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USABLE-SECURITY ATTRIBUTE EVALUATION USING FUZZY ANALYTIC HIERARCHY PROCESS

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Abstract. *Security has always been a vital research topic since the birth of software. A great deal of research has been conducted to determine the ways for identifying and classifying the security issues or goals. In recent years, it has been noticed that high secure software has less usability and has loosed businesses continuity. Without using the services of software, high security becomes worthless. Hence, there is a need to bridge the gap between security and usability of software. Indeed, security mechanisms must be usable to improve the security as well as the usability of software. Although security and usability are not directly related, some of their attributes impact each other indirectly. Attributes play a key role in bridging the gap between security and usability. In this respect, this paper identifies the main factors of security and usability that affect each other directly and indirectly, including confidentiality, integrity and availability and effectiveness, efficiency, and satisfaction. The importance of each attribute in terms of their weight is essential for their impact on the overall security design during the software development process. To evaluate our work, we used the Fuzzy Analytic Hierarchy Process (Fuzzy AHP). The obtained results and conclusions are useful to software developers to achieve more secure and usable software.*
Keywords: Software security, Software usability, Usability of security services, Software development process

1. Introduction.

Major quality factors including maintainability, usability, and security, etc., are always considered during software development [1]. Nowadays, developers are facing usability related problem after delivering the software to end users [2]. Due to high-security design, software is not usable as it could be [1-3]. Practitioners are trying to find a solution to this problem. Usability of software increases, if security is usable [4,5], although, security refers to the prevention of un-authorization [5] while usability ensures 'the keeping simple' formula of software [7]. Thus, the organization wants user-friendly security services of software to enhance revenue. There are some attributes of usable-security that affect the usability of security services including Confidentiality, Integrity and Availability (CIA) which affect directly [8] & Effectiveness, Efficiency and Satisfaction (EES) affect indirectly [6]. So, developers are trying to develop a high-security design with usable-security for improving the usability of software services [9].

Although, security and usability make a negative relation with each other because increasing usability decreases the security of software [9,10], still, there are some factors

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of usability which positively affect the security services including effectiveness that affects security, positively. Unfortunately, efforts have not been made to develop usable-security design during software development. Importance of attributes plays a key role during usable-security design. Plenty of research has been done in the field of prioritizing usability attributes and security attributes [13-15]. However, no attempt has been reported in the literature for prioritizing usable-security attributes to improve the uses of security services. The success of security technology largely depends on user acceptance [13] and usable-security service is in the user's primary needs [5].

The analysis of identifying and prioritizing the usable-security factors is a very critical task. Further, evaluation of usable-security attributes should not focus only on the security services but it is important to whole software services. Further, effective assessment of attributes is necessary to ensure overall security services of software. Outcomes of the evaluation process may allow decision-makers to make appropriate decision as well as action. However, to be able to take appropriate action, decision makers not only need to know the usable-security factors that contribute to security but also identify the most usable factors among them. Hence, to address the relationship between these factors, a hierarchy of usable-security attributes is defined in the next section and Fuzzy AHP is used for prioritization of different usable-security attributes. The results may help the security designers for developing usable-security services during software development. Rest of the paper is organized as follows. Section 2 discusses the importance of usable-security, and Section 3 evaluates usable-security attributes. Section 4 prioritizes the identified attributes and discusses the results. The final conclusion is presented in Section 5.

2. **Usable-Security: User's Demand.** Software security is an idea or method that is implemented to prevent software from malicious attacks [11,12]. According to G. McGraw, software security is about building secure software, i.e., designing software to be secure, making sure that the software is secure, and educating software developers and architects, and users about how to build secure software [15-17]. Due to the wide applicability of software, security has become a crucial component during the software development process [15]. Indeed, software faces threats from various potential malicious adversaries that are growing every day: from web mindful applications running on PCs, to complex media communications [12]. Assessing and maintaining CIA during stages of software development is proved to be one of the best ways to get more secure software. That is why everyone is building a high-security design and this much security design contains very less usability due to lots of complex processes. This problem generates the issues to an end-users end. Due to the very complex design of security, users are not able to use the software with much ease that it could be. Further, IEEE standard defines usability as the degree of ease of use by which user can achieve its desired results without making many efforts [15]. According to a learned Jakob Nielsen, usability is a quality attribute that depends on five components including learnability, efficiency, memorability, errors, and satisfaction [10].

Although, security and usability seem to be found odds, it is revealed that improving one of them affects the other. Techniques to incorporate security issues or goals have already been developed [3], but there is missing an important aspect, i.e., security-usability/usable-security. 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 [7]. The International Standard Organization (ISO) [4] defines usability as the ability that provides specified services with ease of use to the user including effectiveness, efficiency, and satisfaction in a specified context of use. According to this definition, usable-security focuses on the user's goals (effectiveness), the speed with which goals are achieved (efficiency), and users' satisfaction. Hence, security has three major factors of usability that affect indirectly including effectiveness, efficiency, and satisfaction. Further, CIA is the pillars of security. These six attributes play a key role in improving the usable-security services of software.

3. **Evaluation of Usable-Security Attributes.** All decision methodology approaches are differentiated by the way, the objectives and alternative weights are determined [16]. There is a need to assess usable-security for ensuring the security of software for satisfaction and ease of usage. Results evaluation of usable-security attributes should be analyzed deeply and that can be used to enhance the usability of security services. The analysis of prioritization is done by a Multi-Criteria Decision Making (MCDM) method [14]. Although Analytic Hierarchy Process (AHP) is considered good in analyzing a decision in a group, many researchers have found that Fuzzy AHP is more valuable to provide crisp decisions with their weights, too [15]. AHP has been an important tool that is widely used and adopted by decision makers and researchers to complete priority analysis. In order to deal with the uncertainties and ambiguity of human judgment, the authors have come out with a modified version of AHP known as Fuzzy AHP which incorporates fuzzy set theory with AHP methodology [19]. This work contributes as prioritization of usable-security attributes through Fuzzy AHP with the help of the inputs of experts. It finds out the weight and ranks of attributes for usable-security services. In this work, authors have taken six factors of usable-security including confidentiality, integrity, availability, effectiveness, efficiency and satisfaction as shown in Figure 1.

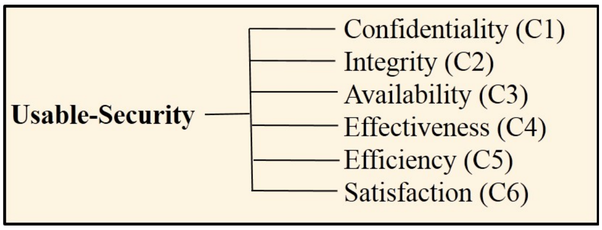

Figure 1. Usable-security attributes

Figure 1 shows that effectiveness, efficiency, and satisfaction are the factors of usability that also affects the security services, positively. Effectiveness is the capability of the user to be able to perform a particular task [18]. Efficiency is captured by measuring the time to complete a task or the number of attempts done to achieve required goals [19]. Satisfaction of the user is important to evaluate usability as software is bound to fail even when it is usable if it is not acceptable to users [20]. As per the definitions of three factors of usability it is clear that these factors affect software security as well [3]. Hence, these factors should be included for assessment of usable-security. Usable-security may be improved through a focus on CIA with EES together. Hence, the priorities of usable-security attributes are important to evaluate the very important attribute among these six factors. Also, the contribution of each attribute in usable-security is calculated. Hence, this section discusses the prioritization of usable-security factors to enhance the usability of security services. The usable-security factors have been identified through a comprehensive literature review and experts' opinions. As discussed earlier, the authors have proven that AHP is one of the best arrangement techniques in a small-scale MCDM problem [19,20], such as the one presented in this section.

The present contribution aims to determine the priority of usable-security factors. For this, a questionnaire is prepared. Thus, it is required to have a group of experienced experts working in the area of usability and security to answer the questionnaires. Fuzzy AHP is chosen for evaluating the importance of usable-security factors because it is capable of controlling vague judgmental inputs given by the participants [5,6]. It is also capable of converting qualitative inputs into quantitative results, in the form of weight and ranking which is a better assessment of usable security [17,18]. Further, the pairwise comparison matrix is prepared through the questionnaire for Fuzzy AHP technique. For evaluating the weight of usable-security attributes, expert's opinions are converted to numeric values. Equations (1)-(3) are used in converting the numeric values into Triangular Fizzy Number (TFN) [4] and denoted as $(l_{ij}m_{ij}h_{ij})$, where l_{ij} is least possible, m_{ij} is most likely and h_{ij} is extreme possible events. Further, TFN $[\eta_{ij}]$ is established as the following:

$$\eta_{ij} = [l_{ij}m_{ij}h_{ij}] \text{ where } l_{ij} \leq m_{ij} \leq h_{ij}$$

$$l_{ij} = \min\left(J_{ijk}\right) \tag{1}$$

$$m_{ij} = \left(J_{ij1}, J_{ij2}, \ldots, J_{ijk}\right)^{1/k} \tag{2}$$

$$h_{ij} = \max\left(J_{ijk}\right) \tag{3}$$

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 participants. Value η_{ij} is calculated based on the geometric mean of stakeholders' scores for a particular comparison. The geometric mean is capable of accurately aggregating and representing the consensus of stakeholders [17] 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 $n \times n$ matrix. The size of the comparison matrix is 9×9, the group size threshold to achieve an acceptable level of consistency is twenty-five participants. Participants of this evaluation include academicians and developers who are having 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 done to generate the fuzzy judgment matrix. The matrix prepared by the researchers after evaluating judgments from twenty participants is shown in Table 1.

4. **Prioritization of Usable-Security Attributes.** 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 [12] as formulated in Equations (4)-(6) which is commonly referred to as the alpha cut method. 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. For this reason, the alpha threshold value has been taken as 0.5. Which have its membership value greater than or equal to an alpha threshold value, represented by α. Alpha cut enables one to describe a fuzzy set as a composition of crisp sets. Crisp sets $\mu_{\alpha,\beta}\left(\eta_{ij}\right)$ simply describe whether an element is either a member of the set or not. Equations (4)-(6) show the alpha cut method.

$$\mu_{\alpha,\beta}\left(\eta_{ij}\right) = \left[\beta \cdot_{\alpha}\left(l_{ij}\right) + (1-\beta) \cdot_{\alpha}\left(h_{ij}\right)\right] \text{ where } 0 \leq \alpha \leq 1 \text{ and } 0 \leq \beta \leq 1 \tag{4}$$

Such that,

$$_{\alpha}\left(l_{ij}\right) = \left(m_{ij} - l_{ij}\right) \cdot \alpha + l_{ij} \tag{5}$$

$$_{\alpha}\left(h_{ij}\right) = h_{ij} - \left(h_{ij} - m_{ij}\right) \cdot \alpha \tag{6}$$

α and β in these equations are used for preferences of experts. These two values vary between 0 and 1. By using Equations (4)-(6) with α and β at 0.5, the result is shown in Table 2.

Table 2 shows the CR value is less than 0.1; hence AHP analysis is correct. The next step is to determine the eigenvalue and eigenvector of the fuzzy pairwise comparison matrix. The purpose of calculating the eigenvector is to determine the aggregated weight of

Table 1. Fuzzy pair-wise comparison matrix based on collected expert's judgment

	Confidentiality (C1)	**Integrity (C2)**	**Availability (C3)**	**Effectiveness (C4)**	**Efficiency (C5)**	**Satisfaction (C6)**
Confidentiality (C1)	1,1,1	1.0000, 1.5157, 1.9331	0.4896, 0.6372, 1.0000	0.4152, 0.5743, 1.0000	0.2215, 0.2871, 0.4152	0.3146, 0.4610, 0.8705
Integrity (C2)	–	1,1,1	0.5743, 0.6657, 0.8022	0.3039, 0.3936, 0.5661	0.2679, 0.3521, 0.5176	0.1663, 0.1969, 0.2531
Availability (C3)	–	–	1,1,1	1.0000, 1.3195, 1.5518	0.3009, 0.4352, 0.8027	0.8027, 0.8705, 1.0000
Effectiveness (C4)	–	–	–	1,1,1	0.5386, 0.9143, 1.5836	0.6083, 1.0592, 1.6829
Efficiency (C5)	–	–	–	–	1,1,1	0.4152, 0.6372, 1.1791
Satisfaction (C6)	–	–	–	–	–	1,1,1

Table 2. Defuzzified final fuzzy pair wise comparison matrix

	Confidentiality (C1)	**Integrity (C2)**	**Availability (C3)**	**Effectiveness (C4)**	**Efficiency (C5)**	**Satisfaction (C6)**
Confidentiality (C1)	1	1.4912	0.6910	0.6410	0.3027	0.5268
Integrity (C2)	0.6706	1	0.6770	0.4143	0.3724	0.2033
Availability (C3)	1.4472	1.4771	1	1.2977	0.4935	0.8520
Effectiveness (C4)	1.5601	2.4137	0.7706	1	0.9636	1.1024
Efficiency (C5)	3.3036	2.6853	2.0263	1.0378	1	0.7172
Satisfaction (C6)	1.8983	4.9188	1.1737	0.9071	1.3943	1
	C.R. = 0.039					

particular criteria. Assume that μ denotes the eigenvector while λ denotes the eigenvalue of fuzzy pairwise comparison matrix η_{ij}.

$$[\mu_{\alpha,\beta}(\eta_{ij}) - \lambda I] \cdot \mu = 0 \tag{7}$$

Equation (7) is based on the linear transformation of vectors, where I represents the unitary matrix. By applying Equations (1)-(7), the weights of particular criteria with respect to all other possible criteria may be acquired. The ranks and weights of usable-security attributes are shown in Table 3.

Table 3. Weight and priority of attributes

S. No.	Usable-Security Attributes	Weights	Percentages	Ranks
1	Confidentiality (C1)	0.1037	10.37%	**5**
2	Integrity (C2)	0.0752	7.52%	**6**
3	Availability (C3)	0.1585	15.85%	**4**
4	Effectiveness (C4)	0.1848	18.48%	**3**
5	Efficiency (C5)	0.2369	23.69%	**2**
6	Satisfaction (C6)	0.2409	24.09%	**1**

The aggregated result in terms of weight is tabulated in Table 3. The results obtained are arranged as follows according to their ranking: Confidentiality (0.1037), Integrity (0.0752), Availability (0.1585), Effectiveness (0.1848), Efficiency (0.2369) and Satisfaction (0.2409). According to the weights and priority, wise ranking ***Satisfaction*** of user holds the highest priority among these six attributes. In actual scenario, there are various usable-security attributes, which are presented in the software development process [8-10,12]. In this research, only six attributes of usable-security being used which affect security have been identified as well as prioritized. For validation of the results, AHP is used as another method. Comparison between Fuzzy AHP and AHP methods is shown in Table 4.

Table 4. Difference between Fuzzy AHP and AHP

S. No.	Usable-Security Attributes	Fuzzy AHP		AHP	
		Weights	Percentages	Weights	Percentages
1	Confidentiality (C1)	0.1037	10.37%	0.0957	9.57%
2	Integrity (C2)	0.0752	7.52%	0.0718	7.18%
3	Availability (C3)	0.1585	15.85%	0.1577	15.77%
4	Effectiveness (C4)	0.1848	18.48%	0.1830	18.30%
5	Efficiency (C5)	0.2369	23.69%	0.2415	24.15%
6	Satisfaction (C6)	0.2409	24.09%	0.2503	25.03%

For accuracy of the calculation, authors compared the results with the AHP method as shown in Table 4. The difference between the two methods is negligible as the calculated Pearson correlation coefficient is 0.99. This prioritization further helps select the usable security properties for building the usable-security services of software. Graphical representation of the comparison of results is shown in Figure 2. Series 1 denotes all values of Fuzzy AHP and Series 2 denotes all values of AHP.

5. **Conclusion.** The aim of the study is to prioritize usable-security attributes at early stages of development. For this purpose, the model integrates security attributes and usability attributes and produces results which are helpful for developers in providing the usable-security services of software. The different security models are helpful to generate

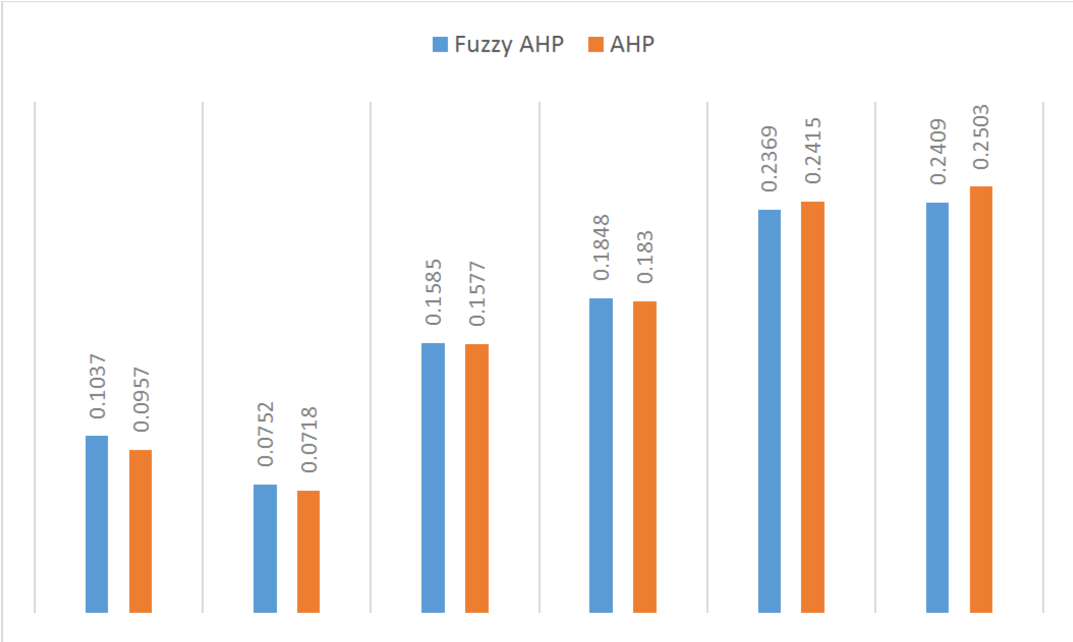

FIGURE 2. Graphical representation of the comparison

quantitative values including object-oriented and service-oriented perspective but there is no such measure available, which can measure security-usability. The model proposed here will help to evaluate the usable-security of software services and satisfaction of the user.

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