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MEASURING THE SECURITY ATTRIBUTES THROUGH FUZZY ANALYTIC HIERARCHY PROCESS: DURABILITY PERSPECTIVE

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Abstract. *Security is a significant issue in software engineering that is receiving vast attention from academic and IT industry. In addition, due to huge investment in secure software development, durability of security is in much demand. However, selecting the right model for software development is becoming more challenging for developers day by day. Security durability attributes play a vital role while designing security during software development. Each attribute has its own importance while integrating durable security during early stage of software development life cycle. This is based upon user's demand and sensitivity of information. Hence, developers need to know about the importance of each attribute when they are developing software to fulfill user's demand. In this paper, authors have proposed an approach for prioritization of these attributes using Fuzzy Analytic Hierarchy Process (Fuzzy AHP) method. Literature survey reveals that the key attributes of durable security are trustworthiness, dependability and human trust. This will help developers to improve the security for longer.*
Keywords: Software security, Priority assessment, Fuzzy analytic hierarchy processes, Performance, Security design, Security factors, Software durability, Security durability

1. **Introduction.** A lot of research is available, attempting to understand and classify the ways in which the security of software can be enhanced [1,2]. While there is always a gap between theory and practice which is hard to fill entirely, the problem can be lessened by establishing a common terminology and improving the accessibility of research results. With the study of security and durability in this contribution, it has been tried to develop obtainable theoretical research for quantifying durable security. Durability is a vital attribute to provide security of software for longer period. To achieve durable security in software while development, identification of security as well as durability attributes are useful [3,4]. Therefore, developers need to understand how to relate security attributes with those of durability and measure the impact of these attributes for enhancing secure life span of software.

Assessment of durable security attributes is necessary to ensure it [5]. Outcomes of evaluation process may allow decision makers to make appropriate decision as well as action [6,7]. However, to be able to take appropriate action, decision makers are not only needed to know about security and durability attributes but their mapping also. Hence, for prioritization of different attributes, fuzzy analytic hierarchy process is used in this contribution. To address durable security issues, prioritization of the attributes is a crucial process. Rest of the paper is organized as follows. In Section 2, needs and importance are discussed. Priority assessment of durable security attributes is calculated in Section 3. Finally, significance and conclusion are given in Sections 4 and 5.

2. **Needs and Importance.** Plenty of research has been done in the field of prioritizing attributes of durable security with fuzzy analytic hierarchy process [7,8]. However, no attempt has been made for prioritizing security attributes which affect durability of security and balancing their trade-offs. Success of security technology largely depends on user acceptance and its long life span [9]. It is a need to assess durable security attributes in terms of durability. Results evaluation of durable security attributes should be analyzed deeply so that it can be used to enhance long life of secure software [9,10]. The analysis of prioritization is done by using fuzzy analytic hierarchy process which is a type of multi-criteria decision analysis [11]. Multi-Criteria Decision Analysis (MCDA) plays a crucial role for performing various conflicting evaluation items like multi-attribute utility theory and analytic hierarchy process and fuzzy analytic hierarchy process [12]. MCDA techniques are mainly divided in the three categories including objectives, alternative weights and their ranks.

AHP is considered good in analyzing a decision in group, but many researchers have found that fuzzy AHP is more valuable to provide crisp decisions with their weightages, too [12]. In addition, it has been an important tool that is widely used to complete priority analysis and adopted by decision makers. For constructing a hierarchy of attributes according to their importance or priority, AHP is working with judgmental input from a group of decision makers [11]. To deal with the uncertainties and ambiguity of human judgment, the authors give a modified version of AHP known as fuzzy AHP [11,12]. Fuzzy AHP is a hybrid technique of fuzzy set theory and AHP. This research contributes a way for assessment of durable security by fuzzy analytic hierarchy process. For collecting data we have taken 21 experts from different fields of academics and industry. With the help of the inputs of experts, this contribution aims to evaluate the security durability attributes in terms of their weight and ranks. Based on these results, security development strategies are selected to mitigate and manage attributes for long life of security of software in future.

3. **Priority Assessment of Durable Security Attributes.** Durable security attributes are usually a qualitative measure. It is a challenge to assess the durable security attributes quantitatively. In addition, weightages and ranks of durable security attributes play a significant role for highly secure design of software. Durable security attributes prioritization for the requirement of durable software is a Multi-Criteria Decision-Making (MCDM) problem [8,9]. This set of criteria often differs in the degree of importance. There have been several tools for solving this kind of problems 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 [10,11].

This section discusses the methodology for deriving weightages of durable security attributes to manage these durable security attributes during security design process. Priority of durable security attributes should be decided before the designing phase. And also, during the implementation and deployment phase, security developers should have knowledge of the important durable security attributes identified and classified before it can make any severe security issue [4]. Ranking and weightages of these attributes are evaluated from fuzzy AHP technique. Fuzzy AHP is capable of controlling ambiguous judgment given by the industry experts and academicians. Fuzzy AHP is also helpful in converting linguistic inputs from expert to numerical outputs which is further helpful to prioritize these attributes [8,9]. The weightes and ranks of durable security attributes may be helpful to developers for selecting the development guidelines. In addition, these guidelines are essential to maintain the Confidentiality, Integrity, and Availability (CIA)

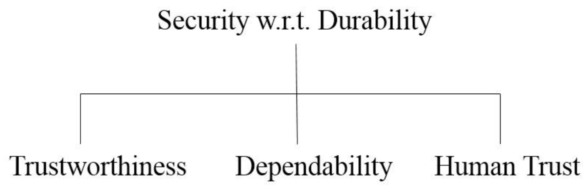

Figure 1. Hierarchy model for security durability

for durable security. Figure 1 discusses about different security attributes of software which are related to durability.

The hierarchical structure of durable security attributes affecting life span is presented in Figure 1. The attributes have been identified through a comprehensive literature review and experts' opinions. The durable security attributes that have been considered in this contribution have already been discussed with their impact on durability in one of our previous work [8]. For integrating durability to security, essential security durability attributes that may enhance security of software design have been considered in this section. The present contribution aims to determine priority of security attributes affecting durability of software. For this aim a questionnaire is prepared from [5]. Thus, it is required to have a group of experienced experts working in area of security to answer the questionnaires. For evaluating the weightages of durable security attributes form expert's opinion, Triangular Fuzzy Numbers (TFNs) equations have been used which is shown in Equations (1)-(3). TFNs $[\eta_{ij}]$ are established as the following:

$$\eta_{ij} = [l_{ij}, m_{ij}, h_{ij}] \quad \text{where } l_{ij} \leq m_{ij} \leq h_{ij}$$
$$l_{ij} = \min(J_{ijk}) \tag{1}$$
$$m_{ij} = (J_{ij1}, J_{ij2}, \ldots, J_{ijk})^{1/k} \tag{2}$$
$$h_{ij} = \max(J_{ijk}) \tag{3}$$

where J_{ijk} shows the relative importance of the values F_i and F_j given by expert k and i and j represent a pair of criteria being judged by participants. F_{ij} represents TFN for the comparison between criteria F_i and F_j, i.e., $F_i - F_j$. Comparison between criteria F_j and F_i is the reverse of F_i and F_j. Value m_{ij} is estimated based on the geometric mean of expert's scores. After getting the TFNs value, a fuzzy pair-wise comparison matrix is established in the form of $n \times n$ matrix which is shown in Table 1.

Table 1. Example of comparison matrix

$\boldsymbol{\eta_{ij}} =$

	Attribute 1	**Attribute 2**	**Attribute 3**	**Attribute 4**	...	**Attribute $\boldsymbol{n}$**
Attribute 1	$(1,1,1)$	F_{12}	F_{13}	F_{14}	...	F_{1n}
Attribute 2	F_{21}	$(1,1,1)$	F_{23}	F_{24}	...	F_{2n}
Attribute 3	F_{31}		$(1,1,1)$	F_{34}	...	F_{3n}
Attribute 4	F_{41}			$(1,1,1)$	...	F_{4n}
⋮	⋮	⋮	⋮	⋮	⋮	⋮
Attribute $\boldsymbol{n}$	F_{n1}	F_{n2}	F_{n3}	F_{n4}	...	$(1,1,1)$

As for this research, the size of the comparison matrix is 3×3, and the size of the group to fulfill an acceptability of consistency is 21 participants [8]. Participants of this evaluation include academicians and developers who are having experience in security attributes. Sample of questionnaire is taken from [8] which is shown in Appendix. Twenty one participants are taken in this survey. After qualitative evaluation, pair-wise comparisons are prepared. The matrix prepared by the researchers after evaluating judgments from twenty-one participants is shown in Table 2.

Table 2. Fuzzy comparison matrix

	Trustworthiness (C11)	Dependability (C12)	Human Trust (C13)
Trustworthiness (C11)	1	1.187, 1.535, 2.028	1.424, 1.645, 1.957
Dependability (C12)	–	1	0.851, 0.979, 1.492
Human Trust (C13)	–	–	1

After it, defuzzification is performed to produce a quantifiable value based on the calculation of TFNs values, which has been derived from [9,10] as formulated in Equation (4), also known as the alpha cut method. Alpha threshold value is any value taken from scale of 0 to 1. For this research work, alpha threshold value has been taken as 0.5. The set $\mu_{\alpha,\beta}$ is called a strong alpha-cut set if it consists of all the elements of a fuzzy set whose membership functions have values strictly greater than a specified value. Equation (4) shows the general form of alpha cut.

$$\mu_{\alpha,\beta}(\eta_{ij}) = [\beta \cdot \eta_\alpha(l_{ij}) + (1-\beta) \cdot \eta_\alpha(h_{ij})] \tag{4}$$

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

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

$$\eta_\alpha(h_{ij}) = h_{ij} - (h_{ij} - m_{ij}) \cdot \alpha \tag{6}$$

α and β in given equations are used for views of experts. By using Equation (4) with α and β at 0.5, the result is shown in Table 3. The values of α and β vary between 0 and 1. The value of α and β is based on fifty-fifty chances.

Table 3. Defuzzification comparison matrix

	Trustworthiness (C21)	Dependability (C22)	Human Trust (C23)
Trustworthiness (C21)	1	1.436	1.890
Dependability (C22)	0.696	1	1.212
Human Trust (C23)	0.529	0.825	1

The next step is to determine the eigenvalue and eigenvector. The purpose of calculating the eigenvector is to determine the aggregated weights of particular attribute. Assume that μ denotes the eigenvector while λ denotes the eigenvalue of fuzzy pair-wise comparison matrix η_{ij}.

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

Equation (7) is based on the linear transformation of vectors, where I represents the unitary matrix.

The combined result in terms of weightage and percentage is given in Table 4. The results thus obtained are arranged according to their ranking: Trustworthiness (0.450178), Dependability (0.304996) and Human Trust (0.244826).

In actual scenario, there are various durable security attributes, which are present in software development process [8-10,12]. In this research, only three durable security attributes which affect life span have been identified as well as prioritized. The hierarchy

Table 4. Security attributes prioritization

	Weightage	**Priority**	**Percentage**
Trustworthiness	0.450178	1	45.0178
Dependability	0.304996	2	30.4996
Human Trust	0.244826	3	24.4826

Table 5. Difference between fuzzy AHP and AHP

Attributes	**Fuzzy AHP**		**AHP**	
	Weightage	Priority	Weightage	Priority
Trustworthiness	0.450178	**2**	0.442747	**1**
Dependability	0.304996	**1**	0.279869	**2**
Human Trust	0.244826	**3**	0.277384	**3**

for these attributes affecting durability is established and their weightage is calculated through fuzzy AHP technique. Comparison between two methods is shown in Table 5.

For accuracy of calculation, we compare it with AHP. The difference between two methods is negligible. Correlation coefficient is 0.97925. This prioritization further helps to calculate the impact of these attributes on durability as well as security. This research also tries to provide a new methodology for calculating numeric measures from the qualitative ones while prioritizing the security attributes.

Priority wise categorization of durable security attributes helps developers to focus on fulfilling the user's demand and enhancing the level of security for longer duration. This work has contributed toward the establishment of a hierarchy which is useful in designing durable security [7]. With the help of the contribution, security developers may be able to pinpoint the essential durable security attributes which further ensure the successful development of durable and secure software design. This may enable developers to concentrate on the most important durable security attributes first and to achieve high satisfaction among customers with optimal maintenance.

4. **Significance.** Software is becoming more complex, as its usage is gradually increasing. This imposes need to have a highly secured software system. Security is one of the most significant quality factors nowadays which is getting maximum attention of software designers as well as users. In this contribution it has examined three durable security attributes while designing durable security during the software development. This contribution will help to easily apply durable security management plan during software development. Major significances of the work are as follows.

- Working on durable security will enhance secure life span of software.
- Focusing on human trust, trustworthiness and dependability during software development will improve durable security.
- Trustworthiness is the most important as well as appropriate factor of security durability to be enhanced to get secure service life of software.

All in all, this contribution prioritizes security attributes which strengthens the fact that trustworthiness and user satisfaction should be given top priority when designing durable and secure software.

5. **Conclusions.** In this research, an extensive literature review was done to identify the major security attributes affecting the durability of secure software. Upon that, a hierarchical structure of attributes is proposed. Next, the opinion of twenty one experts on the three security attributes i.e., human trust, trustworthiness and dependability is collected through a questionnaire. The experts are from software industry as well as academia. Using this opinion, weights of each factor have been calculated with the help of fuzzy AHP. It has been concluded that trustworthiness is the most important factor among the three main security durability factors. For the assurance of durable security, developers need to firstly focus on trustworthiness for optimal maintenance of the software.

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Appendix. Sample of Experts View for the Hierarchical Structure of Durable Security.

- How much do you agree with these security durability attributes have an influence the software?
- Please rank between 1 to 9 (strongly disagree to strongly agree) or 0 if not sure.

Attributes	**Not Sure (0)**	**Strongly Disagree (1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**Strongly Agree (9)**
Dependability										
Human Trust										
Trustworthiness										