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Usability Evaluation of Software Systems using Fuzzy Multi-Criteria Approach

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Abstract

Over the past few decades, Usability has emerged as an extremely important quality factor. Many methods have so far been proposed for usability evaluation but they lack in one way or another. This paper proposes a method for software usability quantification using the fuzzy multiple criteria weighted average approach. This approach has been chosen due to the highly unpredictable nature of the attributes on which usability depends. A case study is presented to prove the feasibility of the quantification technique.

Keywords: *Evaluation, Fuzzy Multi-Criteria, Fuzzy Weighted Average, Multi Criteria Decision Making, Quality, Usability.*

1. Introduction

Usability can be understood as the extent to which software is usable by different types of users with ease and comfort. Usability has been defined by many researchers in various ways [1] [2] [3] [4] [5] [6] [7] but each definition lacked in covering all of the aspects on which usability of software depends. In this paper we have considered usability to depend on 5 factors namely, Effectiveness, Efficiency, Satisfaction, Comprehensibility and Safety as given in [8]. This model presented an integrated taxonomy including all the concepts, factors and attributes that affect the usability of software systems as found out by various researchers. A representation of this taxonomy is shown in table 1. This model is hierarchical in nature and considers multiple criteria upon which usability depends.

Over the years, with the advancement of technology, there has been an exceptional change in the way user's perceive and compare different software systems. Hence, the demand for usable software has increased, making Usability evaluation a key research area. In spite of having great importance in the software engineering process, evaluation and quantification of usability is difficult.

Various usability evaluation techniques have been given by several researchers but they lack in one way or another as explained in [9].

Assessing usability on the basis of the model given in Table 1 can be considered as a multi-criteria decision making (MCDM) problem because of its complex structure including both tangible and intangible measures. There are mainly four families of MCDM methods as given in [10]: (i) the outranking approach (ii) the value and utility theory based, (iii) the multiple objective programming, and (iv) group decision and negotiation theory based methods. When fuzzy set theory was introduced into MCDM research, different fuzzy ranking methods and fuzzy multiple attribute decision making methods emerged. The first category contains a number of ways to find a ranking: degree of optimality, Hamming, comparison function, etc. The second category is built around methods which utilize various ways to assess the relative importance of multiple attributes, fuzzy simple additive weighting methods, analytic hierarchy process, fuzzy conjunctive / disjunctive methods, etc. The third category is fuzzy mathematical programming which includes flexible programming, possibilistic programming, possibilistic linear programming using fuzzy max, etc.

This paper proposes a methodology for quantifying the usability of software using a fuzzy multi-criteria weighted average approach similar to the one used in [11]. Fuzzy logic helps us to deal with the uncertainty and imprecision of the importance and rating of attributes on which usability depends. A case study is then given to validate the feasibility of this approach.

2. Fuzzy Multi-Criteria Weighted Average Approach

The usability of software depends on certain attributes. These attributes are dependent on several sub-attributes which may be further dependent on several characteristics. This hierarchy structure is represented in figure 1.

Table 1. Taxonomy of Proposed Model

Usability				
Effectiveness	Efficiency	Satisfaction	Comprehensibility	Safety
1. Task Accomplishment a. Quantity b. Quality 2. Operability • Precision • Completeness 3. Universality • Accessibility a. Visual b. Auditory c. Vocal • Cultural Universality a. Language b. Cultural conventions 4. Flexibility • Adaptability a. To User Preferences b. To Environment • Controllability a. Reversibility b. Technical Configurability c. Freedom in tasks 5. Errors	1. User Effort a. Physical b. Mental 2. Finance • System Costs a. Equipment b. Consumables • Human Resource Costs 3. Resource Utilization • Throughput • Command Utilization 4. Performance • Execution Time • Memory Load • Decision Complexity	1. Likeability 2. Trustfulness • Stability • Reputation • Intention 3. Comfort • Use of Product • Design a. Search Facilities b. Motivating c. Chaotic 4. Attractiveness • Aesthetics	1. Clarity • Of Structure /Elements a. Formal b. Conceptual • In Functionality a. User Tasks b. System Tasks 2. Learnability • Simplicity • Intuitive • Time to learn 3. Memorability • Of Structure /Elements a. Formal b. Conceptual • Of Functionality a. User Tasks b. System Tasks 4. Helpfulness • Suitability of Documentation a. Descriptions b. Examples • Interactivity of Assistance • User Guidance	1. User Safety • Physical a. Visual b. Auditory c. Bodily d. Mental • Legal • Confidentiality • Safety of Assets 2. Third Party Safety • Physical a. Visual b. Auditory c. Bodily d. Mental • Legal • Confidentiality • Safety of Assets 3. Environmental Safety • Resource Safety • Time between Failures • Hazard Prone Region

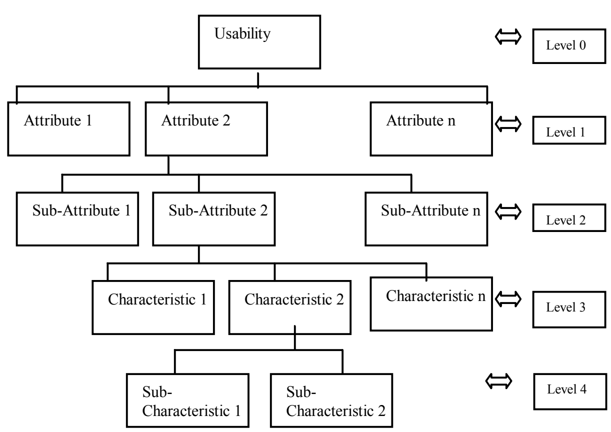

Fig. 1 Hierarchy Structure

The procedure to quantify the usability is as follows:
Step 1: Assign fuzzy ratings (r_i) to all the leaf nodes in the hierarchy structure.
Step 2: Assign fuzzy weights (w_i) to all the nodes (sub-characteristics, characteristics, sub-attributes, attributes) in the hierarchy structure.
Step 3: First the fuzzy weighted average of the sub-characteristics (level 4) is taken to evaluate the rating of the characteristic. Then the fuzzy weighted average of the characteristics (level 3) is taken to evaluate the rating of the corresponding sub-attribute. Then the fuzzy weighted average of the sub-attributes (level 2) is taken to evaluate the rating of the corresponding attribute. Lastly, the fuzzy weighted average of the attributes gives the fuzzy rating for the usability.
Step 4: From the fuzzy rating of usability obtained in the previous step, a crisp value is calculated by the de-fuzzification process using the Centroid Method [13].
The computations performed in this paper quantify the usability in the range [0 to 1].

The fuzzy rating of a sub-attribute is obtained by the weighted average of the characteristics affecting it:

$$r_{sub\text{-}attribute} = r_{characteristic\_1} * w_{characteristic\_1} + r_{characteristic\_2} * w_{characteristic\_2} + \ldots + r_{characteristic\_n} * w_{characteristic\_n}$$

3. Case Study

For the evaluation and working of this usability model, a sample case study of MS Word 2003 has been chosen. The evaluation is shown step by step in the following paragraphs.

A group of 10 users was made to fill a questionnaire in which the fuzzification criteria for all the characteristics and sub-attributes were specified. In the process of fuzzification, fuzzy sets were assigned to real time values. They are assigned as Very High (VH), High (H), Medium (M), Low (L) and Very Low (VL). These abbreviations are used throughout this section. For example, Fuzzification criteria of language is given in Table 3 and fuzzification criteria of cultural conventions is given in Table 3.

Every leaf node, as discussed earlier, is associated with corresponding rating and weight. The rating is the fuzzy value given by the user for a particular sub-characteristic /characteristic/ sub-attribute according to their usage of MS Word 2003. The weight is the fuzzy value given by the user for a particular sub-characteristic/ characteristic/ sub-attribute/ attribute according to its importance for calculating the usability. For example, for the sub-attribute Universality, the two characteristics are Accessibility and Cultural Universality. Cultural Universality further depends on 2 sub-characteristics, Language and Cultural Conventions. The triangular fuzzy numbers are assigned to the fuzzy ratings and weights obtained by the users.

Table 2. Fuzzification Criteria of Language

No. of languages supported	Fuzzy Value
1	VL
2-3	L
4-5	M
6-7	H
>7	VH

Table 3. Fuzzification Criteria of Cultural Conventions

Variation of usage with changing cultures	Fuzzy Value
Extreme	VL
A lot	L
Moderate	M
Slight	H
No	VH

Table 4. Triangular Fuzzy sets for fuzzy ratings

Fuzzy Value	Fuzzy Ratings
VL	(0.0, 0.1, 0.3)
L	(0.1, 0.3, 0.5)
M	(0.5, 0.7, 0.9)
H	(0.7, 0.9, 1.0)
VH	(0.9, 1.0, 1.0)

Table 5. Triangular Fuzzy sets for fuzzy weights

Fuzzy Value	Fuzzy Weights
VL	(0.0, 0.0, 0.25)
L	(0.0, 0.25, 0.5)
M	(0.25, 0.5, 0.75)
H	(0.5, 0.75, 1.0)
VH	(0.75, 1.0, 1.0)

Similarly, Fuzzy ratings of Effectiveness, Efficiency, Satisfaction, Comprehensibility and Safety (leaf nodes) were also obtained. Also Fuzzy weights (attributes/ sub-attributes/characteristics/sub-characteristics) were obtained.

The fuzzy weighted average of Language and Cultural Conventions sub-characteristics give the fuzzy rating for the Cultural Universality characteristic.

$r_{Cultural\ Universality} = r_{Language} * w_{Language} + r_{Cultural\ Conventions} * w_{Cultural\ Conventions}$

$r_{Cultural\ Universality}$ = (0.38, 0.58, 0.78) * (0.475, 0.725, 0.9) + (0.16, 0.34, 0.54) * (0.2, 0.45, 0.7)

$r_{Cultural\ Universality}$ = (0.181, 0.421, 0.702)

$w_{Cultural\ Universality}$ is obtained from the users.

The values of weights and ratings for Effectiveness leaf nodes as obtained from ten users are given in Table 6 and 7.

The fuzzy weighted average of Cultural Universality and Accessibility sub-attributes give the fuzzy rating for the Universality Sub-attribute.

$r_{Universality} = r_{Cultural\ Universality} * w_{Cultural\ Universality} + r_{Accessibility} * w_{Accessibility}$

$r_{Universality}$ = (0.181, 0.421, 0.702) * (0.225, 0.45, 0.775) + (0.158, 0.388, 0.718) * (0.2, 0.45, 0.7)

$r_{Universality}$ = (0.041, 0.189, 0.544)

$w_{Universality}$ is obtained from the users.

Similarly we get the ratings and weights of other sub-attributes under the Effectiveness attribute (Table 8).

Table 8. Ratings and weights of the sub-attributes of effectiveness

Sub-attributes	Fuzzy Rating	Fuzzy Weight
Task Accomplishment	(0.312, 0.612, 0.91)	(0.5, 0.75, 1.0)
Operability	(0.242, 0.512, 0.82)	(0.5, 0.75, 0.1)
Universality	(0.041, 0.189, 0.544)	(0.275, 0.525, 0.775)
Flexibility	(0.137, 0.419, 0.837)	(0.5, 0.75, 1.0)
Errors	(0.54, 0.74, 0.92)	(0.675, 0.925, 1.0)

Table 6. Rating inputs for leaf nodes in taxonomy of effectiveness

	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	Average Rating
Quantity of tasks accomplished	H	H	H	H	H	H	H	H	H	H	(0.5, 0.7, 0.9)
Quality of tasks accomplished	VH	H	H	H	H	H	H	H	H	H	(0.52, 0.72, 0.91)
Precision	H	H	VH	H	H	M	H	M	M	VH	(0.48, 0.68, 0.86)
Completeness	VH	VH	M	M	M	H	M	H	H	H	(0.46, 0.66, 0.84)
Visual Accessibility	H	M	M	M	H	H	M	H	H	H	(0.42, 0.62, 0.82)
Auditory Accessibility	M	L	VL	H	L	M	M	M	M	M	(0.25, 0.44, 0.64)
Vocal Accessibility	L	VL	VL	VL	VL	L	VL	L	L	L	(0.05, 0.2, 0.45)
Language Universality	H	M	L	M	L	H	H	H	H	H	(0.38, 0.58, 0.78)
Cultural Conventions	M	L	VL	VL	L	L	M	M	M	L	(0.16, 0.34, 0.54)
Adaptability to user preferences	H	H	H	M	H	H	H	H	H	H	(0.48, 0.68, 0.88)
Adaptability environment	M	VH	VH	H	H	H	H	H	L	H	(0.48, 0.68, 0.86)
Reversibility	VH	M	H	M	H	H	L	H	VH	M	(0.44, 0.64, 0.82)
Technical Configurability	M	H	VH	M	H	H	H	H	M	M	(0.46, 0.66 0.84)
Freedom in Tasks	H	M	H	M	M	H	H	H	H	H	(0.44, 0.64, 0.84)
Errors	VH	H	H	H	H	H	VH	H	H	H	(0.54, 0.74, 0.92)

Table 7. Weight inputs for leaf nodes in taxonomy of effectiveness

	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	Average Weight
Quantity of tasks accomplished	H	VH	VH	VH	H	H	H	H	VH	H	(0.6, 0.85, 1.0)
Quality of tasks accomplished	H	H	H	H	VH	VH	H	VH	VH	H	(0.6, 0.85, 1.0)
Precision	M	M	H	H	H	H	M	H	H	M	(0.5, 0.65, 0.9)
Completeness	H	H	H	H	H	VH	M	VH	H	H	(0.525, 0.775, 0.975)
Visual Accessibility	H	L	H	H	H	H	L	H	M	H	(0.375, 0.625, 0.875)
Auditory Accessibility	M	L	M	H	H	M	L	M	M	L	(0.225, 0.475, 0.725)
Vocal Accessibility	L	L	L	M	M	M	L	L	M	L	(0.1, 0.35, 0.6)
Language Universality	M	H	M	VH	H	VH	M	VH	M	H	(0.475, 0.725, 0.9)
Cultural Conventions	L	M	M	H	M	L	M	M	M	L	(0.2, 0.45, 0.7)
Adaptability to user preferences	H	VH	VH	VH	H	VH	M	VH	H	H	(0.6, 0.85, 0.975)
Adaptability environment	H	H	L	VH	H	VH	H	VH	L	H	(0.475, 0.725, 0.9)
Reversibility	VH	M	H	VH	VH	VH	M	H	VH	H	(0.575, 0.825 0.95)
Technical Configurability	H	VH	VH	VH	VH	VH	VH	M	M	H	(0.6, 0.85, 0.95)
Freedom in Tasks	H	H	VH	H	H	H	H	H	H	M	(0.5, 0.775, 0.975)
Errors	VH	VH	VH	H	H	VH	VH	VH	H	VH	(0.675, 0.925, 1.0)

Now the fuzzy weighted average of these sub-attributes is taken to give the rating of the Effectiveness attribute.
It is calculated in the same way and the value obtained is (0.365, 0.685, 0.92).
Similarly ratings of all the five attributes are calculated and the weights are obtained by the user (Table 9).

Table 9. Ratings and weights of the attributes of usability

Sub-attributes	Fuzzy Rating	Fuzzy Weight
Effectiveness	(0.365, 0.685, 0.92)	(0.5, 0.75, 1.0)
Efficiency	(0.177, 0.502, 0.815)	(0.5, 0.75, 0.1)
Satisfaction	(0.288, 0.578, 0.89)	(0.6, 0.85, 1.0)
Comprehensibility	(0.242, 0.512, 0.86)	(0.75, 1.0, 1.0)
Safety	(0.124, 0.392, 0.868)	(0.5, 0.75, 1.0)

Now the fuzzy weighted average of these attributes gives the fuzzy rating of Usability.

$r_{Usability} = r_{Effectiveness} * w_{Effectiveness} + r_{Efficiency} * w_{Efficiency} + r_{Satisfaction} * w_{Satisfaction} + r_{Comprehensibility} * w_{Comprehensibility} + r_{Safety} * w_{Safety}$

$r_{Usability}$ = (0.365, 0.685, 0.92) * (0.5, 0.75, 1.0) + (0.177, 0.502, 0.815) * (0.5, 0.75, 0.1) + (0.288, 0.578, 0.89) * (0.6, 0.85, 1.0) + (0.242, 0.512, 0.86) * (0.75, 1.0, 1.0) + (0.124, 0.392, 0.868) * (0.5, 0.75, 1.0)

$r_{Usability}$ = (0.183, 0.514, 0.92)

Now the fuzzy rating of Usability can be defuzzified using the Centroid formula to obtain the crisp value. This value lies in the interval [0 to 1].
$r_{Usability}$ can be represented by a membership function as shown in figure 2.

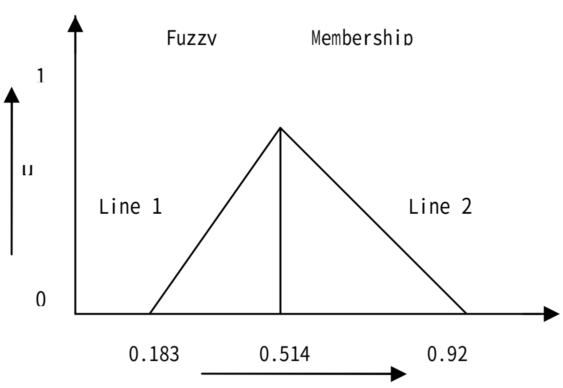

Fig. 2 Fuzzy membership function for Usability

Centroid Formula: $z^* = \dfrac{\int \mu(z)\, z\, dz}{\int \mu(z)\, dz}$

Here z* is the defuzzified crisp value. z is the value on x-axis and μ(z) is the membership function.
Equation of Line 1: $\mu = 3.02z - 0.553$
Equation of Line 2: $\mu = 2.27 - 2.46z$

$z^* = (\int (3.02z - 0.553)z\, dz\ (z= 0.183 \text{ to } 0.514) + \int (2.27 - 2.46z)z\, dz\ (z= 0.514 \text{ to } 0.92)) / (\int (3.02z - 0.553)z\, dz\ (z= 0.183 \text{ to } 0.514) + \int (2.27 - 2.46z)z\, dz\ (z= 0.514 \text{ to } 0.92))$

z* = 0.537 (Software Usability)

4. Conclusion

In recent years, various usability evaluation techniques have been given by several researchers but they lack in one way or another. This is basically due to varying and imprecise definitions of software usability. This paper gives a methodology to quantify the usability of software systems using the fuzzy multi-criteria weighted average approach. The usability model considered as the base model in this paper essentially covers and integrates maximum number of factors and attributes upon which usability of software depends. Using the algorithm described in this paper, usability of similar products may be evaluated. A comparison of the crisp values of usability thus obtained can help to identify which product is more suitable for a given set of users in a certain environment.

References

[1] International Organization for Standardization. ISO 9241-11:1998, Ergonomic requirements for office work with visual display terminals (VDTs), Part 11: Guidance on usability. Geneva, Switzerland: Author, 1998.
[2] International Organization for Standardization/International Electrotechnical Commission. ISO/IEC 9126-1:2001, Software engineering, product quality, Part 1: Quality model. Geneva, Switzerland: Author, 2001.
[3] J. A. McCall, P. K. Richards and G. F. Walters, Factors in software quality, Vols II, Rome Aid Defence Centre, Italy, 1977.
[4] J. Nielsen, Usability engineering. London: Academic Press, 1993.
[5] J. Preece, Y. Rogers, H. Sharp, D. Benyon, S. Holland and T. Carey, Human-computer interaction, Reading, MA: Addison-Wesley, 1994.
[6] A. Dix, J. Finley, G. Abowd and R. Beale, Human-Computer Interaction, 2nd ed. Prentice-Hall, 1998.
[7] A. Seffah, M. Donyaee, R. B. Kline and H. K. Padda, Usability measurement and metrics: A consolidated model, Software Quality Journal, 14, 159–178, 2006.
[8] S. K. Dubey, A. Gulati and A. Rana, Integrated Model for Software Usability, International Journal on Computer Science and Engineering, 4, 429-437, 2012.
[9] A. Gulati and S. K. Dubey, Critical Analysis on Usability Evaluation Techniques, International Journal of Engineering Science and Technology, 4, 990-997, 2012.
[10] R. Fuller and C. Carlsson, Fuzzy multiple criteria decision making: Recent developments, Fuzzy Sets and Systems, 78, 139-153, 1996.

[11] J. S. Challa, A. Paul, Y. Dada, V. Nerella, P.R. Srivastava and A. P. Singh, Integrated Software Quality Evaluation: A Fuzzy Multi-Criteria Approach, Journal of Information Processing Systems, 7, 473-517, 2011.

[12] J. S. Challa, A. Paul, Y. Dada, V. Nerella and P. R. Srivastava, Quantification of Software Quality Parameters using Fuzzy Multi Criteria Approach, IEEE,11, 2001.

[13] T. J. Ross, Fuzzy Logic with Engineering Application, 2nd Edition, Wiley India Pvt. Ltd., New Delhi, India, 2004.

[14] P. R. Srivastava, P. Jain, A. P. Singh and G. Raghurama, Software Quality factor evaluation using Fuzzy multi-criteria approach, Proceedings of the 4th Indian International Conference on Artificial Intelligence, IICAI, 1012-1029, 2009.

[15] S. M. Baas and H. Kwakernaak, Rating and Ranking of Multiple - Aspect Alternatives Using Fuzzy Sets and Systems, Automatica, 13, 47-58, 1975.

[16] A. P. Singh and A. K. Vidyarthi, Optimal allocation of landfill disposal site: A fuzzy multi criteria approach, Iranian Journal of Environmental Health Science & Engineering, 5, 25-34, 2008.

[17] C. W. Chang, C. R. Wu and H. L. Lin, Integrated fuzzy theory and hierarchy concepts to evaluate software quality, Software Quality Journal, 16, 263-276, 2008.

[18] P. R. Srivastava, A. P. Singh, K.V. Vageesh, "Assessment of Software Quality: A Fuzzy Multi – Criteria Approach, Evolution of Computation and Optimization Algorithms in Software Engineering: Applications and Techniques, IGI Global USA, chapter - 11, 200-219, 2010.

[19] IEEE Standard Glossary of Software Engineering Terminology, IEEE Std 610, 12, 1990.

[20] S. Aydin and C. Kahraman, Evaluation of E-Commerce Website Quality usin Fuzzy Multi-Criteria Decision Making Approach, International Jounal of Computer Science, 39, 2012.

[21] R. Zhou, How to Quantify User Experience: Fuzzy Comprehensive Evaluation Model Based on Summative Usability Testing, N. Aykin (Ed.): Usability and Internationalization, Part II, HCII, LNCS 4590, 564-573, 2007.

[22] L. A Zadeh, Fuzzy Logic, Neural Networks and Soft Computing, Communication of ACM, 37, 77-84, 1994.

[23] E. Chang and T. S. Dhillon, A Usability Evaluation Metric Based on a Soft- Computing Approach, IEEE transaction on Systems, Man and Cybernetics- Part A Systems and Humans, 36, 2006

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