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Fuzzy Approach to Prioritize Usability Requirements Conflicts: An Experimental Evaluation

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ABSTRACT The lack of attention to the correlation between the attributes of usability requirements leads to several problems with software development. This paper presents a novel framework that focuses on the mapping of usability requirements attributes to the linguistic assessment from the users using fuzzy logic. Our proposed framework prioritizes conflicting usability requirements attributes. For implementation, we have used MATLAB Fuzzy Logic Tool box. This proposed framework is aimed at helping the requirement analyst in taking better decisions by automating the whole process of identifying and resolving usability requirements conflicts. The major task in the proposed system involves determining the numerical value for each attribute considering their respective importance in different quantitative and qualitative evaluation standards. On the basis of numerical value, conflicts and their respective severities are identified.

INDEX TERMS Human computer interaction (HCI), usability requirements (URs), usability attributes/usability factors, conflict prioritization, fuzzy logic, MATLAB fuzzy logic tool box.

I. INTRODUCTION

The age of ergonomics exploration has drastically altered the consumer's standards of product selection. Unlike our perception of history, now there is great emphasis placed on usability as an important user requirement. It is acknowledged that usability is an integral and important concern in the field of HCI. The first step towards a successful user centered development is the identification of the usability attributes (factors). These usability factors and sub-factors become the basis of usability requirements. These requirements can later be transformed into quantified usability specifications. Software quality factors that have been explored previously, are non-quantifiable [1]–[3]. It is of great importance to gather and compile the usability requirements of all concerned and identify quantitatively the inherent conflicts among them, along with the low level attributes. Equally important is to have these requirements identified at earliest for the convenience of analysis and implementation. The later, these requirements are identified, the more expensive and difficult becomes their analysis and implementation as usability may unknowingly impact software architecture design [4]. We also need to take into consideration the debate on how and why we can enhance usability. Lack of paying attention to such logics, acceptable solution cannot be achieved.

Main concern with usability requirements (URs) is to identify the attributes of URs that are really needed by the users. Usability of a system can be improved by introducing usability attributes to evaluate the usability of a software system [5]. Making it more complex is the fact that the stakeholders, especially the users, do not have an idea about the usability requirements at an early stage. Some of the stakeholders consider one usability requirement important, but others think in different way resulting in emergence of conflicts. In most cases, previous experience can be helpful in making decisions about such conflicts. For example, A conflict among usability requirements can be seen while improving learnability (an attribute of usability), is to develop systems which can direct a user through step by step guidance. However, in some cases, the functionality of the system required to resolve a conflict

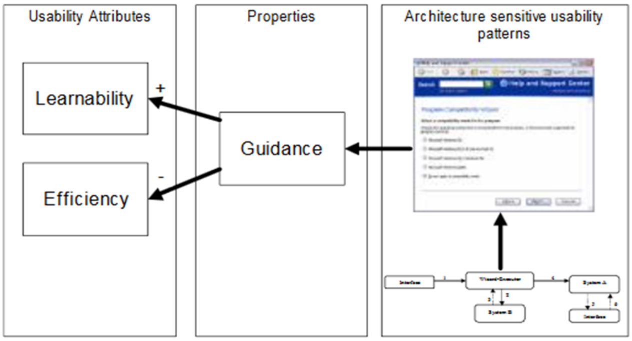

FIGURE 1. Conflict among usability attributes [7] .

can affect the overall efficiency in a negative way [6]. For example, easier to learn systems can be inefficient and harder to learn systems could be more efficient as shown in Fig. 1 [7].

Meeting all the requirements of a variety of stakeholders may not be possible at all times. The ranking of the requirements takes place after collection and analysis of requirements. It is highly recommended to use some software tool for conflict identification [8]. Natural strong interlinking between standard quality aspects [9] make it imperative to highlight it to satisfy all the stakeholders.

In this paper, we have studied existing conflict resolution techniques for their applicability in our problem domain. Our study shows that an appropriate framework that could effectively prioritize conflicts among usability requirements and rank these conflicts is a need of the time. We have found that usability requirements are related to each other in such an intricate manner, that they have inherent conflicts. In order to develop more practical software systems it is highly needed to pay attention to this area. Therefore a framework that can allow to assess the conflicts and quantify the severity of conflicts is suggested to sort out this issue. Our proposed approach is an extension of previous work [10] and therefore extends this already completed work by providing an experimental evaluation for identification and ranking these conflicts to develop more appropriate and usable systems. A novel fuzzy requirement assessment approach is proposed to quantitatively evaluate the set of possible conflicts based on linguistic assessments of usability criteria gathered from the stakeholders. In various fields of daily life decision making plays an important role and usually decisions are made on the basis of information that is almost fuzzy in nature. As the accessible evidence in multicriteria decision making (MCDM) is usually vague or uncertain, so to deal with this uncertainty, fuzzy set theory is used by many researchers and they have developed techniques based on the evidence that human do not think in numeric terms, but they can deal verbal terms or tags of fuzzy sets.

A. CONTRIBUTION OF PROPOSED WORK

Significant investigation has been conducted on the associations and conflicts between quality aspects but not a comprehensive technique is present for prioritizing conflicts among usability requirement attributes separately. A major contribution by introducing this technique is automation and intelligence. This is critical because manual assessment of required usability factors can lead to ambiguities which can potentially cause the project to fail. By introducing an automated and intelligent technique, we achieved a standard which in the case of correct requirement elicitation would always result in correct identification of usability requirement conflicts. This also helps in achieving efficiency as against the human based techniques; proposed intelligent and automated approach would give correct and optimal results in considerably short span of time. Another major achievement of proposed work is in the form of less human resource requirement which would on one hand help in easy scheduling of projects and on the other hand would reduce project cost. Working with our proposed approach also facilitates in making better decisions for negotiation and providing empirical evidence instead of solely relying of previous experience.

The remaining paper is organized as follows; after this brief introduction, Section 2 describes the proposed approach followed by Section 3 consists of implementation and experimental evaluation. Section 4 describes the results while the section 5 discussed the results and last section concludes the paper with the future work description.

II. PROPOSED APPROACH

It is obvious from the previous literature survey and our observation that a new framework for Usability requirement conflicts prioritization is needed. The important feature of our proposed framework is quantification of the conflict for prioritization. The pictorial description of the proposed framework is shown in Figure 2.

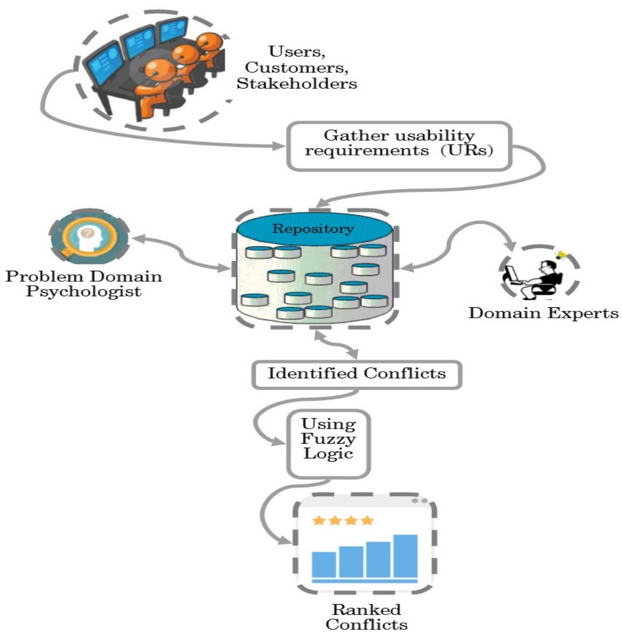

FIGURE 2. Detailed overview framework.

Following steps are involved to carry out this study,

I. Identification of Usability requirement attributes and conflicts among them.
II. Define the input fuzzy values by usability experts.
III. Formulate the rules for relating the inputs to the output by some basic logic operators.
IV. Selecting the membership function and range for each factor (attribute) and sub factor (i.e. Low, medium, and high).

A. IDENTIFICATION OF USABILITY REQUIREMENT ATTRIBUTES AND CONFLICTS

In order to identify conflicts, foremost initial requirement is to map the relationships between usability requirement attributes (Factors and sub factors) at the early stages of software life cycle. In this paper the usability attributes are used considering the facts about usability, particularly focusing on [1], [2], [11]. The definitions of these factors as presented by the authors are:

a) Learnability (ease of learning); new users can easily start work on the system.
b) Efficiency (efficiency of use); professionals can perform their task efficiently.
c) Memorability (easily memorable); those who are not the regular users, can easily recall
d) Errors (less errors); reduced the possibility of errors to occur and easier recovery
e) Satisfaction (pleasing in use); voluntary users feel better and are exultant with the system activity.
f) Effectiveness (more precise and complete); users can attain stated objectives completely with high precision.

In order to sort out the relation among the usability attributes for identification of conflicts a hierarchical order is systematized by authors of this paper in [10].

B. DEFINE THE INPUT FUZZY VALUES BY USABILITY EXPERT

1) FUZZY LOGIC APPROACH TO PRIORITIZE CONFLICTS

The requirements gathered from stakeholders are in linguistic terms. The vagueness in linguistic terms can be sorted out very competently by using fuzzy logic. Fuzzy set theory is characterized by Fuzzy Associative Memories. The distinctive feature of Fuzzy Associative Memories is that these can utilize the domain knowledge about the product and the value judgments of experts and stakeholders about the product. In a fuzzy set theory, an entity may have a membership, symbolized by 1, and may have no membership, symbolized by 0.

Fuzzy sets theory maps the real number to fuzzy numbers [12]. There is an associated membership function in each member of a fuzzy set that handles indefinite information, such as near to 4 or below average. Due to this feature fuzzy set are idyllic to express such attributes those have ambiguity. The fuzzy logic methodology in this research work makes use of a fuzzylogic inference technique that includes the use of the fuzzy set theory, fuzzy set rules and an arbitrary testing for the sake of converting qualitative facts into arithmetical figures [13]. The inference method used here is Mamdani Method [14].

2) MAMDANI METHOD

Mamdani method is extensively acknowledged for holding skilled information. It allows portraying the skills in a more intuitive means just like the way humans do. The rules provided by an expert to constitute the database of rule based systems generally contain imprecisions. Consequently, the method using classical two or multivalued logic cannot be employed for inference in such scenarios. For such situations, [15] and [16] proposed the compositional rule of inference. We have used triangular numbers as the most commonly used forms of fuzzy numbers are triangular and trapezoidal membership functions Fig. 3.

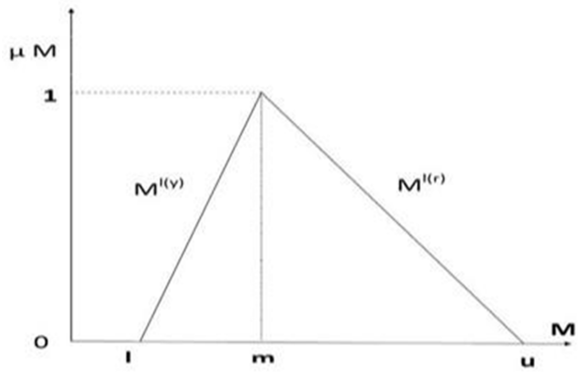

FIGURE 3. Representation of triangular fuzzy numbers.

A Triangular Fuzzy Number can be represented as (l/m, m/u) or (l, m, u), denoted the smallest value, the most feasible value and the biggest promising value respectively The TFN having linear representation on left and right side can be defined in terms of its membership function as

$$\left(\frac{x}{M}\right) = \begin{cases} 0, & x < 1 \\ (x-1)(m-1) & 1 \le x \le m \\ (u-x)(u-m) & m \le x \le u, \\ 0, & x > u, \end{cases}$$

If A= (w1, w2, w3) and B= (x1, x2, x3) are triangular fuzzy Numbers then there operational law using AND operator is A + B = (w1 + x1, w2+ x2, w3+x3).

The main advantages of Mamdani method include its intuitiveness, widespread acceptability and its appropriateness for human input.

C. FORMULATE THE RULES FOR RELATING THE INPUTS WITH THE OUTPUT BY SOME BASIC LOGIC OPERATORS

After identifying conflicts from the repository [10], we formulate tables (See Table 1, Table 2) for assigning fuzzy

TABLE 1. An example of fuzzy assessments for conflicts and attributes impact.

Rules	USABILITY ATTRIBUTE	USABILITY ATTRIBUTE	USABILITY ATTRIBUTE	USABILITY ATTRIBUTE	USABILITY ATTRIBUTE	Conflict
1	High	High	High	High	High	Very Serious
2	High	High	High	High	Medium	Very Serious
3	High	High	High	Medium	Low	Serious
4	High	High	High	Medium	High	Very Serious
...	...	...	...	...	...	...
N	N	N	N	N	N	N

TABLE 2. Scale for conversion of linguistic input to fuzzy triangular values.

	Linguistic input	Fuzzy value
Attribute Priority	Low	0.0, 0.1, 0.3
	Medium	0.2, 0.4, 0.6
	High	0.5, 0.7, 0.9
Conflict Severity	No Conflict	0, 0.1, 0.2, 0.3
	Not Serious	0.1, 0.2, 0.3, 0.4
	Average	0.2, 0.3, 0.5, 0.7
	Serious	0.6, 0.7, 0.8 0.9
	Very Serious	0.7, 0.8, 0.9, 1

values. This involves construction of a mathematical model, consisting of variables and rules in which the fuzzy values assigned and utilized according to the values given in step II for application of Mamdani method. It works on the basis of fuzzy reasoning and has the form of if then conditional statement.

IF ((Condition I is True) AND (Condition II is True)) THEN

⇒ (Result can be inferred)

We can create the rules using strategy of Boolean Algebraic truth table concept. On the basis of this assessment we can formulate the rules as given below:

R1: IF ((Efficiency is high) AND (Learnability is high)) THEN (Conflict will be very serious)

R2: IF ((Efficiency is Moderate) AND (Learnability is high)) THEN (Conflict will be serious)

R3: IF ((Efficiency Low) AND (Learnability is Moderate)) THEN (Conflict will Not Serious)

R4: IF ((Efficiency High) AND (Learnability is Low)) THEN (Conflict will not need to care)

Where

Efficiency = E1, E2, E3, E4,..., En

E1...En are the sub factors of Efficiency and Efficiency is derived from its sub attributes by applying rules like

IF ((E1 is High) AND (E2 is High) AND (E3 is High) AND (E4 is High) AND (E5 is High)) THEN (Efficiency is High)

Other usability attributes are derived in the same way.

In proposed methodology, we are dealing with 6 inputs and each of which needs to give the three verbal values. The rules are formulated in knowledge base on the basis of the possible input combinations. The database and rule base are together termed as the knowledge base. These rules are calculated as: Assume there are J Values corresponding to K inputs, so the maximum number of rules can be calculated using Cartesian artifact of these inputs.

Possible Rules = J*J*J ....*K times

Possible Rules =JK

So here Possible Rules for conflict =(3)(6)=729

Rules for usability attributes derivation are separate from these rules

Fuzzy inference systems perform the following inference operations upon fuzzy if-then rules:

i. Fuzzification is to decide the extent to which the input data meets the condition described in the rules. Here fuzzy inference system plays the role of matching the information given in input to an expected output.

ii. Combine the membership values to get the weight (output) of each rule.

iii. Then it organized the inferred result in an absolute conclusion. At last fuzzy conclusion is converted to a crisp value.

III. EVALUATION

The proposed system is evaluated by applying it on the scenario of an Electronic Healthcare System given bellow:

A. HEALTHCARE SCENARIO

An Electronic Health Care System (EHCS) should be enough usable to facilitate the doctors, nurses and other staff to perform their task smoothly without any hindrance and delay. As well as the system should be pleasant to use with high level of accuracy and extremely low error rate within the specified time period. System operability should be higher by a factor of easy to use. Doctors and nurses can easily access each document to take any action against its results. EHCS should be enough trustworthy to satisfy the patients as well as the Healthcare staff. An Electronic Healthcare System scenario is shown in Fig. 4 and Table 3 presents usability requirements for EHCS.

Usability factors and sub factors describe forms of usability requirements while the current research provides us the opportunity to trace conflicts among them. R1 is an Efficiency requirement for dictation given by the physician arbitrarily. To dictate, the physician must be able to use all the information resources regarding lab tests, nursing credentials and preceding patient information in EHCS. R3 is a Learnability requirement requesting a medium in which it is easy to read and understand the solution. By making the system more

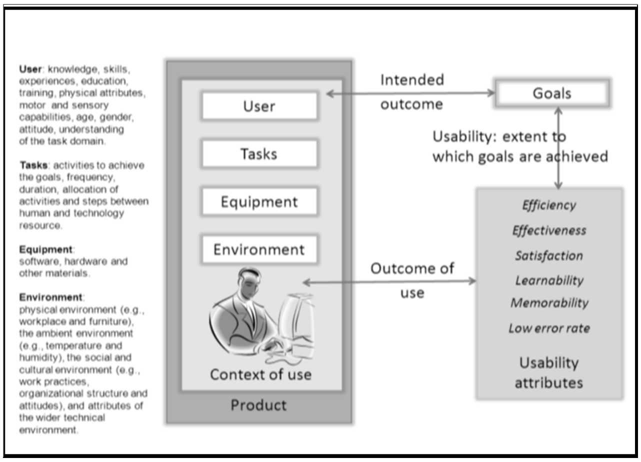

FIGURE 4. Electronic healthcare system.

TABLE 3. Usability requiements for an EHCS.

Requirements for a EHCS	USABILITY Sub-Factors	USABILITY Factors
R1. The physician needs to dictate instantaneously.	Time Efficiency	Efficiency
R2. To dictate, the physician must be able to use all the information resources regarding lab tests, nursing credentials and preceding patient information in (EHCS).	Recourse Efficiency	Efficiency
R3. It should be easy for the nurses to note down dictation and save the physicians comments.	Ease of use	Learnability
R4. Extended suspensions should be tolerated for dictation explanation.	Control ability	Efficiency
R5. At the moment of dictation, the physicians can see the contents of dictation to give the document an expressive way containing all the required information	visibility	Satisfaction
R6. There should be a provision for quiet and self-regulating working.	Consistency	Effectiveness
R7. Dictations should be directed in different context of use and according to the need, e.g. in urgency of switching through documentation should be possible swiftly.	Scalability	Efficiency
R8. There should me an efficient mechanism for accomplishing the everyday jobs.	operability	Efficiency
R9. The system should be spontaneous to cope with patient record (the entry and retrieval of information are a core activity in health care work) using the information systems.	Accessibility	Efficiency
R10. It should be easy to use EHCS so patient record can be easily updated.	Self-Descriptiveness	Learnability
R11. Primary care settings feature a diversity of EHCS users with complex needs and low tolerance for errors.	Error rate	Error
R12. Physicians and nurses need to be able to record a maximum amount of information in a minimum amount of time.	Time Efficiency	Efficiency

learnable it needs to add more functionality that lowers the efficiency of the system. Hence R1 and R3 are conflicting requirements in this scenario (see in Fig. 5(a)). In the same

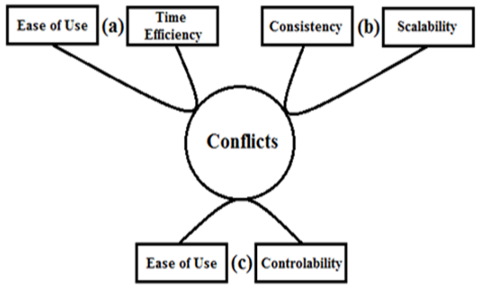

FIGURE 5. Conflicts among usability attributes.

manner we find that R3 and R4 are too in conflict shown in Fig. 5(b). To describe more conflicts, here, we can see that R6 and R7 are also in conflict shown in Fig. 5(c). In a similar fashion like Fig. 5, R9 and R11, R11 and R12 are also conflicting.

Usability expert and domain expert assign the values using scales based on ideas from fuzzy logic according to prioritization of stakeholders shown in Table 4.

TABLE 4. Conflicting sub factors in EHCS.

Factors	Sub Factors	Weights
Efficiency	Controllability	0.89
	Resource efficiency	0.87
	Accessibility	0.98
Learnability	Ease of Use	0.64
	Self-Descriptiveness	0.47
Effectiveness	Consistency	0.83
	Accuracy	0.89
	Quality of Outcome	0.88
Error	Error Rate	0.05
	Error Recovery	0.90

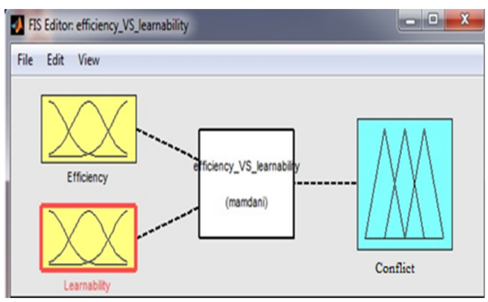

FIGURE 6. Member function efficiency vs learnability.

In our framework, we have defined the member functions for each of the sub-factor that leads to comprise a factor. Firstly, Efficiency vs. Learnabilityİ member functions comparison is generated using Mamdani tool and presented in Fig. 6. For further description of member functions in detail, Efficiency sub-factors i.e. E1, E2, E3, E4, E5 and E6 are presented in Fig. 7(a). Fig. 7(b) and Fig. 7(c) are giving a more clear view of the member function, Efficiency sub-factors El and E2. The rest of the sub-factors are measured,

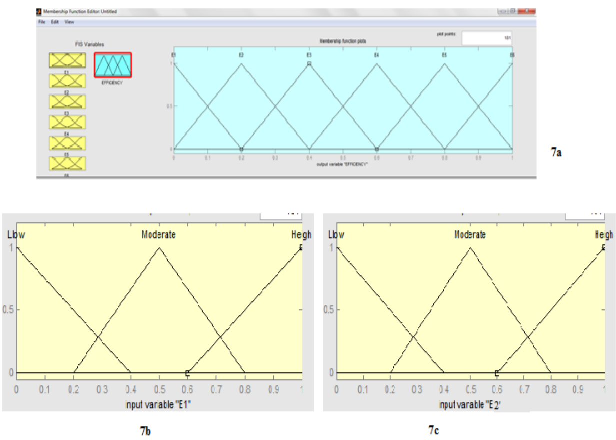

FIGURE 7. Membership function for efficiency attribute .

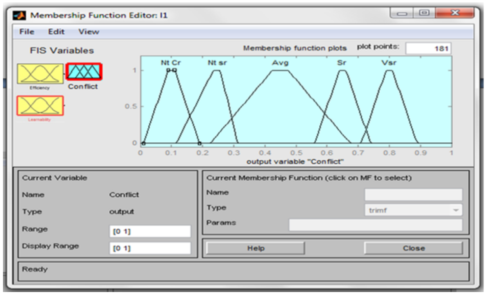

FIGURE 8. Conflict membership function.

using the same way. Membership Function for Conflict is shown in Fig. 8.

After attaining an arithmetical model based on rules and adding rational parameters, input data is fuzzified, processing is conducted in fuzzy realm. Fuzzification is to decide the extent to which the input data meets the condition described in the rules. Here fuzzy inference system plays the role of matching the information given in input to an expected output. It computes conclusion that is inferred from the implemented rules by comparing an input with an illustration of fuzzy systems deposited in the memory. Then it organized the inferred result in an absolute conclusion. At last fuzzy conclusion is converted to a crisp value. The ouput is a single number and this process is called defuzzification.

Fig. 9 and Fig. 10 are the testimony to this fact. Fig. 9 shows the output with a conflict of 0.65 between Efficiency and Learnability when one is moderate and the other is high. Fig. 10 shows a conflict of 0.8 between Efficiency and Learnability when both are highly required. The inferred results are analyzed and discussed in the next section.

IV. RESULTS AND ANALYSIS

Executing the proposed framework over given scenario provides an experimental investigation that examines a phenomenon within its real-life perspective. The point of concern is to be acquainted with the severity of identified conflicts

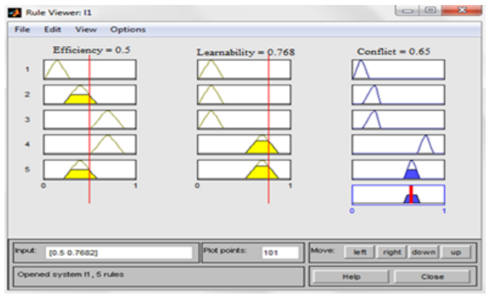

FIGURE 9. Serious conflict .

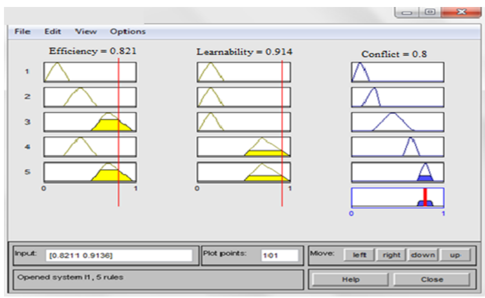

FIGURE 10. Very serious conflict .

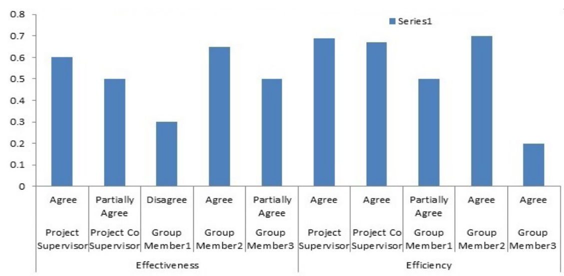

FIGURE 11. Experts reviews for electronic health care system.

that how much they are sever to affect the decision making. As in software development process different stakeholders are involved. They have different points of views against what is significant to them. This is important for any software project and establishes the need for negotiation and decision making on the base of severity of identified conflicts.

A statistical analysis is made to evaluate the proposed approach. For this, some success factors are taken to evaluate results relying upon expert's opinions. This team consist of 20 experts, including Project managers, team leaders, software engineers, Requirement engineer and Requirement analysts. Their reviews are taken and only showed the concluded results in graphical form (Fig. 11). The evaluation is done against two factors, effectiveness and efficiency.

V. DISCUSSION

URs are entirely hard to handle because of their subtle nature and non traceability from all concerns becomes the reason of conflicting requirements. In previous literature the authors recognized the importance of usability requirements, but not a lot of attention is paid to the mapping of usability requirements to its factors and sub factors. To validate our work, we have used the latest evidence about usability sub factors with permissible ranges for numeric attribute values; that are inferred with the help of experts and stakeholders.

On the basis of these cumulative results, it becomes clear that the proposed approach is more flexible and better to identify and prioritize conflicts among usability requirements. This analysis increases the worth of the proposed framework and proves to be a significant move ahead. However, the significance of the role of the analyst in the proposed framework is also being taken into account. It is easy for an analyst to get distracted on a particular area, due to this reason a massive amount of other conflicts will be ignored. But the proposed framework helps to maintain a repository of usability requirements attributes which keeps records of all factors and sub factors of usability requirements. It carries out a proper smash analysis to check the possibility of conflicts among the factors and sub factors of usability requirements. It suggests the conflict among the sub factors on the basis of previous knowledge and automatically prioritizes the conflicts using Fuzzy logic (Mamdani Method). A plus point is that it checks the traceability issues related to the sub-factors and sub sub-factors. It will lessen the rework exertion to sort out the relation among usability attributes for different human interactive systems.

VI. CONCLUSION

Literature review shows that most of the work being carried out in domain of usability engineering lacks any systematic usability assessment technique that focuses on the assessment of the conflicts among usability attributes. It costs a lot of time, rational burden, may be the wrong decision and there is no logical method to make decisions on it. Prioritization of the conflicts among usability attributes is undeniably vital for the development of more usable software systems, we have scrutinized the relationship between usability attributes. Use of the fuzzy logic approach to quantify the conflicts among usability attributes have two advantages: firstly as the data are imprecise, so fuzzy inference is capable of computing such type of data to determine the accurate values. Secondly, fuzzy inference can handle dependencies among variable in the system by decoupling dependable variables. Hence utilization of fuzzy logic helps the ranking procedure by making it trustworthy and accurate. In future center of attention will be on: (a) strengthening of the proposed approach by integrating the entire sub sub-factors of usability attributes in a more comprehensive way. (b) to assist the framework deployment, it is also planned to develop a tool that can facilitate requirement engineers and software developers in managing conflicts among usability requirements automatically.

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