Measurement of Object Oriented Software Usability using Fuzzy AHP

Sanjay Kumar Dubey¹, Arpan Mittal² and Prof. Dr. Ajay Rana³

Abstract—Software usability became an important quality factor in recent years due to the increasing demand of interactive software systems. Now mostly systems are developing using object-oriented methodology. The object-oriented methodology reduces design complexity, so enhances usability. Also object-oriented approach improves the usability of software system when software engineering process combined with usability engineering. This paper proposes an extended ISO-9241 usability model. Since fuzzy modeling approach deals with uncertainty and impreciseness involved in usability and its sub-factors, this paper investigate the application of fuzzy AHP technique to ISO-9241 model and the proposed enhanced ISO-9241 model. The result shows better usability of proposed model in comparison of existing model.

Index Terms—Usability, Model, AHP and Software System

I. INTRODUCTION

Usability is recognized as an important quality attributes due to its social and technical aspects. It is also widely accepted fact that usability is important parameter for interactive software systems. It is also an important field of HCI (Human Computer Interaction). The ISO 9241-11 [9] defines usability as “the context to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use”. Subsequently, ISO/IEC 9126-1 [10] categorized usability a part stating internal and external software quality, defining it as “the capability of software product to be understood, learned, used and attractive to the user under specified conditions”. According to Grudin [11], usability is the question of how satisfactorily users can make use of functionality of system. Inspite of such importance of usability, there were less efforts made to measure the usability. The main reasons behind it are that metrics are very much expensive and there is poor use of usability resources. Also there are usability models to evaluate usability but they lack due to overlapping of usability sub-factors [23]. This paper proposes sub-factors for usability model proposed by [24] and then compare usability of above model with the usability of ISO 9241-11 [9] by using fuzzy AHP technique [4].

II. USABILITY MODEL

This paper uses the fuzzy AHP technique on the usability model proposed by [24]. In above model, the authors of this paper propose multiple sub-factors for the different factors of usability. This is shown as a layered approach in Fig. I.

The multiple factors and sub-factors are defined as follows:

1. Effectiveness ($A_1$): It refers to the capability of the software which users achieve specified goals. It contains the following sub-factors:
a) Accuracy: It evaluates whether the system, after implementing aspects, is giving accurate results when used under specified condition.
b) Speed: It evaluates how quickly a task is performed.
c) Consistency: It allows a user to easily generalize his understanding of different modules of a system.
d) Understandability: It describes the capability of software to enable users to understand the appropriateness of software and its use for particular tasks and conditions of use.
e) Quality of Outcome: It evaluates the quality of the interaction understanding or learning of information in the interface.

ii). Efficiency (A3): It refers to the characteristics of the product that gives best results with use of minimum resources. It contains the following sub-factors:

a) Scalability: It is the ability of a system, network, or process, to handle growing amount of work in a capable manner or its ability to be enlarged to accommodate that growth.
b) Operability: It describes the capability of software to enable users to operate and control it.
c) Compatibility: It indicates that a product can work with or is equivalent to another, better-known product.
d) Time Efficiency: It describes the capability of software to provide appropriate responses, processing time and throughput rates when performing its function under required conditions.
e) Resource Efficiency: It describes the capability of software to use appropriate resources in time when the software implements its function in required conditions.

iii). Satisfaction (A4): It refers to the fulfilment of all requirements by the product as specified by the user. It contains the following sub-factors:

a) Preference: It measures the satisfaction as an interface using users prefer.
b) Pleasant: It indicates the capability of the software component to be attractive to the user.
c) Ease of use: It refers to the capability of the software that it can be used easily by the user.

iv). Learnability (A5): It is the capability of the software product to enable the user to learn its application. It contains the following sub-factors:

a) Wizard or User Guidance: It act as the guide which help the user to understand about the software.
b) Memorability: It refers to the capability of the software that it is easy to remember.
c) Simplicity: It indicates the capability of the software component to be simple to the user.
d) Self-Descriptiveness: It implies to the useful explanation of the software program design.

III. LITERATURE SURVEY

The AHP process presented by Saaty [25] is based on dividing a problem in hierarchical form. This process is one of the mostly used Multi-Criteria Decision Making (MCDM) methods. This process presents a structured way to organize and analyze those decisions, which are complex in nature. Inspite of widely used AHP process, it is unable to judge the expert’s knowledge and it is also ineffective where uncertainty, subjective, vague and imprecise decision making is involved. To overcome this problem fuzzy AHP technique is applied. FAHP uses the concepts of fuzzy theory, therefore FAHP is more objective than traditional AHP [22], [2], [18], [6].


IV. METHODOLOGY

The fuzzy AHP represents relatively more explicitly decision making process than standard AHP [2], [12], [5], [9], [7], [20]. Therefore, this paper uses fuzzy AHP approach given by [4] in which all the major steps are discussed below:

Establish model and problem:

Like a hierarchy, problem should be clearly expressed as a rational system. The structure can be determined by the outlook of the decision makers through brainstorming or other appropriate methods [4].
Establishing Triangular fuzzy numbers (TFN):

A TFN is denoted simply as (U, M, and L). The parameters U, M and L denote the largest possible value, the most promising value and the smallest possible value that describes a event of fuzzy. The triangular fuzzy numbers \( \tilde{a}_{ij} \) are established as follows:

\[
\tilde{a}_{ij} = ( L_{ij}; M_{ij}; U_{ij});
\]

\[
L_{ij} \leq M_{ij} \leq U_{ij} \text{ and } L_{ij}, M_{ij}, U_{ij} \in [9, 1/9]
\]

\[
L_{ij} = \min (B_{ijk});
\]

\[
M_{ij} = \prod_{k=1}^{n} B_{ijk}.
\]

\[
U_{ij} = \max (B_{ijk});
\]

Where \( B_{ijk} \) represents a judgement of experts k.

Establishing fuzzy pair-wise comparison matrix and defuzzification:

The defuzzification method adopted here is derived from Liou and Wang [26], the following formulae can clearly express fuzzy perception.

\[
g_{a_{ij}}(\tilde{a}_{ij}) = [\beta.f_{\alpha}(L_{ij}) + (1 - \beta).f_{\alpha}(U_{ij})], 0 \leq \beta \leq 1, 0 \leq \alpha \leq 1,(5)
\]

where left – end value of \( \alpha \)-cut for \( \tilde{a}_{ij} \) is represented by

\[
f_{\alpha}(L_{ij}) = (M_{ij} - L_{ij}) . \alpha
\]

and right- end value of \( \alpha \)-cut for \( \tilde{a}_{ij} \) is represented by

\[
f_{\alpha}(U_{ij}) = U_{ij} - (U_{ij} - M_{ij}) . \alpha
\]

\[
g_{a_{ij}}(\tilde{a}_{ij}) = 1/ g_{a_{ij}}(\tilde{a}_{ij}), 0 \leq \beta \leq 1, 0 \leq \alpha \leq 1, i > j. \quad (6)
\]

Because this method display the Preferences(\( \alpha \)) and risk tolerance(\( \beta \)) of decision makers explicitly as a result they thoroughly understand the risks occur in different circumstances.

\[
g_{a_{ij}}(\tilde{a}_{ij}) = g_{a_{ij}}(\tilde{a}_{ij}) =
\]

\[
\begin{bmatrix}
C_1 & 1 & g_{a_{12}}(\tilde{a}_{12}) & \cdots & g_{a_{1n}}(\tilde{a}_{1n}) \\
C_2 & 1/g_{a_{21}}(\tilde{a}_{12}) & 1 & \cdots & \cdots \\
& \cdots & \cdots & \cdots & \cdots \\
C_n & 1/g_{a_{n1}}(\tilde{a}_{1n}) & 1/g_{a_{n2}}(\tilde{a}_{2n}) & \cdots & 1
\end{bmatrix}
\]

Determine Eigen Vectors:

Eigen Value of the single pair-wise comparison matrix

\[
g_{a_{ij}}(\tilde{a}_{ij}) \text{ is defined by } \lambda_{\text{max}} .
\]

\[
g_{a_{ij}}(\tilde{a}_{ij}) W = \lambda_{\text{max}} W
\]

and

\[
[ (g_{a_{ij}}(\tilde{a}_{ij}) - \lambda_{\text{max}}) I ] W = 0
\]

where W denotes the eigen vector of \( g_{a_{ij}}(\tilde{a}_{ij}) \), 0 \( \leq \beta \leq 1, 0 \leq \alpha \leq 1

Consistency Test :

To verify the comparison the consistency of the comparison matrix. Saaty [25] proposed a consistency index(C.I.) and consistency ratio (C.R.) are defined as follows :

\[
C.I. = ( \lambda_{\text{max}} - n ) / n - 1 \quad (10)
\]

\[
C.R. = C.I. / R.I. \quad (11)
\]

Where R.I. represents the average consistency index. If C.R.< 0.1, the estimate is accepted; otherwise, a new comparison matrix is to be achieve until C.R.<0.1.

V. CASE STUDY

For Case Study, we have taken two object oriented projects. Project 1 is based on Model 1 in which Learnability factor is not present i.e. there is no documentation, online help and no use case diagrams etc. are available. Project 2 is based on proposed model in which we provide all the Learnability features like Wizard or User Guidance, Memorability, Simplicity and Self-Descriptiveness. The usability of Model 1 and Model 2 is represented by UM1 and UM2 respectively.

Then we applied fuzzy AHP methodology to evaluate the software usability of both the models. The complete procedure is described in following sections.

A. Usability Evaluation for Model 1

This model is given by ISO 9241-11 [9]. In this model, there are three factors that have been chosen for the usability evaluation namely effectiveness (A1), efficiency (A2) and satisfaction (A3) and each factors is further divided into thirteen sub-factors. These sub-factors are same as given in the proposed model (Fig. 1) under effectiveness, efficiency and satisfaction. Weights have been calculated for each factors and sub-factors. This FAHF model for evaluating usability comprises the following steps:

**Step 1: Establish model and problem**

Evaluate the ideal model as three evaluation factors, thirteen sub-factors.

**Step 2: Establish Triangular fuzzy numbers**

Establish Triangular fuzzy numbers using formulas (1)-(4). Each expert makes pair-wise comparison of decision criteria and gives them relative scores as shown in Table I.

**Step 3: [Establish or Construct] the fuzzy pair-wise comparison matrix and defuzzification**

As Table I shows, the questionnaires sampled a group of 12 experts with each respondent making a pair-wise comparison
of the decision elements and assigned them relative scores after defuzzification using formulae (5) and (6) as shown in Table II.

Table I: Fuzzy aggregate pair-wise comparison matrix for level 2

<table>
<thead>
<tr>
<th></th>
<th>Effectiveness</th>
<th>Efficiency</th>
<th>Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effectiveness (A₁)</td>
<td>1,1,1</td>
<td>0.33,1.18,4</td>
<td>0.33,0.71,2</td>
</tr>
<tr>
<td>Efficiency (A₂)</td>
<td>-</td>
<td>1,1,1</td>
<td>0.25,0.54,3</td>
</tr>
<tr>
<td>Satisfaction (A₃)</td>
<td>-</td>
<td>-</td>
<td>1,1,1</td>
</tr>
</tbody>
</table>

Step 4: Determine Eigen Vectors

Eigen Vector W₂ and Eigen Value λₘₐₓ are then determined. According to table II, the matrix is

\[ \begin{bmatrix} 1 & 1.67 & 0.93 \\ 0.59 & 1 & 1.08 \\ 1.07 & 0.92 & 1 \end{bmatrix} \]

AW₂, where I is unitary matrix and λₘₐₓ = g substitution formula (8)

AW₂ = \[ \begin{bmatrix} 1 & 1.67 & 0.93 \\ 0.59 & 1 & 1.08 \\ 1.07 & 0.92 & 1 \end{bmatrix} \] \[ \begin{bmatrix} W_{21} \\ W_{22} \\ W_{23} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \]

Calculating the above two matrices, we get the weights of the level II:

\[ W₂ = \begin{bmatrix} A₁ \ 0.384 \\ A₂ \ 0.286 \\ A₃ \ 0.330 \end{bmatrix} \]

The respective weights of the three evaluative factors are Effectiveness (0.384), Efficiency (0.286), and Satisfaction (0.330).

Similarly, we have applied FAHP process on pair-wise relative weights of sub-factors of factors A₁, A₂ and A₃ on all these weights of sub-factors are listed in column-III of Table III. Thirteen evaluative sub-factors are weighted as: SA₁ is Accuracy (0.118), SA₂ is Speed (0.078), SA₃ is Consistency (0.074), SA₄ is Understandability (0.068), SA₅ is Quality of Outcome (0.046), SA₆ is Scalability (0.063), SA₇ is Operability (0.066), SA₈ is Compatibility (0.038), SA₉ is Time Efficiency (0.061), SA₁₀ is Resource Efficiency (0.058), SA₁₁ is Preference (0.157), SA₁₂ is Pleasant (0.082), SA₁₃ is Ease of Use (0.091).

Step 5: Consistency Test

The consistency of each comparison matrix is tested by formulae (10) and (11), we get

\[ C.I. = \frac{3.033 - 3}{3 - 1} = 0.016 \]
\[ C.R. = 0.016 / 0.58 < 0.1 \]

Step 6: Determine project usability

According to Table III, the usability of the project is determined as follows:

\[ \begin{bmatrix} 0.228 & 0.247 & 0.309 & 0.175 & 0.229 & 0.265 & 0.333 & 0.286 & 0.382 \\ 0.569 & 0.569 & 0.286 & 0.265 \end{bmatrix} * \begin{bmatrix} 0.118 \\ 0.078 \\ 0.074 \end{bmatrix} \]
B. Usability Evaluation for Model 2

In this model, there are four factors that have been chosen for the usability evaluation namely effectiveness ($A_1$), efficiency ($A_2$), satisfaction ($A_3$) and Learnability ($A_4$) and each factors is further divided into seventeen sub-factors. These sub-factors are same as given in the proposed model (Fig. 1). Weights have been calculated for each factors and sub-factors.

This FAHP model for evaluating usability comprises the following steps:

Step 1: Establish model and problem
Evaluate the ideal model as four evaluation factors, seventeen sub-factors.

Step 2: Establish Triangular fuzzy numbers
Establish Triangular fuzzy numbers using formulas (1) - (4). Each expert makes pair-wise comparison of decision criteria and gives them relative scores as shown in Table IV.

Step 3: [Establish or Construct] the fuzzy pair-wise comparison matrix and defuzzification
As Table VI shows, the questionnaires sampled a group of 12 experts with each respondent making a pair-wise comparison of the decision elements and assigned them relative scores after defuzzification using formulae (5) and (6) as shown in Table V.

Step 4: Determine Eigen Vectors
Eigen Vector $W_2$ and Eigen Value $\lambda_{max}$ are then determined. According to table II, the matrix is

$$\det (A – \lambda I) = \begin{vmatrix} 1 & 1.67 & 0.93 & 1.55 \\ 0.59 & 1 & 1.08 & 2.17 \\ 1.07 & 0.92 & 1 & 2.23 \\ 0.64 & 0.46 & 0.44 & 1 \end{vmatrix}$$

$AW_2$, where $I$ is unitary matrix and $\lambda_{max} = g$ substitution formula (8)

$$AW_2 = \begin{bmatrix} 1 & 1.67 & 0.93 & 1.55 \\ 0.59 & 1 & 1.08 & 2.17 \\ 1.07 & 0.92 & 1 & 2.23 \\ 0.64 & 0.46 & 0.44 & 1 \end{bmatrix} \begin{bmatrix} W_{21} \\ W_{22} \\ W_{23} \\ W_{24} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Calculating the above two matrices, we get the weights of the level 2 :

$$W_2 = \begin{bmatrix} \frac{0.300}{A_1} \\ \frac{0.262}{A_2} \\ \frac{0.293}{A_3} \\ \frac{0.145}{A_4} \end{bmatrix}$$

The respective weights of the three evaluitive factors are effectiveness (0.300), efficiency (0.262), satisfaction (0.293), Learnability (0.145).
Similarly, we have applied FAHP process on pair-wise relative weights of sub-factors of factors A1, A2, A3 and A4 one by one and all these weights of sub-factors are listed in column of Table VI, Seventeen evaluative sub-factors are weighted as follows:

SA1 is Accuracy (0.118), SA2 is Speed (0.078), SA3 is Consistency (0.074), SA4 is Understandability (0.068), SA5 is Quality of Outcome (0.046), SA6 is Scalability (0.063), SA7 is Operability (0.066), SA8 is Compatibility (0.038), SA9 is Time Efficiency (0.061), SA10 is Resource Efficiency (0.058), SA11 is Preference (0.157), SA12 is Pleasant (0.082), SA13 is Ease of Use (0.091), SA14 is Wizard (0.046), SA15 is Self-Descriptiveness (0.043), SA16 is Simplicity (0.034), SA17 is Memorability (0.022).

Table VI: Summarizes the results of Eigen vectors for the level 2 to level 3

<table>
<thead>
<tr>
<th>Factors for level 2</th>
<th>Weights for level 2</th>
<th>Sub-Factors for level 3</th>
<th>Weights of the overall</th>
<th>Weights for level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.300</td>
<td>SA1</td>
<td>0.308</td>
<td>0.093</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.465</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SA2</td>
<td>0.202</td>
<td>0.061</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.519</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SA3</td>
<td>0.193</td>
<td>0.058</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.309</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SA4</td>
<td>0.179</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.265</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SA5</td>
<td>0.118</td>
<td>0.035</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.490</td>
</tr>
<tr>
<td>A2</td>
<td>0.262</td>
<td>SA6</td>
<td>0.223</td>
<td>0.058</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.191</td>
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<tr>
<td></td>
<td></td>
<td>SA7</td>
<td>0.233</td>
<td>0.062</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.505</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SA8</td>
<td>0.130</td>
<td>0.035</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td>0.411</td>
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<td></td>
<td></td>
<td>SA9</td>
<td>0.208</td>
<td>0.054</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0.586</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SA10</td>
<td>0.206</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.651</td>
</tr>
<tr>
<td>A3</td>
<td>0.293</td>
<td>SA11</td>
<td>0.476</td>
<td>0.139</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.582</td>
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<tr>
<td></td>
<td></td>
<td>SA12</td>
<td>0.247</td>
<td>0.072</td>
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<td></td>
<td></td>
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<td></td>
<td>0.262</td>
</tr>
<tr>
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<td></td>
<td>SA13</td>
<td>0.277</td>
<td>0.082</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0.266</td>
</tr>
<tr>
<td>A4</td>
<td>0.145</td>
<td>SA14</td>
<td>0.319</td>
<td>0.046</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.623</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SA15</td>
<td>0.300</td>
<td>0.043</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.551</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SA16</td>
<td>0.235</td>
<td>0.034</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0.214</td>
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<tr>
<td></td>
<td></td>
<td>SA17</td>
<td>0.146</td>
<td>0.022</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.293</td>
</tr>
</tbody>
</table>

**Step 6: Determine project usability**

According to Table VI, the usability of the project is determined as follows:

\[
\begin{bmatrix}
0.465 & 0.519 & 0.309 & 0.265 & 0.490 & 0.191 & 0.505 & 0.411 & 0.586 \\
0.651 & 0.582 & 0.262 & 0.266 & 0.623 & 0.551 & 0.214 & 0.293 \\
\end{bmatrix} \\
\times \\
\begin{bmatrix}
0.093 \\
0.061 \\
0.058 \\
0.053 \\
0.035 \\
0.058 \\
0.062 \\
\end{bmatrix} = UM2 = [0.425] \\
0.035 \\
0.054 \\
0.053 \\
0.139 \\
0.072 \\
0.082 \\
0.046 \\
0.034 \\
0.022 \\
\]

**VI. CONCLUSION**

This paper evaluated the usability of software by using Fuzzy AHP. ISO 9241 was considered as a base model, new factor Learnability was added to this model to get model 2. To evaluate the usability of software system, this paper used two projects based on Model 1 and Model 2. These projects were developed using object oriented methodology. The result showed that model 2 is more usable in comparison of Model 1. In future, the result will be validating by other techniques and different object oriented software systems.

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**REFERENCES**


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