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Multi-level Fuzzy system for usable-security assessment

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ABSTRACT

Indubitably, security is an integral aspect of the development of quality software. More importantly, usability is also an elemental and pivotal factor for developing quality software. In fact, it has been noticed that most of the practitioners are trying to develop a highly secure design while maintaining high usability. Unfortunately, the highly secure design of software becomes worthless because the usability of software is very low. Further, usable security is in more demand due to the increasing usage of computers with enhanced usability and need of security in it too. When improving the usability with security of software, underlying security and usability attributes play an important role. For this reason, usable security assessment employs security and usability attributes to achieve the desired security solutions with usability. Different consecutive versions of two software have been taken in this work to assess usable security. Authors are using Fuzzy-AHP methodology to assess the priorities and overall usable-security. In addition, the impact of the security on usability and impact of the usability on security have been evaluated quantitatively. The results obtained and conclusions are useful for practitioners to improve usable-security of software.

1. Introduction

To enhance the security services of software, several research studies have been cited for understanding and classifying the ways for estimating security (Ruoti et al., 2015; Liu, 2011). Due to change in the users' demand, security goals must be reset from time to time. The gap between literatures and actual practices that arise due to this is hard to bridge completely. The goals may be achieved through identification, establishment, and assessment. The main purpose of security is to secure software from malicious attacks. However, at times, a person using the system can himself become the weakest link and, unintentionally, invite attacks. Prevention of un-authorization is the main aim of security while usability focuses on the ease of users 'keeping simple' formula (Liu, 2011; Neilson, 1998). Hence, the focus of organizations should be on maintaining security along with usability.

To achieve this, researchers are trying to improve usable security by assessing it through different methods (Kumar et al., 2016). Plenty of work is available in this area of research but assessing the attributes of security and usability with applicability to real world problems is not found in literature. In addition, the user is the person who authorizes the security settings. Hence, usable and secure services are the need of today's generation (Kumar et al., 2016; Pressman, 2005). Attributes of security and usability both play an important role in assuring security of software (Pressman, 2005). Usable-security of software services may be affected by usability and security attributes including CIAAN (Confidentiality, Integrity, Availability, Accountability and Non-repudiation) and EESU (Effectiveness, Efficiency, Satisfaction and User Error Protection) (Fléchais, 2005; Pressman, 2005). The contribution of these attributes is different yet important in assuring security. Hence, assessment cannot be done by ignoring usability or security attributes. Consideration of attributes of both security and usability will help in a more efficacious and precise assessment.

Further, the assessment of usable-security is a decision-making problem because every organization adopts its own policies and methods (Pressman, 2005; Fléchais, 2005; ISO 9241-11, 1998; McGraw, 1999). The assessment is helpful for decision makers to understand the preferences while ensuring usable-security. Hence,

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the authors of this paper are using Fuzzy-AHP methodology for the assessment. For this assessment, there is a need to establish a hierarchy which defines the affected attributes by usable security. Henceforth, a hierarchy of usable-security attributes is defined in the next section to address and assess the usable-security of software. With the help of the hierarchy and Fuzzy Analytic Hierarchy Process (Fuzzy AHP), usable-security of software has been evaluated. The results achieved by this assessment may help the security designers for developing usable-security during software development.

Rest of the paper has been organized as follows: the second section discusses the relevant work of usable-security of software services. The third section describes the need and importance of usable security assessment. The fourth section enunciates the methodology and discusses the results. The findings and the conclusion have been enlisted in section five and six, respectively.

2. Relevant study initiatives

Usable-security focuses on satisfaction of end user, which has become the prime concern of any organization. However, it is ignored while ensuring security. For example, easy and simple password is easy to remember for users but strong password is required to ensure security of their data. Hence, the assessment of usable-security with its different attributes is essential to notice. Cited below is the available research work in this area:

- **Abrar Ullah et al.,** gives the investigation report related to text and image based questions during online examination (Ullah et al., 2019). Authors assessed the seventy reports of participants which have been collated from nine different countries.
- **Bilal Naqvi and Ahmed Seffah** stated the conflict between security and usability during requirement and design phase (Naqvi et al., 2018).
- **Bai W. et al.,** evaluated the results of usable-security assessment in encrypted messages (Bai et al., 2017). Authors have taken fifty two participants during the assessment. Participants recognized that a less-convenient key exchange model was more secure overall, but considered the key-directory approach to have sufficient security for most of everyday purposes.
- **Majed Alshamari** discusses about the conflicts of usability with privacy and security (Alshamari, 2016). He also discussed in his work the security models that have been developed to reduce conflicts among security and usability. Authors used different attributes of both security and usability to fill the gap between them.
- **P.L. Gorski and L.L. Iacono** provide a critical review on the use of APIs usability for ensuring security of software (Gorski et al., 2016). This paper also recognizes the issues faced by the developers while building systems using the security APIs. In addition, the authors recognize eleven specific usability attributes to evaluate how security APIs should be designed to ensure more security as well as usability.
- **Yasser M. Hausaw** proposed a framework for integrating usable-security during software development life cycle (Hausawi, 2015). The framework depends upon human-computer interaction with respect to security. The work focuses on assessing, balancing, measuring, and evaluating the usable-security of software services.
- **Maha M. Althobaiti and Pam Mayhew** proposed an approach to assess usable-security with its practical implementation (Althobaiti et al., 2014). The authors implemented the model with 100 online banking customers to get better validation of their results. Though the drawback of this work was that the usability was not evaluated quantitatively.

Analyzing the relevance of previous work as cited above, the authors contend that the proposed security and usability evaluation models in the existing literature lack some essential and key evaluation attributes that are of particular interest to a software. Hence, a quantitative evaluation of usability security with an implementation is essential. This research work focuses on evaluation of usable security of two locally developed software including entrance exam and quiz competition software for BBA University, Lucknow, India.

3. Security usability: a point of concern

Software security is an idea or method used to prevent malicious attacks by software (Ruoti et al., 2015; Liu, 2011; Neilson, 1998). In accordance with G. McGraw, the security of software involves building secure software, i.e., developing software to be safe, ensuring that the software is safe, and educating software developers and architects, and users about how to build secure software (McGraw, 1999). The balance between usability and theoretical security is not generally accepted as a fundamental principle in security design. Several authors claim that security is not compromised while usability is in focus during software development.

The evaluation and maintenance of CIA during the development of software proves to be one of the best ways to obtain safer software. This is why everyone wants to build a high-security design and because of the involved complex processes, the security design makes the applications less usable. This problem generates concerns for the end users. Megan Cater, a well-known author on usability cites in one of his work, “Human interfaces for security features must be easy to use so that the users don’t make mistakes in applying security features” (Cater, 2015). Due to the very complex security design, users are not able to use the software easily. Hence, today’s software provider organizations need to invest in both security and usability.

The Microsoft defines usability as a measure of how easy it is to use a product to perform prescribed tasks (Microsoft Corporation, 2000). Furthermore, the IEEE standard defines usability as the degree of ease of use that allows users to achieve their desired results without making many efforts (Whitten, 2004). According to the highly learned Jakob Nielsen, usability is an attribute of quality that depends on five components, including learning, efficiency, memorability, errors, and satisfaction (Neilson, 1998). Efficiency in usability refers to the point at which the user has “mastered” the feature and uses it without requiring further learning. The effectiveness of usability is measured using the rate of completion of the task. User satisfaction tends to the attitude of the user towards system satisfaction (Good et al., 2003). User error protection tends to the degree to which a system protects users against making errors.

Secure systems do not exist in emptiness; they exist for the purpose of providing people with services and as such cannot operate without the involvement of people. Practitioners of security and usability need to learn working on both concepts with the same environment (Anwar et al., 2018; Kulyk and Volkamer, 2018). It is because security and usability seem to work oddly with each other. Improving one decrease the other. There are several methods which have been developed to work with both but every method has its limitations. Usability in the security must be incorporated into usable security from the very beginning and it should be continued till the security services are running (Computer Hope, 2018). Usable-security seems to be perfect solution for all odds that have been there with usability and security. Usable-security and its assessment focus on advantages and limitations of both the methods and, with a proper methodology, a solution to ensure usability with security is developed.

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Hence, security has three major factors of usability that affect indirectly. The three factors being: effectiveness, efficiency, satisfaction and user error protection. Further, CIAAN is the pillars of security (Saltzer and Schroeder, 1975). In context of security, confidentiality refers to the allowance of authorized access to sensitive and secure data (Agrawal et al., 2014). Integrity is a quality of appeal established by the ethical assurance and resolution. Availability, in the context of a computer system, refers to the ability of a user to access information or resources for a specified duration (Agrawal et al., 2014). While accountability in security means that every individual who works with an information system should have specific responsibilities for information assurance. Non-repudiation is the assurance that someone cannot deny something (Non-repudiation, 2008). This work contributes as an assessment of usable-security through Fuzzy AHP. A tree structure of the usable-security attributes is shown in Fig. 1.

Fig. 1 shows that CIAAN (Confidentiality, Integrity, Availability, Accountability and Non-repudiation) and EESU (Effectiveness, Efficiency, Satisfaction and User Error Protection) affect the usable security of software. Usable-security may be improved by focussing on CIAAN with EESU together (Anwar et al., 2018; Beckles et al., 2005). Hence, these factors should be included for assessment of usable-security.

4. Methodology

Numerous researchers have done research works related to usability and security. To assess the usable-security, Multi-Criteria Decision Analysis (MCDA) plays an important role in performing various conflicting evaluation items including multi-attribute utility theory and analytic hierarchy process and fuzzy analytic hierarchy process (Beckles et al., 2005; Buckley, 1985). Further, all decision methodology approaches are differentiated by the way the objectives and alternative weights are determined (Deng, 1999). With the help of MCDA method, an assessment method has been proposed for usable-security for satisfaction and ease of usage because usable-security assessment is a multi-criteria problem. The present contribution aims to assess the usable-security with the help of Fuzzy AHP. To decompose a multi-criteria problem into a hierarchy, AHP was firstly used by Saaty (1980). AHP also measures the importance of the attributes and consistency of the expert's opinions.

Further, to evaluate the subjective and objective values of the attributes, AHP is a better method than other MCDA methods. But, AHP cannot resolve the inherent uncertainty and vagueness related to the mapping of a decision maker's awareness of exact numbers. Authors found that practitioners have combined the Fuzzy theory with AHP as the real world is highly ambiguous to analyze ambiguous real-world problems (Chang et al., 2008; Lious and Wang, 1992). To assess the usable-security through analyzing data and reaching a consensus among experts, this work adopts the Buckley method (Buckley, 1985) and method of the eigenvector is used to evaluate the weights. Further, the AHP method only uses the pair-wise comparison matrix to evaluate ambiguity in MCDA problems as in Eq. (1).

$$A = ([a_{ij}]) = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} 1 & (a_{12}) & \dots & (a_{1n}) \\ 1/(a_{12}) & 1 & \dots & (a_{2n}) \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ 1/(a_{1n}) & 1/(a_{2n}) & \dots & 1 \end{bmatrix} \end{array} \quad (1)$$

where $a_{ij} = 1$ and $a_{ij\ =\ 1/}a_{ij}$, i, j = 1, 2,. . ., n.

An n-by-n matrix, A can be expressed as shown in Eq. (1). Let C_1, C_2,. . ., C_n denote the set of attributes while a_{ij} represents a quantified judgment on a pair of attributes C_i, C_j. The relative importance of the two attributes is rated using a scale (Buckley, 1985; Saaty, 1980). The Fuzzy AHP method comprises four major steps as discussed below:

Firstly, the problem is divided into a hierarchical structure to solve it using Fuzzy-AHP. It should be stated clearly and a hierarchical structure is made for solution shown in Fig. 1. This hierarchy can be made by using expert's opinions and responses in questionnaire or using brainstorming and other such method. The next step is establishing the triangular fuzzy numbers (TFN) from the hierarchy. Fuzzy set theory is capable of handling vague data. A fuzzy set is a class of objects with a graded range of membership. Such an asset is characterized by a membership function, which assigns to each object a membership grade between zero and one. Fig. 2 depicts a triangular fuzzy number.

A TFN is denoted simply as (Lo, Mi, Up). The Eqs. (2)–(4) are used in converting the numeric values into Triangular Fuzzy Number (TFN) [19] and denoted as (Lo_{ij}, Mi_{ij}, Up_{ij}) where, Lo_{ij} is lower value, Mi_{ij} is middle value and Up_{ij} is uppermost level events. Further, TFN [η_{ij}] is established as the following:

$$\eta_{ij} = (Lo_{ij}, Mi_{ij}, Up_{ij}) \quad (1)$$

$$where\ Lo_{ij} \le Mi_{ij} \le Up_{ij}$$

$$Lo_{ij} = min(J_{ijk}) \quad (2)$$

$$Mi_{ij} = (J_{ij1}, J_{ij2}, J_{ij3})^{\frac{1}{x}} \quad (3)$$

$$and\ Up_{ij} = max(J_{ijk}) \quad (4)$$

In the above equations, J_{ijk} shows the comparative importance of the values between two criteria and given by expert *k*. Where *i* and *j* represent a pair of criteria being judged by experts. Value η_{ij} is calculated based on the geometric mean of expert's opinions for a particular comparison. The geometric mean is capable of accurately aggregating and representing the consensus of

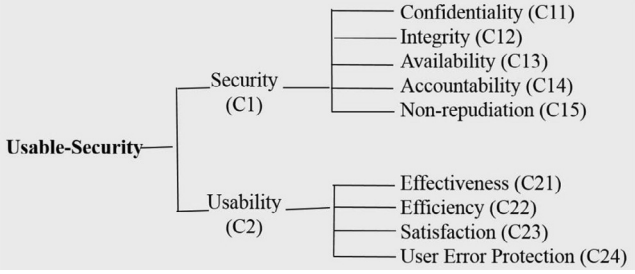

Fig. 1. A Tree Structure of Usable-Security Attributes.

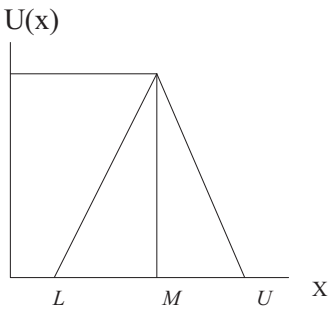

Fig. 2. Triangular Fuzzy Numbers.

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stakeholders and represents the lowest and highest scores, respectively, for the relative importance between the two criteria. After getting the TFN value for every pair of comparison, a fuzzy pair-wise comparison matrix is established in the form of *n x n* matrix. Participants of this evaluation include academicians and developers who have experience in usability and security both. These participants were chosen to ensure the consistency of AHP testing. After qualitative evaluation, TFN membership function and pair-wise comparisons are calculated to generate the fuzzy judgment matrix that is established in the third step. Further, after the construction of the comparison matrix, defuzzification is performed to produce a quantifiable value based on the calculated TFN values. The defuzzification method adopted in this work has been derived from (Buckley, 1985; Deng, 1999; Saaty, 1980) as formulated in Eqs. (5)–(7) which is commonly referred to as the alpha cut method.

$$\rho\alpha,\beta(A) = \left[\boldsymbol{\beta}.A(\boldsymbol{Lo}_{ij}) + (1-\boldsymbol{\beta}).A(\boldsymbol{Up}_{ij})\right] \tag{5}$$

where $0 \le \alpha \le 1$ *and* $0 \le \beta \le 1$
such that,

$$\tilde{\boldsymbol{A}}(\boldsymbol{Lo}ij) = (\boldsymbol{Mi}ij - \boldsymbol{Lo}ij).\boldsymbol{\alpha} + \boldsymbol{Lo}ij \tag{6}$$

$$\tilde{\boldsymbol{A}}(\boldsymbol{Up}ij) = \boldsymbol{Up}_{\boldsymbol{ij}} - (\boldsymbol{Up}ij - \boldsymbol{Mi}ij).\boldsymbol{\alpha} \tag{7}$$

Where α and β in these equations are used for the preferences of experts. These two values vary between 0 and 1. The alpha cut of a fuzzy set is the set of all elements. The alpha threshold value is any value taken from a scale of 0 to 1. Which have its membership value greater than or equal to an alpha threshold value, represented by α. $\tilde{A}_\alpha(Lo_{ij})$ and $\tilde{A}_\alpha(Up_{ij})$ show the lower and upper limit of defuzzified values. The matrix prepared after evaluating judgments from participants is shown in Eq. (8).

$$\rho_{\alpha,\beta}(\tilde{\mathbf{A}}) = \rho_{\alpha,\beta}[\tilde{a}_{ij}] = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} 1 & \rho_{\alpha,\beta}(\tilde{a}_{11}) & \dots & \rho_{\alpha,\beta}(\tilde{a}_{1i}) \\ 1/\rho_{\alpha,\beta}(\tilde{a}_{21}) & 1 & \dots & \rho_{\alpha,\beta}(\tilde{a}_{2i}) \\ . & . & & . \\ . & . & & . \\ 1/\rho_{\alpha,\beta}(\tilde{a}_{j1}) & 1/\rho_{\alpha,\beta}(\tilde{a}_{j2}) & \dots & 1 \end{bmatrix} \end{array} \tag{8}$$

where $\left[\tilde{\boldsymbol{a}}ij\right]$ denotes a triangular fuzzy number for the relative importance of two criteria C_1. Further, alpha cut enables one to describe a fuzzy set as a composition of crisp sets. Crisp sets $\boldsymbol{\rho\alpha}, \boldsymbol{\beta}$ (Ã) simply describe whether an element is either a member of the set or not. Single pair-wise comparison matrix is expressed in Eq. (8) (M. Alenezi et al., 2019). Further, the next step in this procedure is to determine the eigenvalue and eigenvector of the pairwise comparison matrix. The purpose of calculating the eigenvector is to determine the aggregated weight of particular criteria. Assume that $\rho_{\alpha,\beta}$ denotes the eigenvector while λ denotes the eigenvalue of fuzzy pairwise comparison matrix a_{ij}.

$$\left[\boldsymbol{\rho}_{\boldsymbol{\alpha},\boldsymbol{\beta}}\left(\tilde{A}\right) - \boldsymbol{\lambda I}\right].\boldsymbol{\rho} = 0 \tag{9}$$

Eq. (9) is based on the linear transformation of vectors, where *I* represent the unitary matrix. By applying Eqs. (1)–(9), the weights of particular criteria with respect to all other possible criteria may be acquired. To continue the AHP process, check the Consistency Ratio (CR) (Chang et al., 2008; Lious and Wang, 1992). If CR value is less than 0.1, hence AHP analysis is correct otherwise analyzed the AHP process again.

5. Assessment of usable-security

Usable-security is usually a qualitative measure. It's a challenge to assess the usable-security quantitatively. In addition, weights of usable-security attributes play a significant role for security usability of software. The set of criteria often differs in the degree of importance. There have been several tools for solving this kind of problem including AHP method and several soft computing techniques, in which AHP has been a tool that is widely used and adopted by decision makers and researchers to aid in priority analysis (Buckley, 1985). AHP is considered good in analyzing a decision in a group, but many researchers have found that fuzzy AHP is more valuable to provide crisp decisions with their weights too (Saaty, 1980; Chang et al., 2008; Lious and Wang, 1992). This research contributes a way for assessment of usable-security by fuzzy analytic hierarchy process. For collecting data, authors have taken 70 experts from the different fields of academics and industry. With the help of the inputs of experts, this contribution aims to evaluate the usable-security.

To evaluate the usable-security, different versions of two different Developed Software for Babasaheb Bhimrao Ambedkar University (A Central University), Lucknow, India including version 11, version 12, version 13 and version 21, version 22, version 23 have been taken. To assess the best alternative, Fig. 1 shows the hierarchy of the usable-security attributes. Further, Eqs. (1)–(4) are used to evaluate the triangular fuzzy numbers. After qualitative evaluation, pair-wise comparisons are prepared. The constructed aggregated fuzzy pair-wise comparison matrix is shown in Tables 1–3.

According to hierarchy, Tables 1–3 depict the fuzzy aggregated pair-wise comparison matrix at level 1 and level 2. With the help of Eqs. (5)–(8), this paper used α cut method of defuzzification as:

The relative importance of the security and usability attributes is rated as (0.305, 0.389, 0.561).

Then,

From Eq. (6),

$$\begin{aligned}\boldsymbol{\rho}_{0.5}(Lo_{12}) &= (Mi_{security-usability} - Lo_{security-usability}) * 0.5 \\ &\quad + Lo_{security-usability}\boldsymbol{\rho}_{0.5}(Lo_{security-usability}) \\ &= (0.389 - 0.305) * 0.5 + 0.305 = 0.347\end{aligned}$$

From Eq. (7),

$$\begin{aligned}\boldsymbol{\rho}_{0.5}(Up_{security-usability}) &= Up_{security-usability} - (Up_{security-usability} \\ &\quad - Mi_{security-usability}) * 0.5\boldsymbol{\rho}_{0.5}(Up_{security-usability}) \\ &= 0.561 - (0.561 - 0.389) * 0.5 = 0.475\end{aligned}$$

From Eq. (5),

$$\begin{aligned}\rho_{0.5,0.5}(\tilde{A}_{security-usability}) &= [0.5 * 0.347 + (1-0.5).0.475] \\ &= 0.411\rho_{0.5,0.5}(\tilde{A}_{usability-security}) = 2.433\end{aligned}$$

With the help of Eqs. (8) and (9), the weights of particular criteria with respect to all other possible criteria may be acquired as:

$$\begin{bmatrix} 1 & 0.411 \\ 2.433 & 1 \end{bmatrix} \begin{bmatrix} \boldsymbol{\rho}_{\boldsymbol{Security}} \\ \boldsymbol{\rho}_{\boldsymbol{Usability}} \end{bmatrix} = \begin{bmatrix} \mathbf{0} \\ \mathbf{0} \end{bmatrix}$$

$$\left[\boldsymbol{\rho}_{\boldsymbol{\alpha},\boldsymbol{\beta}}(\boldsymbol{\eta_{ij}} - \boldsymbol{\lambda I})\right] = \begin{bmatrix} 1 & 0.411 \\ 2.433 & 1 \end{bmatrix}$$

Table 1
Fuzzy Aggregated Pair-wise Comparison Matrix at Level 1.

	Security (C1)	Usability (C2)
Security (C1)	1,1,1	0.305, 0.389, 0.561
Usability (C2)	–	1,1,1

Table 2
Fuzzy Aggregated Pair-wise Comparison Matrix for Security at Level 2.

	Confidentiality (C11)	Integrity (C12)	Availability (C13)	Accountability (C14)	Non-repudiation (C15)
Confidentiality (C11)	1,1,1	0.690, 0.886, 1.100	0.226, 0.276, 0.357	1.000, 1.516, 1.933	0.490, 0.637, 1.000
Integrity (C12)	–	1,1,1	0.695, 0.950, 1.346	0.268, 0.352, 0.518	0.166, 0.197, 0.253
Availability (C13)	–	–	1,1,1	1.000, 1.320, 1.552	0.301, 0.435, 0.803
Accountability (C14)	–	–	–	1,1,1	0.222, 0.287, 0.415
Non-repudiation (C15)	–	–	–	–	1,1,1

Table 3
Fuzzy Aggregated Pair-wise Comparison Matrix for Usability at Level 2.

	Effectiveness (C21)	Efficiency (C22)	Satisfaction (C23)	User Error Protection (C24)
Effectiveness (C21)	1,1,1	0.658, 1.165, 1.688	1.149, 1.439, 1.697	0.268, 0.352, 0.518
Efficiency (C22)	–	1,1,1	1.193, 1.583, 2.150	1.000, 1.516, 1.933
Satisfaction (C23)	–	–	1,1,1	1.000, 1.320, 1.552
User Error Protection (C24)	–	–	–	1,1,1

Table 4
Aggregated Pair-wise Comparison Matrix for Usable-Security at level 1.

	Security (C1)	Usability (C2)	Weights
Security (C1)	1	0.411	**0.293**
Usability (C2)	2.433	1	**0.707**
C.R. = 0.001			

$$\begin{bmatrix} \rho_{Security} \\ \rho_{Usability} \end{bmatrix} = \begin{bmatrix} 0.293 \\ 0.707 \end{bmatrix}$$

CR values are also less than 0.1. Further, the independent weights of usable-security attributes and CR values are shown in Tables 4–6.

According to the hierarchy, Table 4 shows the defuzzified aggregated pair-wise comparison matrix and local weights of level 1 attributes. It is evident through the results that the usability is more important than security for balancing the usability of security.

According to the hierarchy, Table 5 shows the defuzzified aggregated pair-wise comparison matrix and local weights of level 2 attributes for security. It is clear through the results that the non-repudiation is more important than other attributes for improving the usability of security during software is in use.

According to the hierarchy, Table 7 shows the defuzzified aggregated pair-wise comparison matrix and local weights of level 2 attributes for usability. It is evident through the results that user error protection is more important than other attributes for improving the usability of security of software in use. Table 7 shows the dependent weights and overall ranking of the hierarchy. A1, A2. . . . .An; symbols are described as the alternatives (Agrawal et al., 2019) and objective weights is stated in Table 7.

The composite priorities of levels 2 to 3 are then determined by aggregating the weights throughout the hierarchy. In usable-security, security has 0.293 wt and usability has 0.707 wt It means usability is more important than security and balance between usability and security is needed. For security, confidentiality has 0.183 wt, integrity has 0.115 wt, availability has 0.156 wt, accountability has 0.157 wt, non-repudiation has 0.389 wt and non-repudiation is most important for security. For usability, effectiveness has 0.219 wt, efficiency has 0.287 wt, satisfaction has 0.211 wt, user error protection has 0.283 wt and user error protection is most important for usability.

The six evaluative criteria are weighted as follows: confidentiality (0.054), integrity (0.034), availability (0.045), accountability (0.046), non-repudiation (0.114), effectiveness (0.155), efficiency (0.203), satisfaction (0.149), user error protection (0.200) and efficiency are most important for usable-security of software. The impact of usable-security in different alternatives is determined as:

$$\begin{bmatrix} 0.054, 0.034, 0.045, 0.046, 0.114, \\ 0.155, 0.203, 0.149, 0.200 \end{bmatrix}$$
$$\begin{bmatrix} 0.231 & 0.247 & 0.227 & 0.297 & 0.245 & 0.228 \\ 0.219 & 0.227 & 0.234 & 0.270 & 0.258 & 0.276 \\ 0.281 & 0.234 & 0.237 & 0.237 & 0.243 & 0.260 \\ 0.274 & 0.241 & 0.296 & 0.251 & 0.209 & 0.228 \\ 0.270 & 0.253 & 0.292 & 0.270 & 0.278 & 0.337 \\ 0.233 & 0.238 & 0.266 & 0.234 & 0.255 & 0.260 \\ 0.238 & 0.206 & 0.233 & 0.251 & 0.263 & 0.233 \\ 0.242 & 0.244 & 0.244 & 0.231 & 0.287 & 0.299 \\ 0.202 & 0.237 & 0.266 & 0.238 & 0.283 & 0.292 \end{bmatrix}$$
$$= \begin{matrix} A1 \\ A2 \\ A3 \\ A4 \\ A5 \\ A6 \end{matrix} = \begin{bmatrix} 0.237 \\ 0.234 \\ 0.256 \\ 0.247 \\ 0.267 \\ 0.273 \end{bmatrix}$$

Impact of usable-security for different alternatives is evaluated as 0.237, 0.234, 0.256, 0.247, 0.267 and 0.273 for A1, A2, A3, A4, A5, and A6 respectively. The results show the A6 have highly usable-security.

Table 5
Aggregated Pair-wise Comparison Matrix for Security at level 2.

	Confidentiality (C11)	Integrity (C12)	Availability (C13)	Accountability (C14)	Non-repudiation (C15)	Weights
Confidentiality (C11)	1	0.892	1.173	1.491	0.691	**0.183**
Integrity (C12)	1.121	1	0.994	0.372	0.203	**0.115**
Availability (C13)	0.853	1.006	1	1.298	0.494	**0.156**
Accountability (C14)	0.671	2.688	0.770	1	0.303	**0.157**
Non-repudiation (C15)	1.447	4.926	2.024	3.300	1	**0.389**
CR = 0.0733549						

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Table 6
Aggregated Pair-wise Comparison Matrix for Usability at level 2.

	Effectiveness (C21)	Efficiency (C22)	Satisfaction (C23)	User Error Protection (C24)	Weights
Effectiveness (C21)	1	1.172	1.363	0.372	**0.219**
Efficiency (C22)	0.853	1	1.633	1.491	**0.287**
Satisfaction (C23)	0.734	0.613	1	1.298	**0.211**
User Error Protection (C24)	2.688	0.671	0.770	1	**0.283**
C.R. = 0.010					

Table 7
Summarizes the Results through Fuzzy AHP.

First Level Attributes	Local Weights of First Level	Second Level Attributes	Local Weights of Second Level	Overall Weights	Overall Ranks	Weights for Level 3					
						Project 1 (Entrance Exam Software)			Project 2 (Online Quiz Competition Software)		
						(A1)	(A2)	(A3)	(A4)	(A5)	(A6)
C1	0.293	C11	0.183	0.054	6	0.231	0.247	0.227	0.297	0.245	0.228
		C12	0.115	0.034	9	0.219	0.227	0.234	0.270	0.258	0.276
		C13	0.156	0.045	8	0.281	0.234	0.237	0.237	0.243	0.260
		C14	0.157	0.046	7	0.274	0.241	0.296	0.251	0.209	0.228
		C15	0.389	0.114	5	0.270	0.253	0.292	0.270	0.278	0.337
C2	0.707	C21	0.219	0.155	3	0.233	0.238	0.266	0.234	0.255	0.260
		C22	0.287	0.203	1	0.238	0.206	0.233	0.251	0.263	0.233
		C23	0.211	0.149	4	0.242	0.244	0.244	0.231	0.287	0.299
		C24	0.283	0.200	2	0.202	0.237	0.266	0.238	0.283	0.292

6. Validation

After the implementation through Fuzzy AHP method, this section is using another method, which is called Classical AHP technique to prove the correctness of the whole assessments and results. AHP is a decision aid for helping to solve unstructured problems in economics, social and information sciences (Saaty, 1980; Chang et al., 2008; Lious and Wang, 1992). The impact of usable-security for the different versions has been evaluated through classical AHP to prove the accuracy of the results. In classical AHP, the process of data collection and assessment of that data is same as Fuzzy AHP but the only difference is that no fuzzification is required. Hence, the data is taken in its crisp form for classical AHP.

According to the AHP process, first, a decision hierarchy has been developed which is same as in Fig. 1. In the next step, pair-wise matrix of expert's judgments has been developed but this method is using the numeric values directly on the behalf of TFN values. With the help of the scale, linguistic values are converted into numeric values. Next step is to aggregate the pair wise comparison matrix of expert's judgments while consistency ratio of the pair-wise matrix is checked. Further, according to the set of attributes in the hierarchy, the relative local weights and ranks of each set of attributes have been depicted in Tables 8–11.

According to the hierarchy, Table 8 depicts the aggregated pair-wise comparison matrix and local weights of level 1 attributes. It is clear through the results that usability is more important than security for improving the overall usable-security.

According to the hierarchy, Table 9 shows the aggregated pair-wise comparison matrix and local weights of level 2 attributes for security. It is evident through the results that non-repudiation is more important than other attributes for improving the usability of security software.

According to the hierarchy, Table 10 is showing the aggregated pair-wise comparison matrix and local weights of level 2 attributes for usability. It is clear through the results that the user error protection is more important than other attributes for improving the usability of security while the software is in use. Table 11 shows the dependent weights and overall ranking of the hierarchy.

The nine evaluative criteria are weighted as follows: confidentiality (0.033), integrity (0.031), availability (0.060), accountability (0.041), non-repudiation (0.110), effectiveness (0.157), efficiency (0.205), satisfaction (0.152), user error protection (0.207) and efficiency is most important for usable-security of software. The impact of usable-security in different alternatives is determined as:

$$\begin{bmatrix} 0.033, 0.031, 0.060, 0.041, 0.110, \\ 0.157, 0.205, 0.152, 0.207 \end{bmatrix}$$

$$\begin{bmatrix} 0.231 & 0.247 & 0.227 & 0.297 & 0.245 & 0.228 \\ 0.219 & 0.227 & 0.234 & 0.270 & 0.258 & 0.276 \\ 0.281 & 0.234 & 0.237 & 0.237 & 0.243 & 0.260 \\ 0.274 & 0.241 & 0.296 & 0.251 & 0.209 & 0.228 \\ 0.270 & 0.253 & 0.292 & 0.270 & 0.278 & 0.337 \\ 0.233 & 0.238 & 0.266 & 0.234 & 0.255 & 0.260 \\ 0.238 & 0.206 & 0.233 & 0.251 & 0.263 & 0.233 \\ 0.242 & 0.244 & 0.244 & 0.231 & 0.287 & 0.299 \\ 0.202 & 0.237 & 0.266 & 0.238 & 0.283 & 0.292 \end{bmatrix}$$

$$= \begin{matrix} A1 \\ A2 \\ A3 \\ A4 \\ A5 \\ A6 \end{matrix} = \begin{bmatrix} 0.236 \\ 0.233 \\ 0.255 \\ 0.244 \\ 0.266 \\ 0.272 \end{bmatrix}$$

Usable-security of different alternatives is evaluated as 0.236, 0.233, 0.255, 0.244, 0.266 and 0.272 for A1, A2, A3, A4, A5, and A6, respectively. The results show the A6 has highly usable-security. Difference between the results of usable-security assess-

Table 8
Aggregated Pair-wise Comparison Matrix at Level 1.

	Security (C1)	Usability (C2)	Weights
Security (C1)	1	0.389	**0.280**
Usability (C2)	2.571	1	**0.720**
CR = 0.0011			

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Table 9
Aggregated Pair-wise Comparison Matrix for Security at Level 2.

	Confidentiality (C11)	Integrity (C12)	Availability (C13)	Accountability (C14)	Non-repudiation (C15)	Weights
Confidentiality (C11)	1	0.886	0.276	1.516	0.637	**0.138**
Integrity (C12)	1.129	1	0.95	0.352	0.197	**0.108**
Availability (C13)	3.623	1.053	1	1.32	0.435	**0.215**
Accountability (C14)	0.660	2.841	0.758	1	0.287	**0.148**
Non-repudiation (C15)	1.570	5.076	2.299	3.484	1	**0.391**
CR = 0.036214						

Table 10
Aggregated Pair-wise Comparison Matrix for Usability at Level 2.

	Effectiveness (C21)	Efficiency (C22)	Satisfaction (C23)	User Error Protection (C24)	Weights
Effectiveness (C21)	1	1.165	1.439	0.352	**0.218**
Efficiency (C22)	0.859	1	1.583	1.516	**0.284**
Satisfaction (C23)	0.695	0.632	1	1.32	**0.211**
User Error Protection (C24)	2.841	0.660	0.758	1	**0.287**
CR = 0.022743					

Table 11
Summarizes the Results through Classical AHP.

First Level Attributes	Local Weights of First Level	Second Level Attributes	Local Weights of Second Level	Overall Weights	Overall Ranks	Weights for Level 3					
						Project 1 (Entrance Exam Software)			Project 2 (Online Quiz Competition Software)		
						(A1)	(A2)	(A3)	(A4)	(A5)	(A6)
C1	0.280	C11	0.138	0.033	8	0.231	0.247	0.227	0.297	0.245	0.228
		C12	0.108	0.031	9	0.219	0.227	0.234	0.270	0.258	0.276
		C13	0.215	0.060	6	0.281	0.234	0.237	0.237	0.243	0.260
		C14	0.148	0.041	7	0.274	0.241	0.296	0.251	0.209	0.228
		C15	0.391	0.110	5	0.270	0.253	0.292	0.270	0.278	0.337
C2	0.720	C21	0.218	0.157	3	0.233	0.238	0.266	0.234	0.255	0.260
		C22	0.284	0.205	2	0.238	0.206	0.233	0.251	0.263	0.233
		C23	0.211	0.152	4	0.242	0.244	0.244	0.231	0.287	0.299
		C24	0.287	0.207	1	0.202	0.237	0.266	0.238	0.283	0.292

Table 12
Difference between the Results.

Usable-Security		
Alternatives	Fuzzy AHP	AHP
A1	0.237	0.236
A2	0.234	0.233
A3	0.256	0.255
A4	0.247	0.244
A5	0.267	0.266
A6	0.273	0.272

ment through fuzzy AHP and classical AHP methods is negligible as shown in Table 12. While it can be seen that results are found to be efficient and better using Fuzzy-AHP rather than classical AHP. It is because using Fuzzy with AHP gives more precise inputs and further gives crisp results. Table 12 and Fig. 3 show the difference between the results obtained from Fuzzy AHP and AHP.

According to results, fuzzy AHP and classical AHP methods have different procedures. Further, the results are also different but very similar. To statistically analyse the correlation between results, this work is taking Pearson's correlation method [14] for evaluating the overall correlations between results. The Pearson correlation coefficient measures the strength and direction of relationship between values of two variables. Correlation coefficient shows the impact of the relationship between two values. The scale lies between −1 and +1 [15]. The value near to −1 shows the lower bonding between values and the value near to +1 shows the tighter bonding between values. After statistical analysis, the correlation between results of both methods is 0.9987. Based on these results, the inference focuses on providing suggestions to developers for enhancing the effectiveness and efficiency of security usability of software.

7. Discussion

As the software is becoming more complex, the use of the software is gradually increasing. This establishes the pertinent need to have software with highly compatible security attributes with usability. Security is one of the most significant quality factors nowadays which is getting maximum attention of software designers as well as the users. The aim of this study is to assess usable-security of software at early stages of development. To achieve this purpose, the research paper integrates security attributes and usability attributes and produces results which are helpful for developers in providing the usable-security of software. There are different security models which measure security and usability individually but few such model is available which integrated security and usability in a single row using Fuzzy-AHP and other MCDM methods. The model proposed here will help to evaluate the usable-security of software and enhance the satisfaction of the user end. In this contribution, the author has examined nine usable-security attributes during software development. This contribution will help to easily apply usable-security management plan during software development to enhance the effectiveness

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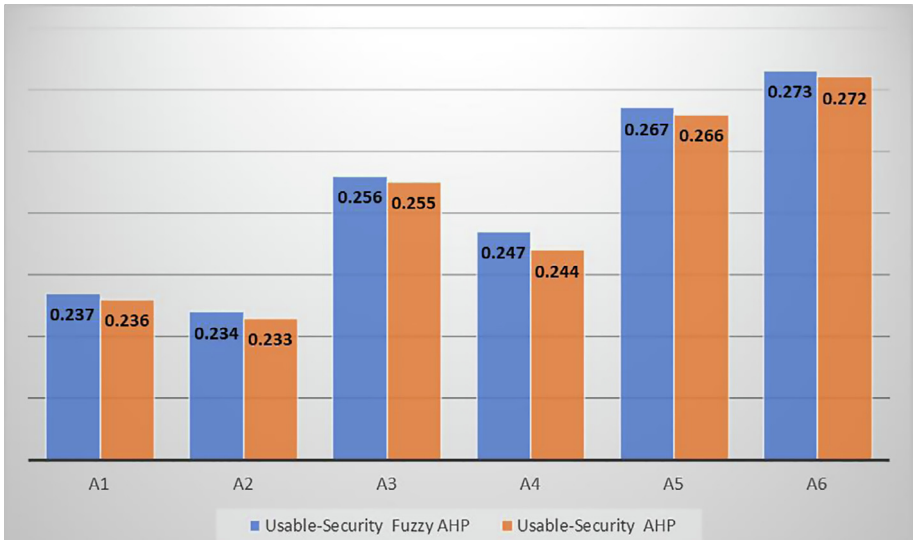

Fig. 3. Difference between the results through Fuzzy AHP and classical AHP.

and user satisfaction. Major significances of the work are as follows:

- Assessing usable-security will enhance effectiveness and user satisfaction thus will increase secure software for the user's sake.
- Focusing on usable-security attributes during software development will improve the usability of secure software.
- User error protection is the most important as well as the appropriate attribute of usable-security to enhance the allover usability of software.
- MCDM method such as Fuzzy-AHP proves to provide more efficient results rather than AHP, hence emerges as a good hybrid technique for usable-security estimation.

A majority of organizations distinguish rapidly changing business and regulatory demands to modify how security (basically maintaining CIA) is managed during software development process. To improve the strength of security usability of the software, the proposed work presents quantitative assessment. All in all, this contribution assesses usable-security of software which strengthens the fact that user error protection and availability should be given top priority while designing usable and secure software.

8. Conclusion

In this research, usability and security attributes are identified and usable-security of software is examined. Assessment of usable-security is a multi-criteria decision problem and that is why this paper has used the Fuzzy AHP method to evaluate the usable-security. Most important attributes with respect to weights have also been evaluated. It has been concluded that the user error protection is the most important factor among the nine main usable-security attributes. For the assurance of usable-security, developers need to, firstly, focus on user error protection and, secondly, the efficiency for ensuring usable-security and software services.

Competing interests

Authors have declared that no competing interests exist.

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