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Measurement of Object Oriented Software Usability using Fuzzy AHP

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***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.

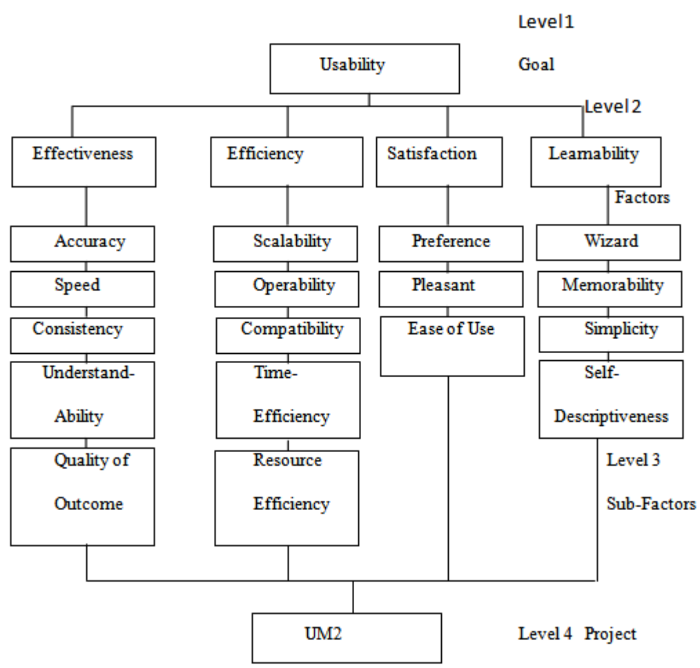

Fig. I: Usability Model

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

i). Effectiveness (A_1): It refers to the capability of the software which users achieve specified goals. It contains the following sub-factors:

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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 (A_2): 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 (A_3): 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 (A_4): 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].

Laarhoven & Pedryez [19] evolved pair wise comparison matrix by Saaty's traditional fuzzy number to remove ambiguity in decision making. They expressed triangular fuzzy numbers in their proposed methods. To modify Saaty's AHP paired comparison values, Buckley [12] expressed the relative a importance criteria by using trapezoidal fuzzy numbers. By his method fuzzy weight was evaluated by taking geometric mean. Ruoning and Xiaoyan [27] extended the AHP approach by proposing the fuzzy judgement matrix. Mohanty and Singh [1] also proposed fuzzy procedure to solve decision problems. Chang [5] proposed a model of triangular fuzzy numbers for the pair wise comparison scale of fuzzy AHP. The logarithmic least square method was used to evaluate the fuzzy weight [28]. For multicriteria decision analysis Gogus and Boucher [17] used fuzzy pairwise comparisons. Zhu [13] improved the criteria for comparing triangular fuzzy numbers sizes by providing the basic theory of triangular fuzzy numbers. Deng [8] presented a simple fuzzy approach to measure qualitative multicriteria analysis problems. Mikhailov [14] proposed a new method, based on geometrical representation of the prioritization process. A new process for direct fuzzification of the λ_{max} to evaluate fuzzy weights was proposed by Csutora and Buckley [21]. Yu [3] presented a GP-AHP model for solving fuzzy AHP problems in group decision making. Mikhailov [15] introduced a new approach which derives priorities from fuzzy pairwise comparison judgements. Enea and Piazza [16] proposed an approach related to the constraints of fuzzy AHP.

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].

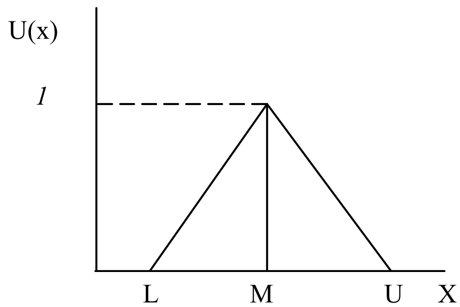

Fig. II: Triangular Fuzzy Numbers

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 $\tilde{m}_{ij}$ are established as follows:

$$\tilde{m}_{ij} = (L_{ij}; M_{ij}; U_{ij});$$

$$L_{ij} \le M_{ij} \le U_{ij} \text{ and } L_{ij}, M_{ij}, U_{ij} \in [9, 1/9] \quad (1)$$

$$L_{ij} = \min (B_{ijk}); \quad (2)$$

$$M_{ij} = \sqrt[n]{\prod_{k=1}^{n} B_{ijk}}, \quad (3)$$

$$U_{ij} = \max (B_{ijk}); \quad (4)$$

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.

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

where left – end value of α- cut for $\tilde{a}_{ij}$ is represented by

$$f_\alpha(L_{ij}) = (M_{ij} - L_{ij}) . \alpha + L_{ij}$$

and right– end value of α- cut for $\tilde{a}_{ij}$ is represented by

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

$$g_{\alpha,\beta}(\tilde{a}_{ji}) = 1/ g_{\alpha,\beta}(\tilde{a}_{ij}), 0 \le \beta \le 1, 0 \le \alpha \le 1, i > j. \quad (6)$$

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

$$g_{\alpha,\beta}(\tilde{A}) = g_{\alpha,\beta}([\tilde{a}_{ij}]) =$$

$$\begin{array}{c} C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{bmatrix} 1 & g_{\alpha,\beta}(\tilde{a}_{12}) & \cdots & g_{\alpha,\beta}(\tilde{a}_{1n}) \\ 1/g_{\alpha,\beta}(\tilde{a}_{12}) & 1 & \cdots & g_{\alpha,\beta}(\tilde{a}_{2n}) \\ \vdots & \vdots & & \vdots \\ 1/g_{\alpha,\beta}(\tilde{a}_{1n}) & 1/g_{\alpha,\beta}(\tilde{a}_{2n}) & \cdots & 1 \end{bmatrix} \quad (7)$$

Determine Eigen Vectors:

Eigen Value of the single pair-wise comparison matrix $g_{\alpha,\beta}$ is defined by λ_{max}.

$$g_{\alpha,\beta}(\tilde{A}).W = \lambda_{max} W \quad (8)$$

and $$[(g_{\alpha,\beta}(\tilde{A}) - \lambda_{max} I]W = 0 \quad (9)$$

where W denotes the eigen vector of $g_{\alpha,\beta}$ ($\tilde{A}$), $0 \le \beta \le 1$, $0 \le \alpha \le 1$

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 :

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

$$C.R. = C.I. / R.I. \quad (11)$$

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 1in 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 (A_1), efficiency (A_2) and satisfaction (A_3) and each factors is further divided into thirteen sub-factors. These sub-factors are same as given in the proposed model (Fig. I) under effectiveness, efficiency and satisfaction. 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 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 II: Aggregate pair-wise comparison matrix for level 2

	Effectiveness (A_1)	Efficiency (A_2)	Satisfaction (A_3)
Effectiveness (A_1)	1,1,1	0.33,1.18,4	0.33,0.71,2
Efficiency (A_2)	-	1,1,1	0.25,0.54,3
Satisfaction (A_3)	-	-	1,1,1

Step 4: Determine Eigen Vectors

Eigen Vector W_2 and Eigen Value λ_{max} are then

	Effectiveness (A_1)	Efficiency (A_2)	Satisfaction (A_3)
Effectiveness (A_1)	1	1.67	0.93
Efficiency (A_2)	0.59	1	1.08
Satisfaction (A_3)	1.07	0.92	1

determined. According to table II, the matrix is

$$\det(A - \lambda I) = \begin{bmatrix} 1 & 1.67 & 0.93 \\ 0.59 & 1 & 1.08 \\ 1.07 & 0.92 & 1 \end{bmatrix}$$

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

$$AW_2 = \begin{bmatrix} 1 & 1.67 & 0.93 \\ 0.59 & 1 & 1.08 \\ 1.07 & 0.92 & 1 \end{bmatrix} \begin{bmatrix} W_{21} \\ W_{22} \\ W_{23} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

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

$$W_2 = \begin{matrix} A_1 \\ A_2 \\ A_3 \end{matrix} \begin{bmatrix} 0.384 \\ 0.286 \\ 0.330 \end{bmatrix}$$

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

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

Factors	Weights for level 2	Sub-Factors	Weights for level 3	Weights of the overall	Weights for level 4
					Software project (UM1)
A_1	0.384	SA_1	0.308	0.118	0.228
		SA_2	0.202	0.078	0.247
		SA_3	0.193	0.074	0.309
		SA_4	0.179	0.068	0.175
		SA_5	0.118	0.046	0.229
A_2	0.286	SA_6	0.223	0.063	0.265
		SA_7	0.233	0.066	0.333
		SA_8	0.130	0.038	0.286
		SA_9	0.208	0.061	0.382
		SA_{10}	0.206	0.058	0.569
A_3	0.330	SA_{11}	0.476	0.157	0.569
		SA_{12}	0.247	0.082	0.286
		SA_{13}	0.277	0.091	0.265

Similarly, we have applied FAHP process on pair-wise relative weights of sub-factors of factors A_1, A_2 and A_3 on all these weights of sub-factors are listed in column-III of Table-III. Thirteen evaluative sub-factors are weighted as:SA_1 is Accuracy (0.118), SA_2 is Speed (0.078), SA_3 is Consistency (0.074), SA_4 is Understandability (0.068), SA_5 is Quality of Outcome (0.046), SA_6 is Scalability **(**0.063**),** SA_7 is Operability (0.066), SA_8 is Compatibility (0.038), SA_9 is Time Efficiency (0.061), SA_{10} is Resource Efficiency (0.058), SA_{11} is Preference (0.157), SA_{12} is Pleasant (0.082), SA_{13} 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. = (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:

[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] *

[0.118

0.078

0.074

0.068 = UM1 = [0.327]
0.046
0.063
0.066
0.038
0.061
0.058
0.157
0.082
0.091]

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. I). 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.

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

	Effectiveness (A_1)	Efficiency (A_2)	Satisfaction (A_3)	Learnability (A_4)
Effectiveness (A_1)	1,1,1	0.33,1.18,4	0.33,0.71,2	0.33,1.44,3
Efficiency (A_2)	-	1,1,1	0.25,0.54,3	0.5,2.10,4
Satisfaction (A_3)	-	-	1,1,1	0.5,2.23,4
Learnability (A_4)	-	-	-	1,1,1

Table V: Aggregate pair-wise comparison matrix for level 2

	Effectiveness (A_1)	Efficiency (A_2)	Satisfaction (A_3)	Learnability (A_4)
Effectiveness (A_1)	1	1.67	0.93	1.55
Efficiency (A_2)	0.59	1	1.08	2.17
Satisfaction (A_3)	1.07	0.92	1	2.23
Learnability (A_4)	0.64	0.46	0.44	1

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 λ_{max} are then determined. According to table II, the matrix is

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

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

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

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

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

The respective weights of the three evaluative 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 A_1, A_2, A_3 and A_4 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:

SA_1 is Accuracy (0.118), SA_2 is Speed (0.078), SA_3 is Consistency (0.074), SA_4 is Understandability (0.068), SA_5 is Quality of Outcome (0.046), SA_6 is Scalability **(**0.063**)**, SA_7 is Operability (0.066), SA_8 is Compatibility (0.038), SA_9 is Time Efficiency (0.061), SA_{10} is Resource Efficiency (0.058), SA_{11} is Preference (0.157), SA_{12} is Pleasant (0.082), SA_{13} is Ease of Use (0.091), SA_{14} is Wizard (0.046), SA_{15} is Self-Descriptiveness (0.043), SA_{16} is Simplicity (0.034), SA_{17} is Memorability (0.022).

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

Factors	Weights for level 2	Sub-Factors	Weights for level 3	Weights of the overall	Weights for level 4 Software project
A_1	0.300	SA_1	0.308	0.093	0.465
		SA_2	0.202	0.061	0.519
		SA_3	0.193	0.058	0.309
		SA_4	0.179	0.053	0.265
		SA_5	0.118	0.035	0.490
A_2	0.262	SA_6	0.223	0.058	0.191
		SA_7	0.233	0.062	0.505
		SA_8	0.130	0.035	0.411
		SA_9	0.208	0.054	0.586
		SA_{10}	0.206	0.053	0.651
A_3	0.293	SA_{11}	0.476	0.139	0.582
		SA_{12}	0.247	0.072	0.262
		SA_{13}	0.277	0.082	0.266
A_4	0.145	SA_{14}	0.319	0.046	0.623
		SA_{15}	0.300	0.043	0.551
		SA_{16}	0.235	0.034	0.214
		SA_{17}	0.146	0.022	0.293

Step 5: Consistency Test

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

C.I. = (4.06-4)/ (4-1) =0.02

C.R. = 0.02 /0.90 < 0.1

Step 6: Determine project usability

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

$$[\ 0.465\ 0.519\ 0.309\ 0.265\ 0.490\ 0.191\ 0.505\ 0.411\ 0.586\ 0.651\ 0.582\ 0.262\ 0.266\ 0.623\ 0.551\ 0.214\ 0.293\ ] * \begin{bmatrix} 0.093 \\ 0.061 \\ 0.058 \\ 0.053 \\ 0.035 \\ 0.058 \\ 0.062 \\ 0.035 \\ 0.054 \\ 0.053 \\ 0.139 \\ 0.072 \\ 0.082 \\ 0.046 \\ 0.043 \\ 0.034 \\ 0.022 \end{bmatrix} = UM2 = [0.425]$$

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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