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GÜNEY GÜRSEL

NEŞE ZAYİM

KEMAL HAKAN GÜLKESEN

ALİ ARİFOĞLU

OSMAN SAKA

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A new approach in the evaluation of hospital information systems

Güney GÜRSEL[1,*], Neşe ZAYİM[2], Kemal Hakan GÜLKESEN[2], Ali ARİFOĞLU[3], Osman SAKA[2]

[1]Department of Medical Information, Gülhane Military Medical Academy, Ankara, Turkey
[2]Department of Biostatistics and Medical Informatics, Akdeniz University, Antalya, Turkey
[3]Informatics Institute, Middle East Technical University, Ankara, Turkey

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Abstract: Hospital information system (HIS) evaluation frameworks have largely been discussed in the literature. However, existing frameworks lack one important aspect: to what extent user expectations of HISs are met. In this study, user expectation data are collected by means of the 'expectation questionnaire'. The internal consistencies of the answers to the questionnaire are measured by Cronbach's alpha coefficient. Fuzzy logic methodologies are used to evaluate the expectation variables in the proposed evaluation framework. The evaluation variables are not represented in the results equally; they are reflected by the weights assigned by the users. Our proposed framework provides the overall degree of to what extent the user expectations are met. It also gives the opportunity to analyze to what extent each expectation is met and the degree of to what extent different user groups' expectations are met. The proposed framework is not a rival of but is rather an alternative or complementary to the existing frameworks. It is a different approach and has a different computation methodology, supported by fuzzy logic. The acceptable meeting ratio depends on the evaluator; we do not propose a threshold.

Key words: Evaluation, medical informatics, hospital information system, fuzzy logic

1. Introduction

In our era of information technology (IT), health institutions invest huge amounts of money in hospital information systems (HISs). The purpose of these investments is to make health care more effective and efficient. The findings from a considerable amount of studies reveal the negative effects of IT implementation on health care [1]. It is estimated that nearly 70% of IT implementation projects fail [2], resulting in the loss of huge amounts of money and, more importantly, loss of confidence in these implementations. Despont-Gros et al. summarized the major reasons for failure as technical issues, project mismanagement, organizational issues, and explosive growth of information systems (ISs) [3]. However, the reason for failure in any IT implementation is rarely purely technical [4]. The other reasons can be avoided, or at least the rate of failure can significantly be decreased, by means of easy-to-use management tools for evaluating, prioritizing, monitoring, and controlling IT investments [5].

The considerably high rate of failures despite huge investments raises one big question: "Is the system good enough?" Many investigations by the IT industry have been conducted to get the answer. The academic translation of these investigations is 'evaluation'. Then, what is evaluation? Before stating what evaluation

*Correspondence: ggursel@gata.edu.tr

is, let us state what evaluation is not. Although the terms are used interchangeably, evaluation is not equal to assessment. One can find many different definitions of "evaluation" in the literature. Drawing from the literature, in this study, evaluation is defined as the measuring of the extent of meeting the specified criteria of a system in a specified context. Evaluation is a transdisciplinary issue. Therefore, there is no generic template of what to evaluate and how to perform evaluations. The effective evaluation of any HIS is crucial to determine if these systems adequately meet the requirements/needs of users and health care organizations.

1.1. Evaluation frameworks for HIS

Seddon et al. described evaluation framework as a decisional space defined by the characteristics of the evaluation context that helps in the selection of the appropriate approach [6]. Many HIS evaluation frameworks were proposed in the literature. Some of them will be examined in terms of the innovations that they brought to the evaluation concept.

Yusof et al.'s human, organization, and technology-fit factors (HOT-fit) framework [7] is based on the idea that humans, organizations, and technology are essential components of HISs. It extended the IS success model. Shaw's evaluation framework, called CHEATS [8], identifies 6 aspects for evaluating information communication technologies in health: clinical, human and organizational, educational, administrative, technical, and social. Dixon's information technology adoption model (ITAM) is a theoretical framework [9]. It proposes the term 'fit' and states that perceived usefulness and perceived ease of use are not dependent on the system design features, but rather on this 'fit' of the user and system design features. Ammenwerth et al. stated that it is not clear whether the ITAM was formally validated [2]. Kazanjian and Green's health technology assessment framework was represented as a conceptual tool for decision making in health technologies [10]. The aim of this model is to help health technology decisions. It claims to have greater power than existing frameworks in the evaluation of ISs in health care. However, no evidence has been provided to justify this claim. Heeks' design-reality gap model states that the amount of change between 'where we are now' and 'where the HIS wants to get us' is central to health IS success and failure [11]. The difference is called 'design–reality gaps'. It is stated that the analysis has confirmed that the dimensions employed are necessary and sufficient to provide an understanding of the design–reality gaps. Ammenwerth et al.'s fit between individuals, task, and technology (FITT) framework advocates that the existing models are failing to include one important aspect: the interaction between the user and the task [2]. It calls this interaction 'fit' and claims that IT adoption in healthcare depends on this fit. This fit is between the attributes of the users, the attributes of the technology, and the attributes of the clinical tasks and processes. Goodhue et al.'s task technology fit (TTF) framework [12] examines the influence of 3 factors, the individual abilities, technology characteristics, and task requirements, on performance and on user evaluation of IT systems, highlighting the significance of the interaction (fit) of those 3 factors. It argues that TTF is the extent to which technology functionality matches task requirements and individual abilities.

1.2. An alternative approach to evaluation

Existing frameworks claim to be generic and whole-system evaluation frameworks. Almost all of the definitions of evaluation express that the evaluation takes place in a specified context; that is, it must focus on the context and evaluate it in great detail. The specified context makes the frameworks differ from each other. In this study, we propose a new framework with a different approach in scope. Instead of evaluating all of the aspects of HISs, it focuses on one issue, user expectation, and evaluates it deeply.

In HISs, end users must be the central part of the system. Evaluation must take into account their feelings, reactions, and behaviors. The evaluation of ISs is in vain if the human factors are not at the center of the evaluation process [13].

User satisfaction is one of the most widely used indicators of success in IS research. DeLone and McLean's IS success model defines 6 dimensions of the IS success, which are system quality, information quality, system use, user satisfaction, individual impacts, and organizational impacts [14]. The level of the users' satisfaction has a direct impact on the system usage. If the IS cannot satisfy its users, the users will not use the system anymore. If they think that the system is "poor", whatever good virtues it has are not important.

Geer et al. defined expectation as a belief about the probabilities associated with a future state of affairs [15]. In a survey of ISs, "user expectations" was ranked second in a list of 33 items affecting user satisfaction [16]. Additionally, 3 (system quality, system use, and user satisfaction) of the 6 dimensions of DeLone and McLean's IS success model are directly related to the user expectations from an IS.

The existing frameworks do not evaluate the extent to which the expectations of healthcare users are met by HISs. Some evaluate this as a variable in the section of "user satisfaction", but we do not know to what extent a HIS meets the satisfied or dissatisfied user's expectations from a HIS. The purpose of the proposed framework is evaluating to what extent a HIS meets the end user expectations from a HIS.

The existing frameworks analyze the systems rather than evaluate them. There is no ratio or grade or something concrete to make a decision on the evaluated system. They do not give the opportunity to compare the systems because of the lack of previously mentioned concrete outputs. The evaluation result in the proposed framework is a concrete numerical value. This numerical value can be calculated for the whole HIS as well as for each variable and for each end user asset.

Existing frameworks are criticized for not having been thoroughly tested [2]; several have been used for pilot evaluations. Some are conceptual. All of the frameworks evaluate the dimensions and variables that they define equally. There is no priority or importance assignment. Variables or dimensions should not be treated equally. In our proposed framework, each evaluation variable (Table 1) is represented in the evaluation results by the degree of its importance to the end users.

Table 1. Proposed framework variables.

Usage expectations	System and data expectations	Improvement expectations	Managerial expectations
Ease-of-use	Consistency	Improve service quality	Reporting facilities
Need for training	Privacy	Decreasing work load	Decision support
Help manuals	Security	Bringing positive change	Function Sufficiency
Speed	Availability	Research facilities	
User support	Interoperability		

In the proposed framework, fuzzy logic methodologies are used as a different approach and evaluation technique in HIS evaluation. None of the existing frameworks employed fuzzy logic methodologies. Fuzzy logic is used when the boundaries are not clear. In linguistic variables such as Likert scale ratings, the context is very suitable for fuzzy logic operations, because they have ambiguity and multiplicity in meaning. Hence, they are represented as a range of fuzzy numbers instead of crisp values. Fuzzy logic methodologies can be summarized as fuzzification (converting the linguistic variable or crisp number into fuzzy numbers), fuzzy operations (addition, division, multiplication, and subtraction), and defuzzification (converting fuzzy numbers into crisp numbers).

2. Materials and methods

The "Expectation Questionnaire" was formed and used for data collection. There are questions for each of the expectation variables (Table 1) to evaluate the expectation. Moreover, one additional importance question is asked to capture the weight of each variable. Users are asked to express their expectation rating using the 5-point Likert scale (strongly agree, moderately agree, not sure, moderately disagree, and strongly disagree) and importance weights using the 5-point Likert scale (very important, important, averagely important, not so important, and not important), which are our linguistic variables in fuzzy logic operations.

HISs in 2 hospitals were evaluated using the proposed framework as a case study. In the case study, a hospital with a newly deployed HIS (Hospital A, with a 5-month deployed HIS) and a hospital with a HIS in routine use (Hospital B) were selected to see the early deployment evaluation results and routine use evaluation results. Volunteering HIS end users in the hospitals participated in the study. These hospitals will be mentioned as Hospital A and Hospital B in the rest of the article.

The internal consistencies of the scales are measured by Cronbach's alpha coefficient using the SPSS. A Cronbach alpha value of greater than 0.70 is considered reliable.

Expectation ratings and importance weights are converted into fuzzy triangular numbers (fuzzified). We use these fuzzy numbers to compute the expectation meeting ratio (EMR). A fuzzy number F on K is defined to be a fuzzy triangular number if its membership function μ_f: K → [0,1] is equal to [17]:

$$\begin{array}{l} \mu f{=}(1/(m{-}l))x - (l/(m{-}l))x \in [l,m] \\ \mu f{=}(1/(m-u))x - (l/(m-u))x \in [m,u] \quad l \leq m \leq u \end{array}, \tag{1}$$

where l is the lower value, m is the mean value, and u is the upper value of the fuzzy number F.

The final fuzzy numbers are converted into crisp numbers because fuzzy numbers do not have usable meaning in the real world. After the fuzzy operations given by Eqs. (2), (3), and (4), the center of area (COA) defuzzifier is used to convert the fuzzy numbers.

Each linguistic variable is characterized by a triangular fuzzy number that has an approximate value ranging between 0 and 1 for the importance and between –1 and 1 for the rating. Assuming that the distance between the linguistic variables is equal, the mean values for the importance are determined as: not important = 0, not so important = 0.25, averagely important = 0.5, important = 0.75, and very important = 1. For the ratings, they are determined as: strongly disagree = –1, moderately disagree = –0.5, not sure = 0, moderately agree = 0.5, and strongly agree = 1. Next, to reflect the fuzziness of the term, the lower and upper bounds are determined as the previous and next terms' mean values, respectively. The importance weights, expectation ratings, and fuzzy numbers used in the evaluation are given in Table 2.

Table 2. Importance weights, expectation ratings, and their corresponding triangular fuzzy numbers.

Importance weights	Fuzzy number	Expectation ratings	Fuzzy number
Very important (W_1)	0.75, 1, 1	Strongly agree (R_1)	0.5, 1, 1
Important (W_2)	0.5, 0.75, 1	Moderately agree (R_2)	0, 0.5, 1
Averagely important (W_3)	0.25, 0.5, 0.75	Not sure (R_3)	–0.5, 0, 0.5
Not so important (W_4)	0, 0.25, 0.5	Moderately disagree (R_4)	–1, 0.5, 0
Not important (W_5)	0, 0, 0.25	Strongly disagree (R_5)	–1, –1, –0.5

The final importance weight, W_i, of an expectation variable i can be given as:

$$Wi = 1/n\sum_{k=1}^{n} Rk, \tag{2}$$

where n is the number of users.

By aggregating the expectation rating answers given by the users, the final rating of the expectation variable i can be given as:

$$Ri = 1/n\sum_{k=1}^{n} Rk, \tag{3}$$

where n is the number of users.

The EMR can be obtained by the weighted average formula:

$$EMR = \sum_{k=1}^{n} WkRk / \sum_{k=1}^{n} Wk, \tag{4}$$

where n is the number of variables, W is the weight, and R is the rating.

In Eqs. (2), (3), and (4), the addition, multiplication, and division operations are fuzzy operations; hence, W, R, and the resulting EMR are fuzzy numbers. We need a crisp number to make a conclusion, so the EMR needs to be defuzzified. We obtain the EMR using the best nonfuzzy performance (BNP) [18] based on the COA method. Let the EMR be (l, m, u), and then the BNP can be calculated by:

$$BNP = l + \left[(u - l) + (m - l)\right]/3. \tag{5}$$

With this method and the fuzzy numbers given in Table 2, the BNP takes values between –0.83 and 0.83. The final EMR is found by converting the BNP into a percentage (where –0.83 is 0 and 0.83 is 100).

To give a simple example showing fuzzification and defuzzification, let us have 3 users evaluating variable i. Let the users answer the question of importance as {*very important, important, and very important*} and let the answer rating (expectation meeting question) be {*strongly agree, moderately agree, and strongly disagree*}. We fuzzify the answers by replacing the corresponding fuzzy number given in Table 2. The answers are then {*(0.75, 1, 1), (0.5, 0.75, 1), (0.75, 1, 1)*} for importance and {*(0.5, 1, 1), (0, 0.5, 1), (–1, –1, –0.5)*} for rating. Now the fuzzification is over. Using Eqs. (2), (3), and (4), the EMRs are computed as 0.15, 0.5, and 0.62. This output (a fuzzy number) has no meaning in such a form. Hence, it needs defuzzifying. Using Eq. (5), defuzzification can be done as 0.15 + [(0.62 – 0.15) + (0.5 – 0.15)] / 3, which is 0.42. Now we have a crisp number that can be commented on.

3. Results

Cronbach's alpha coefficient, showing the reliabilities (internal consistencies), is 0.871 for the importance weights and is 0.966 for the expectation ratings in Hospital A, and respectively 0.942 and 0.959 in Hospital B. The total Cronbach alpha value for the importance weights is 0.881 and for the expectation ratings is 0.970. All of the Cronbach alpha values are apparently high and greater than 0.7, showing that the answers to the questions are internally consistent.

The distributions of the users that participated in the study are given in Table 3. In Hospital A, 504 out of 660 questionnaires were returned by the users (response rate is 76.4%). In Hospital B, this number is 96 out of 100 (response rate is 96.0%). The roles of the users participating in the study at Hospital A were: 13.3% office workers, 7.3% laboratory technicians, 3% biologists, 33.7% nurses, 35.7% physicians, and 6.4% other. Three users did not answer this question. In Hospital B, these rates were 5% office workers, 27.1% nurses, 19.8% doctors, and 45.8% other.

Table 3. Distribution of users participating in the study (number/percentage of whole). *ATC: attitude towards change, **Cons: conservative.

Hospital A				Total: 504/660 response rate = 76.4%			
Title		Education		IS experience		ATC*	
Officer	67 /13.0	Primary	1	None	-	Cons.**	12/2.3
Lab. tech.	37/7.3	Secondary	31/6.2	Inadequate	23/4.6	Open	319/63.0
Biologist	15/3.0	University	459/91	Average	200/40.0	Depends	459/91.0
Nurse	170/33.7			Good	243/48.2		
Physician	180/35.7			Advanced	30/5.9		
Other	32/6.3						
Hospital B				Total: 96/100 response rate = 96.0%			
Title		Education		IS experience		ATC*	
Officer	5/5.2	Primary	1/1.0	None	-	Cons.**	2/2.1
Lab. tech.	1/1.0	Secondary	29/30.2	Inadequate	3/3.1	Open	64/66.7
Biologist	1/1.0	University	57/59.4	Average	27/28.1	Depends	30/31.2
Nurse	26/27.1			Good	51/53.1		
Physician	19/19.8			Advanced	15/15.6		
Other	44/45.8						

Table 4. EMRs (%) for the expectation variables.

		Hospital A		Hospital B	
		BNP	EMR (%)	BNP	EMR (%)
Usage expectations	Ease of use	–0.37	27.89	0.11	56.77
	Need for training	–0.21	48.77	0.15	59.00
	Help manuals	–0.01	49.63	0.20	62.20
	User support	–0.06	46.63	0.14	58.12
	Speed	–0.31	31.72	0.18	60.88
System and data expectations	Consistency	–0.02	48.65	0.23	63.91
	Privacy	–0.28	48.28	0.23	63.52
	Security	0.14	58.07	0.24	64.11
	Availability	0.22	62.96	0.34	70.63
	Interoperability	–0.20	38.23	0.19	61.12
Improvement expectations	Improve service quality	–0.53	46.83	0.44	76.47
	Decreasing work load	–0.27	33.82	0.31	68.39
	Bringing positive change	–0.35	28.82	0.15	58.66
Managerial expectations	Reporting facilities	0.08	54.65	0.28	66.73
	Decision support	–0.03	47.98	0.25	65.19
	Function sufficiency	–0.17	40.05	0.13	57.81
	Research facilities	–0.26	34.28	0.07	54.08
	General	–0.16	40.36	0.21	62.65

In both hospitals, the majority of the users were university graduates (91.0% in Hospital A and 59.4% in Hospital B). Most of the users defined themselves as having average and good IS experience in both hospitals.

In Hospital B, most of the users defined themselves as open to technological changes, while in Hospital A, the majority said this changes depending on what the technological change it is.

Table 4 gives the EMR results in the hospitals. In Hospital A, the system and data expectations group had the highest EMR, at 48.65%, whereas the highest was in the improvement expectations group in Hospital B, at 67.94%. The usage expectations group has the lowest EMR rates in both hospitals, at 27.89% in Hospital A and 56.77% in Hospital B. Expectation variable speed had the lowest EMR in both hospitals, at 20.86% in Hospital A and 49.95% in Hospital B, whereas security had the highest EMR, at 62.96% in Hospital A, and improve service quality had the highest EMR at 76.47% in Hospital B.

4. Discussion

In this study, we propose an evaluation framework supported by fuzzy logic based on user expectations. This framework is not a rival of but rather might be an alternative or complementary to the existing frameworks. This is a different approach and a different point of view toward the evaluation of healthcare ISs.

Although fuzzy logic applications/methodologies are used in HISs, they are not used while evaluating them in the evaluation frameworks. The evaluated context in HISs is very appropriate for fuzzy logic methodologies. In our proposed framework, we use fuzzy logic methodologies to give us elasticity for evaluation. In rating-based evaluations it is easier to express the ratings linguistically rather than using numbers. In that case, the problem of ambiguity could emerge as in the rating of 'not sure', which has a negative meaning as 'somewhat disagree', neutral meaning as 'no idea', or a positive meaning as 'somewhat agree'. This detail will be missed if we use crisp rating values. Fuzzy logic gives us the opportunity to take these blurred boundaries into consideration [19]. With this approach, we think that the framework becomes more realistic by covering the uncertainty of the weights and ratings.

The turnout was 76.4% for Hospital A and 96% for Hospital B. These rates are considerably high. The high participation shows that the users saw the evaluations as an opportunity to express their feelings and problems, both to the management and to the IS staff. This can also be interpreted as, because the framework is generated from the actual expectations of the users, the evaluation process becoming more effective. In addition, the users think that their ideas and thoughts are important for management. The message of 'your ideas are taken into account for improving the system' given to the users may help increase user acceptance of and attention to the IS. It can be said that if the evaluation is user-centric, participation becomes high.

Using weights in the evaluation changes the results. When we look at the usage expectations, if the variables are reflected equally in the result, then the usage expectation EMR would be 39.52% for Hospital A. The result is 27.89% when the weights are taken into account.

In Hospital A, we see that the EMRs are considerably low. The HIS had been used for 5 months (newly deployed) at the time that the framework was applied. There are many difficulties in implementing a new HIS, as reported in the literature [20]. Some may be technical (frequent outages, speed problems, etc.) and some may be organizational or user-centric (poor implementation planning, resistance to change, etc.). With respect to these problems, the expectations may be poorly met in a newly adopted HIS. These results can be interpreted as the framework working as intended.

The results of tests in these hospitals show that the framework has a high reliability, with Cronbach's alpha coefficients of 0.87–0.97, which is commonly used as a measure of the internal consistency or reliability.

In both hospitals, the lowest EMR in the usage expectations dimension shows that users think that HISs are not easy to use. On the basis of variables, having the lowest EMR in both hospitals again for speed tells us that HISs are not fast enough. We can make comments about the variables that have low EMRs, but for the high ones, it depends on the threshold that the management aims for. We do not propose an acceptable EMR to the evaluators. This is left for the evaluator. This threshold is relative to the context and situation. As in Hospital A, example, for a newly adopted system, it can be approximately 40, while it might be 50 or 70 for another hospital's management and perhaps 90 for management with higher standards.

In comparisons of the effectiveness of the framework with the existing ones, the most striking would be the form of output. As an example of output, for ease of use, one might describe it as 'it is taking a lot of her limited time' for HOT-fit [7], or 'EMR for ease of use is 27.89%'. In the first sentence, more questions arise, such as: What defines 'a lot'? We can also think about another output from the design–reality gap model [11], 'the expert system was relatively difficult to use', or a concrete percentage.

The proposed framework can give detailed information to the evaluator. While it can be evaluated for a whole HIS, it can also be filtered according to user profiles. This elasticity gives us different opportunities. With these filtering options, new studies, such as 'what user characteristics can affect the expectations', may be performed. The framework can also be customized according to the evaluator's evaluation context. The expectations can be grouped differently (Table 1 gives our grouping). The EMRs can be computed for these new groups. Additionally, it also enlightens the evaluator as to lack of communication with the user. If a variable is expected to give a high EMR but the result is the opposite, then we must seek the answer in communication. It means that either the users are not well aware of that virtue of the system or the information about that variable is faulty.

The proposed framework was applied to 2 HISs, and, to see the difference, these HISs were chosen in different stages, where one was newly deployed and the other was in routine use. The hospitals were of different types and the users were also different, to see if the framework is applicable to different types/sizes of hospitals. There was no comparison in this study. The intention was to see the results of the framework in different stages of HISs and different types/sizes of hospitals.

As a future work, to improve the study, the framework can be used to analyze if the hospital type makes any difference in the user expectations. To conduct such a study, different types of hospitals using the same system should be examined. However, if the systems are different, this study cannot be performed, because it would be misleading and give way to wrong findings. Another improvement can be made by using the same set of competent users to evaluate different HISs. The thing that we must be careful about is that all of the systems should be different for these sets of users. Otherwise, a system that is familiar to the users will most probably be the first to meet the expectations.

In conclusion, we develop a new framework to evaluate a HIS based on user expectations. It gives detailed information on each dimension of the user expectations and it is supported by fuzzy logic in the background. Its application in 2 hospitals is promising and we believe that the framework will be a useful evaluation tool for HISs.

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