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A FUZZY-DELPHI BASED DECISION-MAKING PROCESS FOR MEASURING USABLE-SECURITY OF WEB BASED SMART HOSPITAL MANAGEMENT SYSTEM

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Abstract. *According to user's needs and security challenges, the preference of key factors is an essential task during development of web application for smart hospital management system. The preference procedure of factors for usable-security is an instrumental step for achieving the goals of developing a web based application. Hence, the usable-security factors preference is a Multi-Criteria Decision-Analysis (MCDA) problem. This paper studies the basic usable-security factors and evaluates the importance of these factors through Fuzzy-Delphi Analytical Hierarchy Process (Fuzzy-Delphi AH-P) process. For evaluating the usable-security factors importance, six best noteworthy factors have been taken in this study. The combined method of Fuzzy-Delphi and AHP would support the practitioners to select the most conversant usable-security factors in a consistent way during development of Web based Smart Hospital Management System (WSHMS). Further, this work would also be useful during web application development for smart hospital management system.*

Keywords: Web based smart hospital management system, Usable-security factors, Analytic hierarchy process, Fuzzy-Delphi method

1. **Introduction.** Usable-security has continuously influenced the quality of Web based Smart Hospital Management System (WSHMS). Further, usable-security of WSHMS is required for the system because sensitive information is always at risk. Experts have spent lots of money in dealing with this debacle but, unfortunately, most of the WSHMS still remains insecure [1,2]. Practitioners have to contend with the burden of developing more and more web applications in minimum time with optimal usable-security. Thus, they are often left confused while selecting the significant factors during WSHMS development. The factors of usability and security affect the usable-security of WSHMS. In addition, to achieve the desired goals, which factor will improve usable-security more than the other factors is a big question amongst the practitioners. Experts have been continuously exploring for new approaches to solve the conflicts that arise during the preference of factors and meet the users' need with maximum efficacy. In the given context, this study proposes a process based on MCDM method to prioritize the usable-security factors on the basis of weightages and ranking [3,4].

With the help of Fuzzy-Delphi AHP method, usable-security performance, minimization of maintenance cost and environmental flexibility of WSHMS development can be improved. An approach to find the significant factors which have negative or positive impact on each other can be a very inflexible one. Hence, to address usable-security issues of WSHMS, prioritization of the factors is a critical procedure. This research work has opted for six factors of usable-security and these include confidentiality, integrity, availability, effectiveness, efficiency, and satisfaction for assessment [5,6]. With the help of

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the results, this paper evaluates the impact of usable-security factors for practitioners to simplify the guidelines. Rest of the paper is organized as follows. In Section 1, need and importance of this work have been discussed. In Section 2, the usable-security attributes have been introduced. In Section 3, the methodology is described. Further in Section 4, usable-security assessment has been done along with the enumeration of the results of the case study for practitioners. Thereafter, the conclusion of this research study is profiled in Section 5.

2. **Usable-Security Attributes.** During development, numerous usable-security factors influence each other. Usable-security factors are useful for designing better security. An improper preference of usable-security factors may become a reason for the lack of usability of WSHMS. Further, usable-security failure affects the production, usefulness, and status of the organizations' trading. For accurate preference of usable-security factors, Multi-Criteria Decision Making (MCDM) approach would be highly effective and valuable for the development organizations to improve the usable-security of WSHMS [7,8]. Moreover, it may also be useful for maintaining the usable-security for a longer span of time.

The method of MCDM includes establishing criteria, evaluating alternatives, application of a ranking system, assessing criteria weights and evaluation of overall impact [9,10]. Different MCDM methods commonly make different results for a set of alternative decisions relating to several criteria. One of the wide uses of MCDM is Analytic Hierarchy Process (AHP) [11,12]. According to the earlier discussion, the first stage is constructing a hierarchy of factors [12]. It is the process which is the most critical aspect of usable and secure design. However, most of the practitioners are confused about choosing the most appropriate factors for significantly enhancing the usability of secure web applications for smart hospital management system [7,8]. In this article, the contributors of this paper have taken only six key factors of usable-security that are shown in Figure 1.

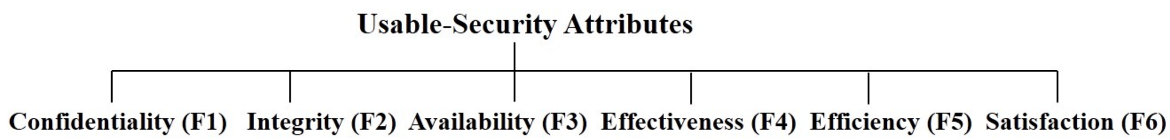

Figure 1. Hierarchy of key factors

Figure 1 shows the key attributes of usable-security. The factors have been identified through a comprehensive literature review and practitioners' opinions. The usable-security factors that have been considered in this contribution have already been discussed with their impact on usability [8]. For integrating usability to security, essential security usability factors that may enhance security of web based healthcare management system design have been considered in [14].

3. **Methodology.** Fuzzy-Delphi AHP is an iterative process to collect and revise practitioner's judgments with the help of information gathering, analysis methods and forecasts [8,10,11]. Fuzzy-Delphi AHP is also used for evaluating decisions by initial opinions of practitioners. This is one of the topmost MCDM processes that have been useful in defining the unstructured problems during WSHMS development [6,7]. Further, fuzzy set theory has given a significant involvement for accepting uncertainty and inconsistent judgments, such as the nature of human decisions analysis which was not well tackled in the classical AHP [6,7].

Also, fuzzy AHP allows other comprehensive justification of undefined and confusing knowledge of practitioners [4,5]. The fuzzy AHP process often changes old methodologies by statistical approaches. Fuzzy-Delphi is a method for constructing a cluster relationship

Table 1. Linguistic scale

Symbol	Intensity of importance	Assigned numerical value
WI	Without importance	1
LI	Low importance	3
MI	Moderate importance	5
SI	Strong importance	7
VEI	Very extreme importance	9

process in a single process. In AHP process, the authors state the objectives with the help of Figure 1 and estimation is achieved through ratio-scale pair-wise judgments [4-6]. On the basis of the objectives, there is a survey taken for getting the opinions of experts. The scale is presented in Table 1.

After taking the opinions of experts with the help of Table 1, it needs to be evaluate the Coefficient of Variation (CV). To evaluate the CV and CVR, Equation (1) has been used for measuring the accuracy [3,4]. If CV is less than 0.5, then extra opinions are stopped and process goes to upcoming step otherwise again the experts' opinions are reckoned.

$$CVR = \left(SE - \frac{T}{2}\right) \Big/ \left(\frac{T}{2}\right) \tag{1}$$

where, SE is the number of opinions of practitioners representing that a factor is "significant" and T is the total number of opinions. Opinions of practitioner's are stopped, if CV reaches 0.5. The CVR is estimated to certify how relevant or significantly desirable the specified usable-security factors are in WSHMS. Further, CVR lies between $+1$ and -1 and $+1$ is representing the significant opinions. Content Validity Ratio (CVR) is assessed in this process. Pair-wise comparison matrix is formed, if the CVR is greater than 0.29 again the experts' opinions are reckoned.

The CV shows the standard deviations ratio. Further, CV helps to compare the overall fuzziness of the data gained. After this, opinions of experts are measured directly for creating the pair-wise comparison matrix. Further, pair-wise comparison matrix for usable-security factors is shown in Equations (2)-(3) [2,3]. In addition, with the help of Equations (4)-(5), there is necessity to determine the Consistent Ratio (CR) to check the uniformity of the results. If the CR is greater than 0.1, then the opinions of experts must be revised otherwise process goes to upcoming step that is aggregating the fuzzy numbers.

$$A = [a_{ij}]_{n*n}, \tag{2}$$

where i, $j = 1, 2, 3, \ldots, n$.

$$A = \begin{bmatrix} (1,1,1) & a_{1j}, b_{2j}, c_{3j} & a_{1n}, b_{1n}, c_{1n} \\ - & (1,1,1) & a_{2n}, b_{2n}, c_{2n} \\ - & - & (1,1,1) \end{bmatrix} \tag{3}$$

$$CR = CI/RI \tag{4}$$

$$CI = (\tau_{\max} - n)/(n-1) \tag{5}$$

where, Consistency Index (CI) shows the deviation of consistency and Random Index (RI) presents the size of matrix (n) [5]. If the CR is greater than 0.1, then pair-wise comparisons matrix must be re-constructed, otherwise process goes to upcoming step that is aggregating the fuzzy pair-wise comparisons. For fuzzyfying and aggregating the opinions of experts during constructing pair-wise comparison matrix, Triangular Fuzzy Numbers (TFNs) are taken in this study and represented by Equations (6)-(9). Further, there is a need of defuzzification process. In this work, defuzzification process is completed by technique of geometric average [13].

$$A_{ij} = (a_{ij}, b_{ij}, c_{ij}) \tag{6}$$

$$a_{ij} = Min(B_{ijk}) \tag{7}$$

$$b_{ij} = \left[\prod B_{ijk}\right]^{1/n} \tag{8}$$

$$c_{ij} = Max(B_{ijk}) \tag{9}$$

where, B_{ijk} shows relative significance of factors i over factors j from viewpoint of kth and $k = 1, 2, 3, \ldots, n$. Further, a_{ij} shows the limit point of minimum values of experts' opinions and c_{ij} shows the limit point of maximum values of experts' opinions. b_{ij} lies between minimum and maximum values of experts' opinions and b_{ij} shows geometrical mean of these decisions. It is clear that fuzzy numbers are defined in a manner that $a_{ij} \leq b_{ij} \leq c_{ij}$ and lies between 1/9 and 9. Relative fuzzy weights of usable-security factors are estimated through Equation (10). After getting the final weights of each factor, all values obtained become non-fuzzy based on Equation (11) [4,7].

$$W_i = Z_i \otimes (Z_j \otimes \cdots \otimes Z_n) \tag{10}$$

$$W_i = \left(\prod W_{ij}\right)^{1/n} \tag{11}$$

All in all, final weightages and rakings of the factors are evaluated with the help of Equations (1)-(11).

4. **Assessment and Results.** On the basis of the factors, authors prepare a survey form and took 101 professionals' opinions. With the support of the opinions and Fuzzy-Delphi AHP method, authors estimated the usable-security through integrating decision's uncertainty [10]. After this, the experts assigned scores to the factors of usable-security, qualitatively and converted it into numeric values with the help of scale [11,12]. With the help of scale that is shown in Table 1, contributors of this paper constructed pair-wise comparison of each expert's opinion. Further, data collecting is completed by using

Table 2. CV and CVR outcomes

Usable-security factors	CV	CVR
Confidentiality (F1)	0.0800	0.500
Integrity (F2)	0.1000	0.200
Availability (F3)	0.2500	0.600
Effectiveness (F4)	0.1900	0.400
Efficiency (F5)	0.2200	0.200
Satisfaction (F6)	0.2500	0.400

Table 3. Pair-wise comparison matrix

Experts	Criteria	Confidentiality	Integrity	Availability	Effectiveness	Efficiency	Satisfaction
1	Confidentiality (F1)	1.0000	1.2900	1.8000	1.2900	1.8000	1.2900
	Integrity (F2)	0.7800	1.0000	1.4000	1.0000	1.0000	1.8000
	Availability (F3)	0.5600	0.7100	1.0000	0.7200	1.4000	1.0000
	Effectiveness (F4)	0.7800	1.0000	1.4000	1.0000	1.4000	1.4000
	Efficiency (F5)	0.5600	0.7200	1.0000	0.7100	1.0000	0.7200
	Satisfaction (F6)	0.7800	0.5600	1.0000	0.7100	1.4000	1.0000

TABLE 4. Fuzzy Delphi paired comparison matrix

Criteria	Confidentiality			Integrity			Availability			Effectiveness			Efficiency			Satisfaction		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Confidentiality (F1)	1.0000	1.0000	1.0000	1.0000	1.3600	1.8000	1.0000	1.6800	3.0000	1.0000	1.6000	1.8000	1.4000	2.4500	3.0000	0.7100	1.1800	1.4000
Integrity (F2)	0.5600	0.7400	1.0000	1.0000	1.0000	1.0000	1.0000	1.2500	1.6700	0.7100	1.1800	1.4000	1.4000	1.8100	2.3400	1.4000	2.4500	3.0000
Availability (F3)	0.3400	0.5900	1.0000	0.6000	0.8000	1.0000	1.0000	1.0000	1.0000	0.6000	0.9500	1.4000	1.0000	1.4500	1.6700	1.0000	1.6000	1.8000
Effectiveness (F4)	0.5600	0.6300	1.0000	0.7100	0.8500	1.4000	0.7100	1.0500	1.6700	1.0000	1.0000	1.0000	1.0000	1.5300	2.3400	1.0000	1.2500	1.6700
Efficiency (F5)	0.3400	0.4100	0.7100	0.4300	0.5600	0.7100	0.6000	0.6900	1.0000	0.4300	0.6600	1.0000	1.0000	1.0000	1.0000	1.0000	1.2500	1.6700
Satisfaction (F6)	0.7100	0.8500	1.4000	0.3400	0.4100	0.7100	0.5600	0.6300	1.0000	0.6000	0.8000	1.0000	0.6000	0.8000	1.0000	1.0000	1.0000	1.0000

Table 5. Weightages and ranking of usable-security factors

Criteria	Fuzzy weights			Non-fuzzy weights	Percentage	Ranking
Confidentiality (F1)	0.0090	0.1500	0.2800	0.1400	14.00%	4
Integrity (F2)	0.1200	0.2600	0.4800	0.2500	25.00%	1
Availability (F3)	0.1300	0.2100	0.3200	0.2000	20.00%	2
Effectiveness (F4)	0.1100	0.1900	0.3300	0.1800	18.00%	3
Efficiency (F5)	0.1100	0.1300	0.2100	0.1200	12.00%	5
Satisfaction (F6)	0.1000	0.1200	0.1900	0.1100	11.00%	6

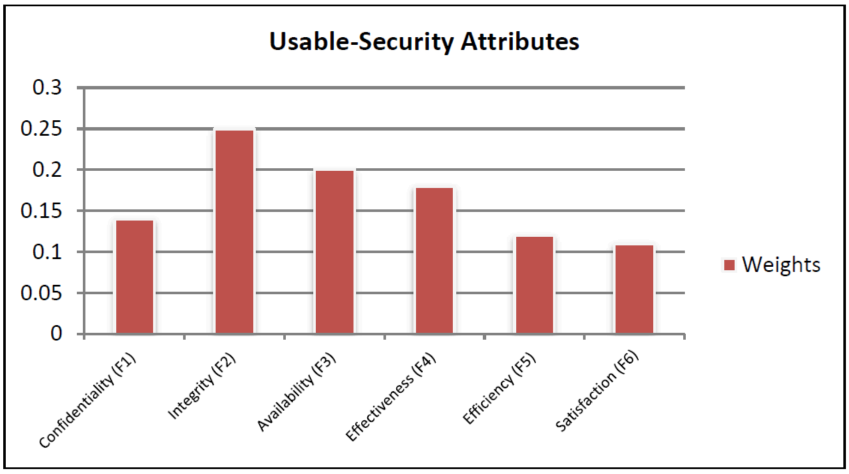

Figure 2. Graphical representation of usable-security factors

linguistic scale through a planned set of successive survey. For gathering and joining the opinions of practitioners, a systematic qualitative procedure is taken [5].

During the expert's opinion process, the differing weight vectors become the cause of frequent vague measurement and also lead to serious judgments. To evaluate the CV and CVR, Equation (1) has been used for measuring the accuracy [3,4]. Further, Table 2 is showing the final outcomes of CV and CVR, after extra estimations are stopped. As per the opinion of the first expert, the pair-wise comparison matrix has been presented in Table 3. The resulting comparison matrix has been shown in Table 4. Further, Table 5 shows the results of fuzzy and crisp weights and ranking scores for each factor.

The outcome of this research will ensure better patient care and improved patient centric care in the Saudi healthcare organizations. According to these results, integrity is a very essential factor of usable-security during WSHMS development. Further, graphical representation of the results is shown in Figure 2. Outcomes of this paper will help to security practitioners for managing usable-security design during development WSHMS to increase the satisfaction of the users. This research contribution gives two main impacts in usable-security of web application development. First, evaluating the impact of usable-security factors will improve usefulness and satisfaction of the users thus will enhance secure smart hospital management system for the customer's sake. And second, integrity is the very essential factor usable-security to improve the whole usability of secure smart hospital management system.

5. **Conclusion.** This paper outlines a Fuzzy-Delphi based Decision-Making Process for Measuring Usable-Security of Web based Smart Hospital Management System in Saudi Arabian healthcare facilities. Healthcare organizations are facing many challenges, including privacy concerns for patient information. Unsuitable preference of usable-security factors may harm or cause failure of usable-security for the WSHMS. Thus, preference of these factors is important which is done in this work by decision makers using Fuzzy-Delphi AHP method. Experts mostly select the best guidelines of development. The guidelines are based on MCDM methods. In addition, different MCDM methods regularly produce different outcomes for ranking of factors to users' satisfaction. The results of this paper are showing the potential of the proposed Fuzzy-Delphi AHP. Furthermore, it can help the experts in obtaining more strong decisions, especially in usable-security design for WSHMS development. The results have been changed through the conditions of WSHMS industry, available development technology of the security and their availability. In future, the expert group will be larger for big datasets. To provide more attention on usable-security quantification area, only a set of security attributes and usability attributes have been chosen from the various security attributes and usability attributes, respectively. There can be more specific attributes of usable-security and it may be integrated later for better results.

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