multiple perspectives of stakeholders and utilizes the concept of correlation to compute weighted priorities of requirements 17. Wieger' method takes account of various concerns of stakeholders by incorporating cost, value, risk and penalty w.r.t. requirements being prioritized. Comprehensive simulation is used to prioritize the requirements of agile and plan based strategies subject to lowest cost or highest value of requirements [6]. Requirements prioritization using cost and benefit analysis establishes the importance of requested requirements. Analytical Hierarchy Process (AHP) is a decision-making technique with respect to a number of criteria that works on the concept of comparing every two requirements pair wise [12]. Fuzzy AHP resolves the fuzziness associated with requirements by a single decision-maker [35], [36]. Requirements Triage method expresses various concerns of stakeholders with respect to feature sets such as non functional requirements, business goals and other requirements [20].However, these prioritization techniques overlook feasibility of obtaining the candidate requirements as well as the fuzzy concerns of stakeholders. To resolve the feasibility problem and stakeholders' apprehensions, an integrated approach is required that may satisfy all stakeholders and assist the developer to ascertain the essential requirements of stakeholders within constrained resources [31]. In our previous work an Integrated Approach [31] was undertaken with the objective of resolving stakeholders' individual and diverse concerns which may be fuzzy in nature that facilitate developers to obtain a prioritized list of feasible requirements.

It is observed that none of the prioritization methods may be perfect to meet simultaneously all the requirements of an application. A most appropriate prioritization method for one application may not be a perfect fit for another application. A wrong selection of a requirements prioritization method may result in wastage of resources causing customers' dissatisfaction. The overall objective of this work is twofold: (i) to evaluate various prioritization methods with respect to a number of criteria and (ii) to identify the prioritization method most suitable to an application.

The rest of this paper is organized as follows. The Section 2 introduces Multi-Criteria Decision-Making method. Section 3 evaluates prioritization methods from literature followed by their asymptotic complexity. Further our previous work is elaborated with an experimental study to analyse complexity. Section 4 evaluates these prioritization methods with respect to a number of parameters. Section 5 employs multi criteria based method to select an appropriate prioritization method. Section 6 illustrates the proposed method with an experimental study and finally section 7 concludes the paper.

II. INTRODUCTION TO MULTI-CRITERIA DECISION-MAKING METHOD (MCDM)

Multi-Criteria Decision-Making is an analytic method to necessitate the consideration of different courses of action under a number of parameters [9]. MCDM is assumed to yield the best choice out of relevant alternatives w.r.t. a number of criteria. Let $X = \{x_1, x_2 \ldots \ldots x_n\}$ and $C = \{c_1, c_2 \ldots \ldots c_n\}$ be a set of alternatives and a set of criteria characterizing a decision situation, respectively [9].Multi-Criteria Decision-Making evaluates r_{ij}, the relative ratio of the gap an element has from the minimum value and the difference between maximum and minimum value in the range from 0 to 1 using the equation below:

$$r_{ij} = \left(r'_{ij} - \min_{j \in N_m} r'_{ij} \right) \div \left(\max_{j \in N_m} r'_{ij} - \min_{j \in N_m} r'_{ij} \right) \tag{1}$$

Where r'_{ij}, an arbitrary real number employs the degree to which a specific criterion is satisfied by an alternative. If $w_1, w_2 \ldots \ldots w_m$ are weights signifying the relative importance of criteria $c_1, c_2 \ldots \ldots c_m$ in a given application, then weighted average may be computed by the following equation:

$$r_j = \left(\sum_{i=1}^{m} w_i r_{ij} \right) \div \left(\sum_{i=1}^{m} w_i \right) \qquad (j \in N_n) \tag{2}$$

A fuzzy set is characterized by a fuzzy interval of real numbers, each with a grade of membership between 0 and 1. Generally in practice triangular fuzzy numbers are used due to their computational simplicity. Triangular fuzzy numbers are expressed as (l, m, u) and the parameters l, m, and u respectively indicate the smallest value, the most promising value and the largest possible value that describe a fuzzy event [33].Weighted Average Defuzzification method, given below is undertaken to produce quantifiable results for the fuzzy values which are approximate rather than precise[9], [1].
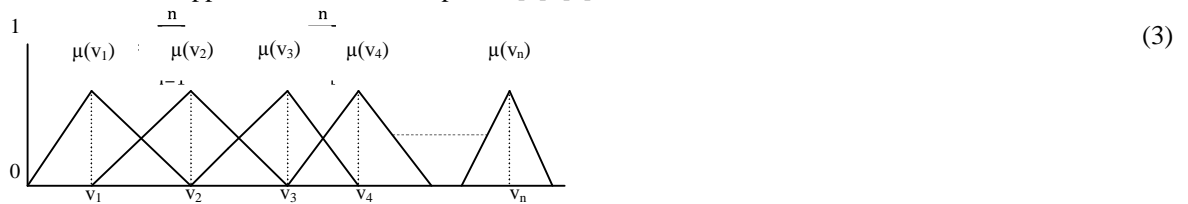
$$\tag{3}$$

Fig. 1.Defuzzification of union of sets i.e. $A_1 \cup A_2 \ldots \cup A_n$

Where d: defuzzified value, v_i: values of the points that define triangular fuzzy set, $\mu(v_i)$: the membership values of the points treated as weights.

Multi-Criteria Decision-Making has been employed in a number of applications such as the selection of infrastructure projects [32], distribution center location [34] and a suitable candidate selection for an organization [8] etc.

III. REQUIREMENTS PRIORITIZATION METHODS

Requirements prioritization assists developers to rank requirements as per their importance. Since, by and large there are more requirements than can be implemented; decision makers cope with selecting the precise set of requirements for their software product[19], [20]. In order to select the correct set of requirements, the decision-makers must comprehend the relative priorities of the elicitated requirements. Various prioritization methods have been accounted in literature with their distinguished methods of computing relative priorities. The objective of this work is to illustrate and evaluate the existing prioritization methods against a number of parameters viz. size of project, feasibility measure, complexity analysis, feature sets, negotiation and conflicts resolution etc. as illustrated in Table 2. This section commences with a brief discussion of prioritization methods followed by their asymptotic complexity and terminates with a concluding complexity analysis.

A. AHP (Analytical Hierarchical Process)

The Analytical Hierarchical Process (AHP) given by Saaty is a very popular method for decision-making subject to requirements prioritization [12],[13]. It works on the concept of building reciprocal matrix by comparing every pair of requirements. Any inconsistency in scales obtained by decision maker may be captured by the consistency ratio. AHP is a decision-making method for prioritizing the requirements with respect to a number of criteria. But it has a number of drawbacks. It works only with a single decision-maker while in real applications various stakeholders are involved to give their different opinions. In real applications, it becomes difficult to assign exactly crisp values for the comparison of requirements. Generally stakeholders have fuzzy and uncertain views about the relative importance of requirements with one another. The AHP does not capture fuzziness inherent in stakeholders' thoughts while comparing requirements pair wise. This method appears to be suitable if there are a nominal number of requirements, but in real applications where thousands of requirements may be there, it becomes cumbersome to deal with this method. In addition to a large number of comparisons, repeated checking of consistency ratio increases the extra efforts of decision-maker.

(1) Asymptotic Complexity of AHP method

Complexity analysis of algorithm is concerned with the determination of resources consumed by program in terms of time and space[4]. The time complexity of AHP method involves computing the time complexity of reciprocal matrix, normalized values, average values, checking of consistency ratio and finally to evaluate all requirements on each criterion.
Say n: number of candidate requirements,
m: number of criteria.
Therefore upper bound of asymptotic complexity employing big-Oh notation results as $O(n^2 \times m)$.

B. Fuzzy AHP (FAHP)

Fuzzy AHP termed as extended form of AHP, also works on the conventional concept of pair wise comparison of requirements except that it captures the vagueness and fuzziness inherent in human thoughts by employing fuzzy linguistic terms on a scale of triangular fuzzy numbers to improve the conventional scaling scheme[35].It is not possible for stakeholders to compare every pair of requirements exactly in crisp terms. For comparison of requirements, they are provided scales in linguistic terms by the developer which are mapped against fuzzy numbers (l,m,u). So obtained fuzzy numbers are converted to crisp intervals $^{\alpha}A$ by α-cut operation [18, 33]:

$$^{\alpha}A = [l^{\alpha}, u^{\alpha}] = [(m - l)\alpha + l, -(u - m)\alpha + u] \tag{4}$$

Crisp values against the crisp intervals $[l_{\alpha}, u_{\alpha}]$ representing the degree of optimism for decision-makers, may be computed as [10], [33]:

$$C_{\alpha i}^{\mu} = \mu\,I_{\alpha u} + (1 - \mu)\,I_{\alpha l}\,, \text{where } \mu \in [0,1] \tag{5}$$

The FAHP inherits all features of AHP such as simplicity of computation, involves less computational expense, lack of cumbersome mathematical operation. In addition to that it has the capability to deal with fuzziness and vagueness inculcated in pair wise comparison.

(1) Asymptotic Complexity of FAHP method

FAHP leads to obtain same upper bound of asymptotic complexity $O(n^2 \times m)$.

C. Wieger's Method (WGM)

Wieger's method computes the priority of a requirement by dividing the value of a requirement by the sum of costs and technical risks associated with it [16]. Pertaining to benefit, penalty, cost and risk associated with a requirement, Wieger suggests the scale 1-9 to set their rating. Value of the requirement may be assessed by the benefit given to customer and the penalty incurred, in case requirement is not accomplished.

(1) Asymptotic Complexity of WGM

Wieger's method does not provide any well defined basis to evaluate value, cost, risk and penalty of a requirement [19]. As this method computes priority value against aforesaid parameters for every requirement, its asymptotic complexity comes to linear order $O(n)$. But missing systematic, structured guidelines and lack of clarity for specifying the scales lead to only rough guesses of prioritization results.

D. Priority Assessment from Multiple Perspectives (PAMP)

This method of requirements prioritization assesses the priority of requirements subject to the multiple perspectives [17]. Prioritizing requirements involves various stakeholders such as users, developers, managers with their own perceptions. In the inception of entire process, low level requirements are captured from various stakeholders and placed under various categories of high level requirements. Firstly, these high level requirements are assigned some priorities by them. Afterwards local priorities of various requirements before every phase of integration are computed using the following equation:

$$P_{R_{i-1}} = P_{R_i} * RD_{i,i-1}\quad \text{where } 1 \le i < n \tag{6}$$

Where $P_{R_{i-1}}$ is the local priority associated with $R_{i-1}{}^{th}$ requirement and $RD_{i,i-1}$ is the relative value calculated by equation:

$$RD_{i,i-1} = n_1/n_2 \tag{7}$$

Where n_1 is the satisfaction degree of R_i and n_2 is the satisfaction degree of R_{i-1} which may be decided by the consensus among stakeholders. The consistency of requirements is checked by the following equation:

$$RD_{i,k} \ne RD_{i,j} * RD_{j,k}\quad \text{iff } 1 \le i, j, k \le n \tag{8}$$

This method takes into account the perception of various stakeholders to reach to a consensual list of prioritized requirements. Though it does not incorporate pair wise comparisons just as is done using AHP, however judging about correlation/cross impact between every two requirements of two perspectives requires traversing of relationship matrix $n_1{}^2$ number of times, where n_1 represents number of requirements captured from each stakeholder/perspective. This method deals with negotiation of requirements from multiple perspectives to eventually obtain a consensual prioritized list of requirements.

(1) Asymptotic Complexity of PAMP

Upper bound of asymptotic complexity for obtaining the integrated set of prioritized requirements be obtained as the summation of complexity associated with computing initial global priorities, consistency checking of prioritized requirements, weighted priorities, normalized priorities, adjusted priorities and final priorities and hence leads to the final asymptotic complexity as $O(n_1{}^3 \times s)$. If n represents total number of requirements collected from all stakeholders/perspectives and s represents number of all stakeholders, then complexity may be represented in terms of n. By replacing n_1 by (n/s) in $O(n_1{}^3 \times s)$ asymptotic complexity so obtained is $O(n^3/s^2)$.

E. Requirements Triage (RT)

Automated Requirements Triage is named as Pirogov that encompasses three stages to obtain a prioritized list of requirements [20]. Initially requirements captured from a large set of stakeholders are organized into a number of clusters of various features using clustering methods. Afterwards these clusters are prioritized manually by human analysts using any of prioritization methods such as AHP, B-Tree or Win-Win reported in literature [12], [21].Moreover for resolving negotiation among stakeholders

at cluster level, out of these methods this paper recommends Win-Win, the collaborative approach most. Finally requirements in clusters are prioritized by computing prioritization score and global priority score.

Proximity scores in building of various clusters, involves three set of variables namely; a set of n requirements captured by stakeholders named as source elements or queries $q=\{q_1,q_2…q_n\}$, a set of n target elements/requirements $\{a_1,a_2..a_j,..a_n\}$ against which similarity measure is computed and $\{t_1,t_2….t_k\}$ represents the stemmed words treated as index terms or key words left after a preprocessing is done for elimination of non-useful words such as conjunctions, adverbs and pronouns[11]. Automation of requirements is achieved by the following equation:

$$PS_r = \sum_{i=1}^{|C|} pr(C_i \,|r)RC_i \tag{9}$$

Where PS_r is prioritization score for a requirement r of a cluster C_i. The following equations used to compute global priority score (GPS) as shown below:

$$GPS = \sum_{j=1}^{|CM|}[(\sum_{i=1}^{|C|} pr(C_i \,|r)RC_{ij})X\ w_j] \tag{10}$$

Once a requirement is classified in a broad variety of clusters such as NFR thereafter is related to attributes security, performance or usability using the following weighted indicator term:

$$P_{r_{Q(t)}} = (1/N_Q \sum_{i=1}^{N_Q} freq(d_{Q,i,t})/|d_{Q,i}|) * (N_{\frac{Q(t)}{N(t)}}) * (NP_{Q(t)}/NP_Q) \tag{11}$$

$P_{rQ}(t)$ measures the extent of presence of a specific attribute Q in a requirement t.$P_{rQ}(t)$ is computed as the multiplication of three terms. First term specifies the average of occurring of requirement t in Q type document d_Q, where $|d_{Q,i}|->$ is the size of document set Q. Second term computes the percentage of Q type documents in total training set N(t). Third term represents the ratio of number of projects containing Q type requirements that incorporate t over number of projects containing Q that do not incorporate term t.

This method possesses the capability to prioritize a very large set of requirements against multiple attributes with significantly reduced human efforts.

(1) Asymptotic Complexity of Requirements Triage

Upper bound of asymptotic complexity of obtaining prioritized list of requirements supported by this semi automated method is obtained by summation of complexity of obtaining clusters , prioritizing requirements within clusters and classifying clusters related to attributes such as security, performance etc. This results in the final complexity of Triage method as $O(n^3)$.

F. An Integrated Approach to Requirements prioritization (IA)

An integrated approach deals with individual and consolidated concerns of the stakeholders so that the system developed on these concerns may obtain the prioritized list of requirements and eventually satisfy all the stakeholders. The details of this method are illustrated in our previous work [31]. This method exclusively incorporates three following steps to obtain a prioritized list of requirements.

i.   Initially deals with capturing the stakeholder's individual concerns with respect to goals and constraints of conflicting requirements and utilizes Yager's method [28], [29] to obtain optimal decision fuzzy set μ^w_{Dk} using the following equation:

$$\tag{12}$$

$$\mu^w_{Dk} = _{k=1,m}[\mu_{G_{k1}}{}^{v_{k1}} \bigwedge \cdots \mu_{G_{kn}}{}^{v_{kn}} \bigwedge \mu_{C_{k1}}{}^{w_{k1}} \cdots \bigwedge \mu_{C_{km}}{}^{w_{km}}]$$

Crisp decision point D_k can be derived by the following equation:

$$D_k = \bigvee_{k=1,m} [\mu_{G_{k1}}{}^{v_{k1}} \bigwedge \cdots \mu_{G_{kn}}{}^{v_{kn}} \bigwedge \mu_{C_{k1}}{}^{w_{k1}} \cdots \bigwedge \mu_{C_{km}}{}^{w_{km}}] \tag{13}$$

$$Where \bigvee = max, \bigwedge = min$$

ii.   Afterwards obtains a value of α against which a compatible total ordering is achieved that ensures the final settlement of conflicting requirements on which all stakeholders would agree [31].

iii.   Finally assists the developers to obtain prioritized list of requirements using goal_points and agent_points.

Following equation is used to compute Weighted Mean (WM) with respect to goal_points.

$$\tag{14}$$
$$WM_i = \left(\sum_{i=1,j=1}^{t,r} GP_{ij} * W_j\right) \qquad where \qquad \sum_{j=1}^{r} W_j = 1$$

ACs are prioritized in terms of feasibility and importance of goals. Arranging ACs in descending order of weighted mean would provide a most productive prioritized list of ACs. Fig. 2 illustrates the priority analysis of various agent cards with respect to agent points and their weighted mean.

This work addresses the fuzziness and vagueness associated with stakeholders' concerns using Fuzzy Multi-Person Decision-Making method and facilitates the developers in prioritizing and deciding which agents are beneficial to achieve in the limited constraints
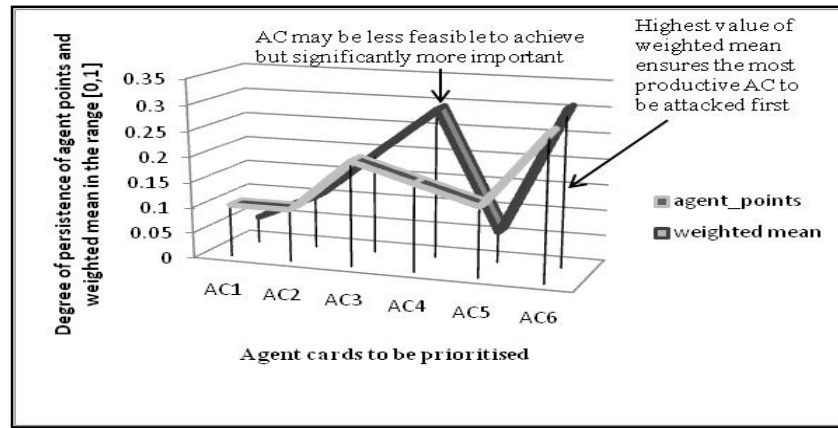
Fig. 2.Priority analysis of various ACs with respect to agent_points, and weighted mean

(1) Asymptotic Complexity of Integrated method

The upper bound of asymptotic complexity of Integrated method is obtained as the summation of complexity of all three steps i.e. individual concerns, consolidated concerns and requirements prioritization. Complexity for obtaining individual concerns is computed in terms of obtaining the intersection of membership value of each goal and constraint w.r.t. every conflicting requirement for every stakeholder [31]. Assuming number of stakeholders as s and conflicting requirements as m, complexity for individual concerns is obtained as $O(m \times s)$. Number of goals g and constraints c not significantly large lead to obtain complexity as $O(1)$. Asymptotic complexity $O(m^3 \times s)$ for requirements negotiation may be obtained as the summation of complexity for obtaining preference orderings, social relation, various α values, α cuts and total ordering. In addition, for obtaining the asymptotic complexity for third step, suppose r is as number of ACs, t as number of goals with each AC and m as number of conflicting requirements. The complexity would be represented in terms of these three parameters i.e. of the order of t x m x r. But as t x r= n: total number of requirements, hence complexity with respect to third step is represented by the order of n and m i.e. $O(m \times n)$. Finally upper bound of asymptotic complexity of an Integrated Approach corresponding to all three steps described above results as $O(m^3 \times s) + O(m \times n)$.

IV. EVALUATING REQUIREMENTS PRIORITIZATION METHODS

The primary objective and challenge before any prioritization method is to ensure the delivery of most essential functionality on time while meeting high customer expectations, tight schedules, and limited resources [13]. Presently a number of prioritization methods available in literature that may roughly be divided in two categories: methods based on (1) multiple criteria and (2) negotiation concept [19]. AHP, Fuzzy AHP, Cost Value Approach, Automated Triage belong to first category and Priority Assessment method encompasses the negotiation approach to compute final priority of requirements. An Integrated Approach encompasses both as it satisfies all stakeholders involved while meeting a number of criteria in the form of conflicting requirements. Wieger's approach also tries to involve a number of stakeholders w.r.t. a number of criteria like cost, value, risk and penalty but lacks a concrete mathematical approach for their consensus. The subsequent subsections evaluate above described requirements prioritization methods against asymptotic complexity and a number of parameters viz. size of the project, feasibility analysis, feature sets , Individual concerns, conflicts resolution etc.

A.   Complexity analysis

This subsection analyses requirements prioritization methods viz. AHP, Wieger's method, Fuzzy AHP, Priority assessment, Automated Triage and an Integrated Approach with respect to their asymptotic complexity. The upper bound of asymptotic complexity using big-Oh notation of all these prioritization methods except Wieger's method and Integrated Approach results in at least $O(n^2)$. If the least upper bound of asymptotic complexity $O(n)$ of Weiger's method considered as an informal method is overlooked, then asymptotic complexity of an Integrated Approach is observed significantly less whilst compared to other prioritization and negotiation algorithms. Hence method described above is capable to deal with feasibility of requirements and resolve conflicting issues among high number of stakeholders at a lower cost of execution time. In spite of having slightly higher complexity in comparison to Wieger's method and significantly lesser than remaining ones, an Integrated Approach appears to be one of the most suited methods pertaining to CPU utilization as shown in Fig. 5.

B.   Intensive Analysis

This subsection discusses an intensive analysis of prioritization methods communicated in section 3against a number of parameters viz. size of project, feasibility measure, feature sets, individual concerns, fuzziness captured, negotiation and conflicts resolution among stakeholders, the results of which are summarized in Table 2.

Table 1.   Analysis of various prioritization methods based on multiple parameters

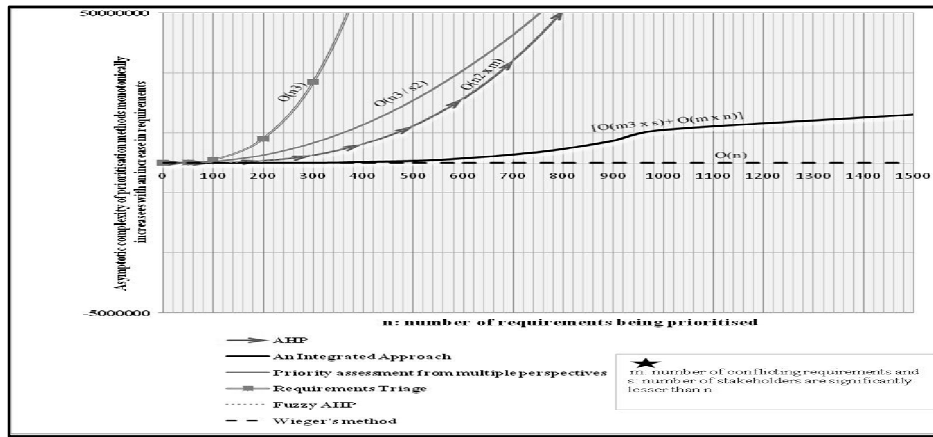| Requirements Prioritization Methods / Multiple criteria identified	AHP (Saaty-1980, Karlsson 1996)	WGM (2003)	FAHP (Sheu-2004, Yajun Yang-2008)	PAMP (2004)	RT (2007)	IA (2010)
Ease of use	expressive	informal	expressive, logic based, formal	expressive, logic based, formal	expressive, logic based, formal	expressive, logic based, formal
Concepts	pair wise comparison	assessment of value of a requirement	pair wise comparison	multiple perspectives based	clustering based	agents, goals, tasks
Multi Criterion	many criteria specific to domain	value, cost, risk, penalty	many criteria specific to domain	high level requirements viz. usability, security, reliability	various clusters such as feature sets, NFRs, business goals and attributes viz. security, performance	conflicting requirements viz. cost, schedule, performance, functionality and risk
Size of the project	small sized and moderate sized	very small sized and small sized	small sized and moderate sized	small sized, moderate sized and high sized	very high sized projects	moderate, high sized and very high sized projects
Feasibility measure	high / weights calculated w.r.t. a number of criteria	less / priorities assigned to requirements	high / weights calculated w.r.t. a number of criteria	less and moderate / final priorities assigned to requirements	High / priority score and priority value assigned to requirement	very high / agent_points, goal_points
Feature Sets	negligible	negligible	negligible	less and moderate level / framed as high level requirements	very high / business goals, functional requirements, NFR, cross cuttings etc.	less and moderate level / framed as ACs
Individual concerns of stakeholders	negligible	negligible	negligible	negligible	negligible	very high / in the form of goals , constraints
Conflicts resolution	negligible	less / during capturing of scales	negligible	less / Implied in an integrated set of requirements	very less / at cluster level or within a cluster	very high / in the form of optimum total ordering high
Requirements negotiation	negligible	negligible	negligible	very high / an integrated set of requirements	very less / at cluster level or within a cluster	not directly but via conflicting requirements
Resolving fuzziness in conflicts resolution	negligible	negligible	negligible	negligible	negligible	very high / preference ordering of conflicting requirements
Resolving fuzziness in comparison of requirements	negligible	negligible	very high / fuzzy scales	negligible	very less / at cluster level	very less
Automation/ implementation	can be automated but requires a lot of manual efforts for doing pair wise comparisons	can partially be automated due to lack of information	can be automated but requires lot of manual efforts for doing pair wise comparisons	can be automated	can be semi automated as prioritization of clusters is achieved manually	can be automated

Fig.5. Prioritization methods compared against complexity parameter

The size of the project may be small, moderate, large or very large determined by the nature of application. Feasibility measure is an appraisal for implementing a requirement within assigned estimates. Feature set has emerged as one of the most important criteria utmost demanded in real time large applications [20]. Similar kind of requirements incorporating common features, require such kind of prioritization method that may orient the prioritization of requirements at feature level instead of going into their micro details.

Thousands of requirements in very large sized projects need to be clustered on feature sets such as business goals, functional requirements, non functional requirements etc. Individual concerns are associated with resolving the personal concerns of stakeholders in decision-making. Fuzziness is concerned with capturing vagueness and uncertainty inherent in human thoughts. Negotiation and conflicts resolution cope with obtaining integrated set of requirements that may satisfy all the stakeholders involved. Fig. 6 exhibits the percentage of existence of these parameters in prioritization methods discussed above.

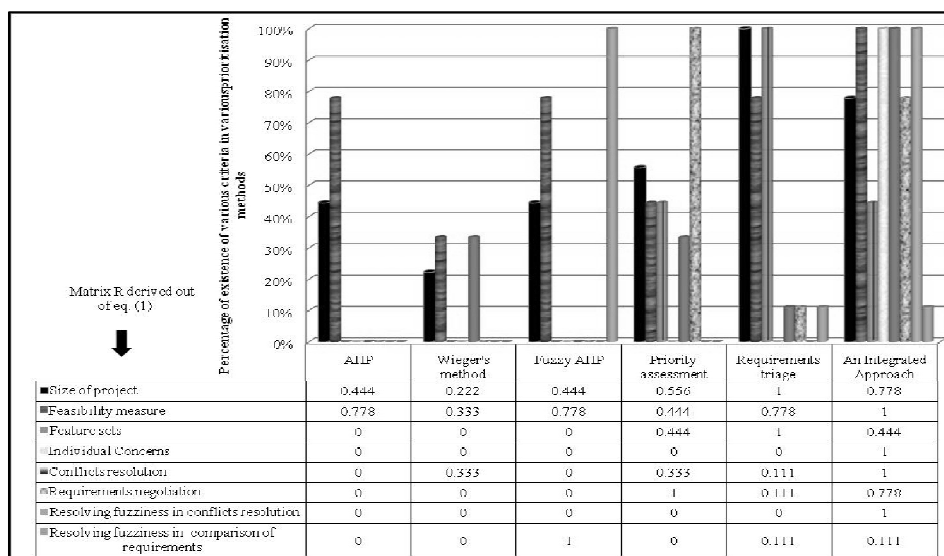|	AHP	Wieger's method	Fuzzy AHP	Priority assessment	Requirements triage	An Integrated Approach
Size of project	0.444	0.222	0.444	0.556	1	0.778
Feasibility measure	0.778	0.333	0.778	0.444	0.778	1
Feature sets	0	0	0	0.444	1	0.444
Individual Concerns	0	0	0	0	0	1
Conflicts resolution	0	0.333	0	0.333	0.111	1
Requirements negotiation	0	0	0	1	0.111	0.778
Resolving fuzziness in conflicts resolution	0	0	0	0	0	1
Resolving fuzziness in comparison of requirements	0	0	1	0	0.111	0.111

Fig.6. A comparative analysis of various prioritization methods w.r.t. multiple criteria

Fig. 6 clearly illustrates that apart from size of the project and feasibility measure, remaining parameters are missing in AHP method. Wieger's method due to an informal method is capable to deal with very small sized project with less intensity of feasibility measure and conflicts resolution. Triage method may direct very large sized projects at their feature sets but lacks fuzziness in individual concerns and conflicts resolution. Likewise feasibility measure, individual concerns, conflicts resolution are utmost accomplished by an Integrated Approach and requirements negotiation by Priority Assessment. Out of all prescribed methods, only Fuzzy AHP and Integrated Approach cope up with the fuzziness inherent in human thoughts.

Because of distinguished features of these requirements prioritization methods, it is observed that one prioritization method is not always perfect to meet the demands of software projects. Selection of an appropriate prioritization method always depends on the nature of the application, size of the project and many other parameters prescribed above[29]. For instance an application, very large in size, consisting of thousands of requirements may need to choose such a prioritization method which may facilitate to cluster feature sets so that time to prioritize requirements may be reduced-Similarly another application involving a very large number of stakeholders having their individual diverse issues which might be subjective in nature may require selection of a method that is capable to resolve their conflicting concerns. Therefore there is a need for some method that may facilitate to choose an appropriate method of prioritization. The subsequent section provides the guide lines to reach to the selection of an appropriate prioritization method.

V. FUZZY MULTI-CRITERIA DECISION-MAKING METHODOLOGY FOR SELECTING PRIORITIZATION METHOD

An effective prioritization method selection procedure for a specific software development system is one of the most significant requirements for organizations. The expense of selecting the weak/wrong prioritization method has forced the companies to be far more concerned regarding selection of a most suitable prioritization method [26].Due to high number of prioritization methods it is necessary to short list and rank prioritization methods according to the characteristics of an application. To reduce cost, error and time there is a strong desire from industries towards two processes:

- Specifying the requirements criteria for a given application to be developed.
- Matching between the profiles of prioritization methods.

The selection of an appropriate prioritization method from a given set of various prioritization methods $X = PM_1, PM_2 \ldots \ldots PM_p$ is guided by comparing their profile with a required profile in terms of given criteria $C = \{C_1, C_2 \ldots \ldots C_c\}$.
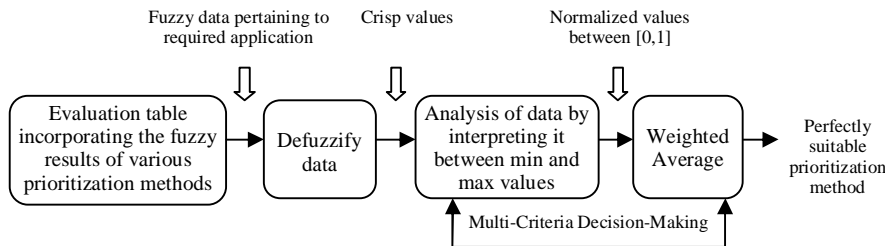

Fig. 7. Framework for selecting most appropriate prioritization method using Fuzzy Multi-Criteria Decision-Making

Procedural steps involved in selecting appropriate requirements prioritization:

(1) Linguistic terms specifying the extent of parameters in various requirements prioritization methods specified in evaluation table viz. Table 2 are converted to its corresponding crisp values using eq. (3).
i.e. $P'=[p_{ij}]'$, where P′ is a matrix consisting of entries p_{ij}, which shows the extent of parameters in crisp form with respect to a number of requirements prioritization methods.

(2) Obtain matrix $P=[p_{ij}]$ consisting of real numbers in [0,1], where each entry p_{ij} expresses degree to which criteria C_j is satisfied by alternative $X_j (i \in c, j \in p)$. P may be viewed as a matrix representation of a fuzzy relation on C x X. Entries of matrix P are obtained using eq. (1) by computing the relative ratio of how far an element is from the minimum value and the gap between maximum and minimum value.

(3) Figure out the weights w_i (i=1..c) from various stakeholders as per the requirement/importance of criteria C_1, C_2…….C_c in a specific application. Linguistic terms/fuzzy weights are converted into corresponding crisp values using eq. (3) and consensual weights between [0,1] are obtained using the following equation :

$$\text{Consensual weight} = \frac{\text{Avg. of crisp weights for various stakeholders}}{\text{max of crisp values}} \qquad (15)$$

Consensual weight facilitates to obtain aggregated weightage/importance of the parameter.
(4) Obtain weighted average for each prioritization method using eq. (2).
(5) Arrange prioritization methods in decreasing order of values of weighted average.

The highest weight will ensure the most suitability of prioritization method for a given application.

A. Experiment and result

To illustrate the application of proposed method, a scenario was considered in a software industry which had to select appropriate requirements prioritization method out of a number of methods described above. The application necessitated rapid selection of elicited requirements in which stakeholders were more concerned for size of the project, frequently occurring feature sets and less apprehensive about their individual and mutual concerns. Table 2 elaborates the degree of persistence of various parameters in subjective terms/linguistic terms in the prioritization methods which eventually using eq.(3) is transformed to matrix R′ exhibiting their corresponding crisp values.

$$R' = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ C_8 \end{array} \begin{bmatrix} AHP & WM & FAHP & PAMP & RT & IA \\ 4 & 2 & 4 & 5 & 9 & 7 \\ 7 & 3 & 7 & 4 & 7 & 9 \\ 0 & 0 & 0 & 4 & 9 & 4 \\ 0 & 0 & 0 & 0 & 0 & 9 \\ 0 & 3 & 0 & 3 & 1 & 9 \\ 0 & 0 & 0 & 9 & 1 & 7 \\ 0 & 0 & 0 & 0 & 0 & 9 \\ 0 & 0 & 9 & 0 & 1 & 1 \end{bmatrix}$$

Matrix R consisting of membership values of various criteria in [0,1] with respect to prioritization methods may be obtained using eq. (1) as exhibited in fig. 6.

Stakeholders involved in a software project express their concerns for the importance of various criteria in linguistic terms as demonstrated in Table 3. The ultimate objective is to obtain a final consensual value of weight for a criterion that may correspond to the views of all stakeholders. Eq. (15) results in consensual weights. Weighted average calculated in Table 4 shows the degree of fitness of prioritization methods in the application with respect to a number of criteria. The resulting weighted average pertaining to the prioritization methods described above, imparts an appropriate ranked list in descending order of their aptness for the application.

Table 3.   Fuzzy/linguistic weights and their crisp values

Stakeholders	Criteria(C)							
	C_1 Size of project	C_2 Feasibility measure	C_3 Existence of feature sets	C_4 Individual Concerns	C_5 Existing mutual conflicts	C_6 Negotiation required	C_7 Fuzziness/ subjectivity required at conflicts time	C_8 Fuzziness/ subjectivity required at comparison of requirements
Stakeholder$_1$	very high 9	moderate 5	very high 9	negligible 0	negligible 0	very less 1	negligible 0	very less 1
Stakeholder$_2$	very high 9	less 3	very high 9	very less 1	negligible 0	very less 1	negligible 0	very less 1
Stakeholder$_3$	very high 9	less and moderate 4	very high 9	negligible 0	very less 1	very less 0	negligible 0	negligible 0
Stakeholder$_4$	very high 9	moderate 5	very high 9	negligible 0	negligible 0	very less 1	negligible 0	very less 1
Average of crisp values	9.0	4.25	9.0	0.25	0.25	1.0	0	0.75

Table 4.   Weighted avg. assigned to various prioritization methods w.r.t. various criteria

Criteria (C)	Consensual weights	Requirements prioritization methods (X)					
		AHP	WM	FAHP	PAMP	RT	IA
C_1	w_1:1.000	0.4440	0.2220	0.4440	0.5550	1.0000	0.7770
C_2	w_2: 0.4722	0.3669	0.1572	0.3669	0.2096	0.3669	0.4722
C_3	w_3: 1.000	0	0	0	0.4440	1.0000	0.4440
C_4	w_4: 0.0277	0	0	0	0	0	0.0277
C_5	w_5: 0.0277	0	0.0092	0	0.0092	0.0030	0.0277
C_6	w_6: 0.1111	0	0	0	0.1111	0.0123	0.0863
C_7	w_7: 0	0	0	0	0	0	0
C_8	w_8:0.0833	0	0	0.0833	0	0.0092	0.0092
$\sum w_i$=	2.7222						
$\sum w_i r_{ij}$ =		0.8109	0.3885	0.8942	1.3290	2.3669	1.8351
$(\sum w_i r_{ij})/(\sum w_i)$		0.3009	0.1441	0.3318	0.4932	0.8784	0.6741

VI.CONCLUSION

As a number of requirement prioritization methods have been devised in literature, this work characterizes these methods with respect to a number of criteria and employs multi criteria based approach to synthesize a most suitable prioritization method for an application. This will assist developer to envisage these methods to address the needs of the stakeholders and enable him in developing product promptly without depletion of resources.

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