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Evaluating the Effect of Software Quality Characteristics on Health Care Quality Indicators

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ABSTRACT

Introduction: Various types of software are used in health care organizations to manage information and care processes. The quality of software has been an important concern for both health authorities and designers of Health Information Technology. Thus, assessing the effect of software quality on the performance quality of healthcare institutions is essential.

Method: The most important health care quality indicators in relation to software quality characteristics are provided via an already performed literature review. ISO 9126 standard model is used for definition and integration of various characteristics of software quality. The effects of software quality characteristics and sub-characteristics on the healthcare indicators are evaluated through expert opinion analyses. A questionnaire comprising of 126 questions of 10-point Likert scale was used to gather opinions of experts in the field of Medical/Health Informatics. The data was analyzed using Structural Equation Modeling.

Results: Our findings showed that software Maintainability was rated as the most effective factor on user satisfaction (R^2=0.89) and Functionality as the most important and independent variable affecting patient care quality (R^2=0.98). Efficiency was considered as the most effective factor on workflow (R^2=0.97), and Maintainability as the most important factor that affects healthcare communication (R^2=0.95). Usability and Efficiency were rated as the most effectual factor affecting patient satisfaction (R^2=0.80, 0.81). Reliability, Maintainability, and Efficiency were considered as the main factors affecting care costs (R^2=0.87, 0.74, 0.87).

Conclusion: We presented a new model based on ISO standards. The model demonstrates and weighs the relations between software quality characteristics and healthcare quality indicators. The clear relationships between variables and the type of the metrics and measurement methods used in the model make it a reliable method to assess the effect of software quality on healthcare organizations' quality performance.

Keywords: Healthcare outcome, Healthcare quality indicator, ISO 9126, Software quality characteristics, Software quality evaluation, Health Information Technology (HIT)

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Introduction

Quality in services is increasingly becoming important in healthcare world and many criteria have so far been defined to achieve and assess it. Health Information Technology (HIT) is favored and used widely in healthcare organizations as an important way to fill the existing "quality chasms" and achieve a better and qualitative performance (1). On the other hand, one of the most important HIT properties that affect its performance is how deployment of qualitative software can support the existing processes better. Software quality is thus an important concern of the software world as well. How these two quality concerns of the two different worlds are related to each other is a complex topic yet to be explored. There is no consensus about the definition of software quality among the experts. In fact, the definition of software quality is a multifaceted concept and is determined by a number of properties. One of the popular definitions offered for software quality states that software quality is to meet articulated needs and efficiency, the application development standards documented explicitly, as well as implicit characteristics expected from advanced professional software (2). Different characteristics have been defined for software quality in different studies. Many of them overlap with similar definitions; this is perhaps the most important challenge of classification of the software quality (3, 4). Qualitative models were proposed to describe and delineate the different quality attributes of software quality. The models have developed further to a new standard internationally. International Standard Organization (ISO) and the International Electro-technical Commission (IEC) established ISO 9126 standard in 1991. This standard provides a framework for assessing the quality of software products. Ten years later in 2001 and then in 2003, the standard

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was redefined and developed further to a new version by Abran (5). Currently, a qualitative model of software products ISO/IEC25010:2011 succeeded ISO/IEC9126-1: 1991 (6). Although in the new version, some amendments to the old version were made, the main frame of software characteristics and sub-characteristics remained unchanged.

The assessment of the effect of software quality on the performance of healthcare institutions is essential. Several studies have examined the effect of some components of software quality (e.g. user friendly interface) on some indicators of healthcare institutions (e.g. user satisfaction) (7-9). While these studies offered valuable insights, their findings were not comprehensive and were concerned with being uni-dimensional. To the best of our knowledge, no study has so far examined the effect of all software quality characteristics on healthcare quality indicators. In this study, we aimed to evaluate the impact of software quality characteristics on the quality performance of healthcare organizations. To this end, it was necessary to define the concept of software quality first. ISO 9126 standard model was used as a standard way of defining software quality characteristics. We aimed to analyze the impact of all software quality characteristics on healthcare common quality indicators and to come up with a model that explains the dynamics that exist between the software quality characteristics and healthcare quality indicators.

Methods

Software quality characteristics from ISO 9126 standard were considered as independent variables in this study. These variables and their definitions are presented in Table 1.

The results of our previous literature review on extracting the most important healthcare quality indicators in relation to software quality characteristics were applied (8). The six quality indicators of healthcare institutions that emerged from the literature review were considered as the dependent variables (Table 2) (8). The effects of software quality characteristics on healthcare indicators were evaluated based on medical/health informatics experts' opinion.

A questionnaire comprising of 126 questions was developed. The questions' answers were 10-point Likert scales, ranging from 0 (the lowest effect) to 9 (the most influential) as well as an extra Not Applicable (NA) option (please see the companion file). The relevancy of the questions was checked with five medical/health informatics experts and its reliability was calculating by alpha Cronbach.

The target population was medical/health informaticians. The questionnaire was sent via email to anyone that we know in the field internationally. We also posted the questionnaire to "Eval Group", a European based international health informatics evaluation online community http://listman.umit.at/mailman/listinfo/eva. Only 21 questionnaires were completed and returned after two reminders within two months. The questionnaire data were extracted and analyzed using LISERL® scientific software version 8.5. The aim of the analyses was to determine which software quality characteristics is more effective on healthcare indicators. In other words, we were interested to know whether we can find a new model for the factors' relationships.

Table 1. The definition of software quality characteristics and sub-characteristics based on ISO9126

Characteristics	Sub- Characteristics	Definition
Functionality (Fun)	Suitability	Can the software perform the tasks required?
	Accurateness	Are the results as expected?
	Interoperability	Can the system interact with another system?
	Compliance	How is the compliant capability of the software with laws and guidelines?
	Security	Does the software prevent unauthorized access?
	Maturity	Have most of the faults in the software been eliminated over time?
Reliability (Rel)	Fault tolerance	Is the software capable of handling errors?
	Recoverability	Can the software resume working and restore lost data after failure?
	Understandability	Does the user comprehend how to use the system easily?
Usability (Usa)	Learnability	Can the user learn to use the system easily?
	Operability	Can the user use the system without much effort?
	Time behavior	How quickly does the system respond?
Efficiency (EFF)	Resource behavior	Does the system utilize resources efficiently?
	Analyzability	Can the software faults be easily diagnosed?
Maintainability(Main)	Changeability	Can the software be easily modified?
	Stability	Can the software continue functioning after changes are made?
	Testability	Can the software be moved to other environments?
	Adaptability	Can the software be tested easily?
	Install ability	Can the software be installed easily?
Portability (Por)	Conformance	Does the software comply with Por. standards?
	Replace ability	Can the software easily replace other software?

Table 2. Healthcare indicators evaluated in relation to software quality characteristics

Allocated Number	Health care Indicator
1	User satisfaction
2	Quality of patient care
3	Clinical Workflow and Efficiency
4	Care providers communication and information exchange
5	Patient satisfaction
6	Care costs

A Structural Equation Modeling (SEM) was used to explore the causal relationships between the variables because of the following reasons. There were a large number of the variables; we were trying to evaluate the effect of several independent variables on dependent variables; there was an interest to recognize the causal relationship between the variables and determine the priority of independent variables based on their effect; we aimed to identify hidden variables and determine the relationship between them.

After entering the data into the LISERL® scientific software, the independent variables were grouped based on dependent variables. In addition, each characteristic and related sub-characteristics was compared with each of the dependent variables (healthcare indicators). For example, "Fun1" is selected as a name to evaluate the relationship between variable Fun and its sub-characteristics with dependent variable of user satisfaction (based on questionnaire's classification) and "Fun2" was chosen for analyzing the relationship between Functionality characteristics and its sub-characteristics with dependent variable of patient care quality.

Therefore, all 126 dependent variables were classified based on 6 groups of dependent variables. R^2 represented the scale of effect between the two type the most influential relationship. T-test was used to evaluate the relationship among the variables at the significance level of 0.05. If t-value was less than 1.96, the relationship should be considered insignificant. In this study, due to small sample size, some of the relationships were evaluated at significance level of 0.08. It means that t-values near 1.96 were also acceptable.

Finally, factor loading was used to examine the strength of the relationship between factors (latent variables) and visible variable.

Factor loading varies between zero to one. If it is less than 0.3, the relationship is poor and it can be ignored. Factor loading between 0.3 and 0.6 is acceptable and if it is greater than 0.6, the relationship is very good.

Results

The results showed that among the independent variables that affect the user satisfaction, Maintainability was the most effective factor (R^2=0.89). This means 89% of the changes in user's satisfaction were related to Maintainability. T-value analysis showed the significance of the equation too, which was confirmed by the small error rate.

In Estimate Analysis, factor loading (λ=0.95) was greater than 0.3, and the error rate was less than one. Likewise, as it can be seen in Table 3, Functionality was the most important variable affecting the quality of patient care (R^2=0.98). Efficiency was the most important variable affecting the clinical workflow (R^2=0.97). Maintainability was the most important variable affecting the Communication (R^2=0.95). Also, Usability and Efficiency were the most influential variables on Patient satisfaction (R^2=0.80, 0.81). In addition, the most important variables affecting Care costs were Maintainability, Efficiency, and Reliability (R^2 = 0.74, 0.87, 0.87).

Following the recognition of the most important variables, the relationship and the effectiveness of the hidden variables for each question were evaluated. Less effective questions with low R^2, low t-value, and low factor loading, and with high error rate were omitted. Conversely, highly effective questions were preserved. The results are presented in Table 4. Figure 1 graphically shows the relationship between the hidden factors and main questions in LISERL® scientific software.

Table 3. Analysis of the relationship between independent and dependent variables

Dependent variable	Independent variable	R^2	T-values	Estimate (λ)	Error rate
User satisfaction Main	1	0.89	1.53	0.95	0.11
Quality of patient care	Fun 2	0.98	7.09	1.28	-0.65
Clinical work flow	Eff 3	0.97	3.58	1.15	-0.32
Communication	Main 4	0.95	5.14	0.98	0.047
Patient satisfaction	Eff 5	0.81	2.25	0.90	0.19
	Usa 5	0.80	1.70	0.89	0.20
Care costs	Main 6	0.74	4.02	0.86	0.41
	Eff 6	0.87	4.10	0.93	0.78
	Rel 6	0.87	zcd 3.17	0.68	0.15

Table 4. Analyses of the effective questions in establishing the hidden and main variables

Main Variable	Hidden Variable	Questions	Estimate	Error Rate	T-values	R^2
User satisfaction	Main1	103	2.42	0.43	1.47	0.93
		104	2.32	0.90	2.54	0.86
		106	2.52	0.64	1.93	0.91
Quality of patient care	Fun2	9	1.36	2.57	2.67	0.42
		10	1.01	2.88	3.53	0.26
Work flow	Eff3	71	1.38	1.19	1.43	0.62
	Fun4	17	1.92	0.16	7.24	0.99
		18	1.37	3.09	3.51	0.42
	Rel4	41	1.50	2.04	5.89	0.77
		42	1.12	3	3.46	0.44
	Usa4	59	2.20	2.76	5.77	0.69
		60	2.40	2.02	7.41	0.84
Communication	Eff4	74	2.41	0.65	5.81	0.95
		92	1.98	2.38	2.18	0.54
	Por4	93	1.55	2.62	2.09	0.46
		94	1.39	2.33	2.20	0.46
		116	2.33	1.81	8.62	0.93
	Main4	117	2.01	2.73	6.76	0.80
		118	2.18	2.87	6.02	0.74
Patient satisfaction	Usa5	62	3.02	-0.90	19.31	1
		63	2.98	2.62	18.35	0.95
	Eff5	76	2.70	0.86	9.86	0.84
	Rel6	47	2.14	0.64	9.74	0.97
		48	2.29	2.61	7.49	0.84
Care costs	Main6	124	2.18	2.46	7.09	0.92
		125	2.22	0.15	7.87	1.00
		126	1.87	3.08	5.52	0.74
	Eff6	78	2.24	1.32	5.32	0.87

The Final Model

A final model was developed by selection of variables with high R^2 value. This model shows that Maintainability is the most important (independent) variable that affects user satisfaction; Functionality is the most important (independent) variable that affects the quality of patient care; Efficiency is the most important (independent) variable that affects the Workflow; Maintainability is the most important (independent) variables that affect Communication; Usability and Efficiency are the two most important variables that affect Patient satisfaction; and the most important variables affecting the Cost of care are Efficiency, Maintainability and Reliability (Figure 2).

The presented model is verified using Root of Mean Square Error (RMSEA). This parameter for our model was 0.00, which emphasizes the significance of the model. Moreover, the model error was calculated by

$$\left(\frac{-square}{df} = \frac{393.07}{286} = {}^{1}\!/_{38}\right).$$

where Chi-square=393.47 and df = 286, the model error was 1/38 < 3. This represents that the resulting model is invoked.

The final model fitness was also evaluated using three other indicators. These three parameters were:

1.The Parsimony Normed Fit Index (PNFI) which was calculated by (nfi=pratio×nfi) and its value was 0.50. This index should not be more than 0.50.

2.Relative Fit Index (RFI) which was calculated by

$$\left(1 - \frac{x_m^2/dfm}{x_{n/dfn}^2}\right)$$

and its value was equal to 0.73. The more this integer is near to 1, the higher the fitness is.

3.Incremental Fit Index (IFI) which was calculated by

$$\left(1 - \frac{x_m^2/dfm}{x_{n/dfn}^2}\right)$$

and its value for our model was 1.08. This parameter should be greater than 0.9 to indicate the model fitness.

Figure 1. The relationship between the dependent and independent variables and their measuring questions

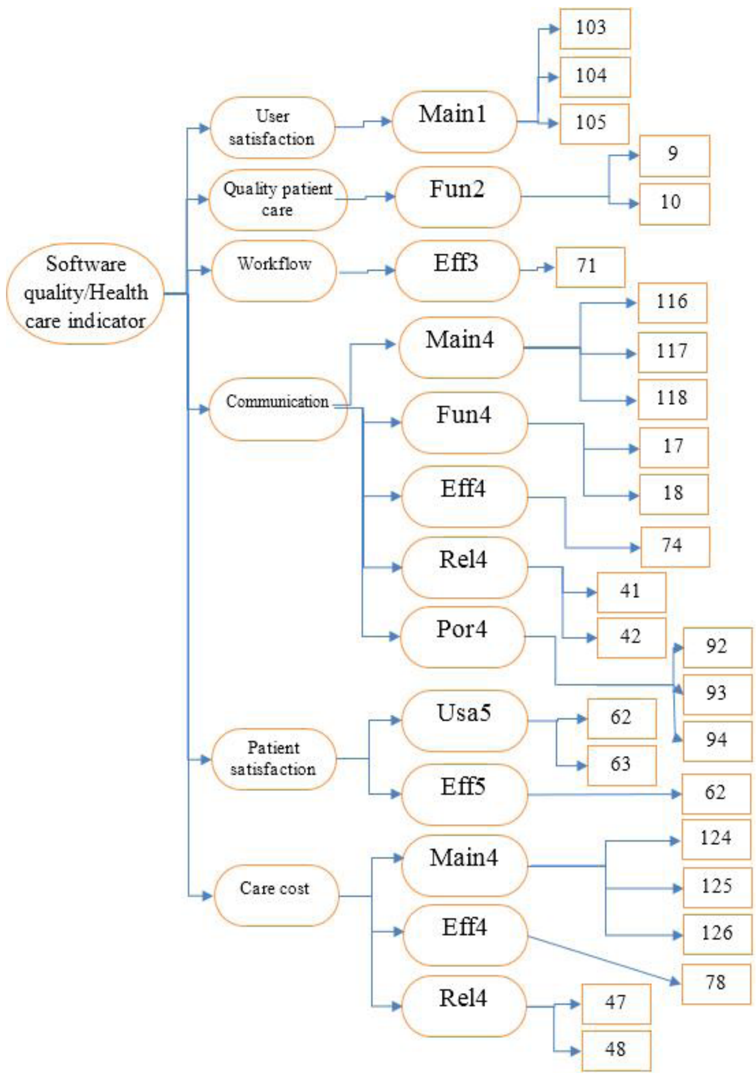
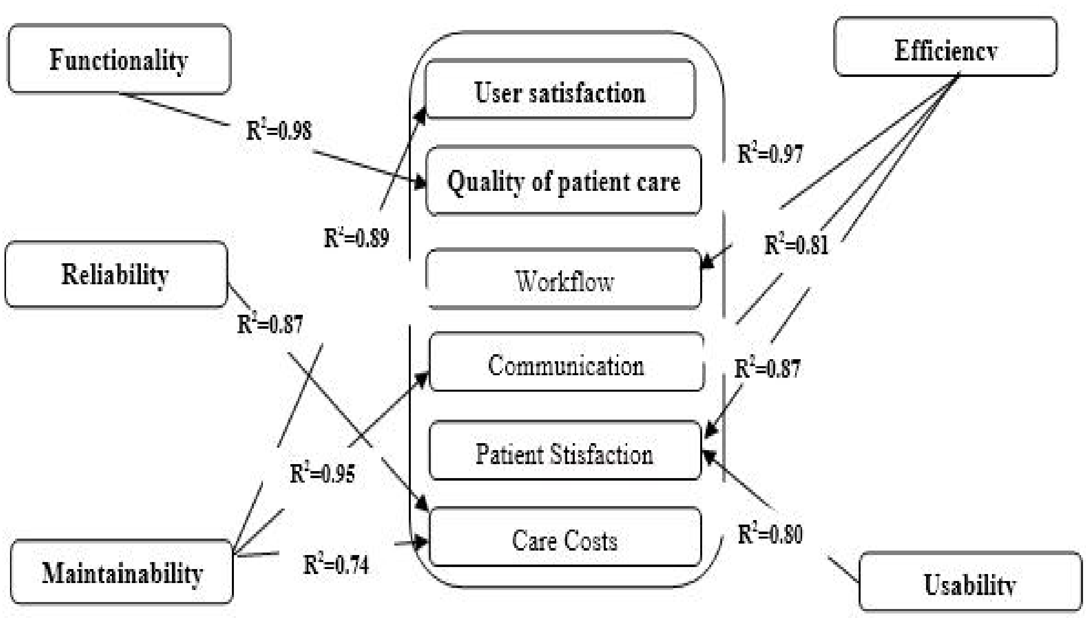


Figure 2. Final model of relationships among software quality and health care indicators



Discussion

We evaluated the impact of software quality characteristics on the quality performance indicators of healthcare and developed a new model through analyzing the knowledge provided by health informatics experts. The model can be used for assessing the effect of software quality characteristics (and sub-characteristics) on important healthcare indicators. The strength of the model is that all dimensions of software quality were analyzed and each variable's weight in affecting healthcare indicators was determined.

Quality of an information system in patient care activities is a multifaceted issue and depends on important properties of software such as service timeliness and system reliability. Timeliness means being on time for a service to be provided or delivered to users. In other words, the time period between giving a command and its execution, which in turn relates to the nature of information too. Reliability means that the repetition of collecting, storing, and presentation processes by a system leads to the same results. Repeated tests on the same data, for example, should produce similar results (1, 9).

Quality of software is presented by various criteria, for example, ease of use, speed of process, quality of user interface, display of color and design. Some studies showed that system quality affects user satisfaction indirectly (7). Other studies defined characteristics such as availability of system manual, system security, providing interoperable communication, stability and compatibility of system, and ease of system use for system quality and stated that system quality has a direct effect on its perceived usefulness (10-14).

The effect of some of software quality characteristics such as reliability, functionality, performance and usability have also been evaluated upon various measures of healthcare, such as daily activities, user satisfaction, communication among staff, workflow, stress in workplace and clinical processes (15-18).

Use of terminologies, system flexibility, system capabilities, commensurate with the tasks, and system design are among the software properties, by which many studies examined the effects of software quality on healthcare indicators such as patient satisfaction and quality of patient care (10-12).

Several limitations can be mentioned for this study and should be considered in interpreting its results, too. Like any other subjective studies that are based on self-reporting and using questionnaire for collecting data, findings have their own limitations. Our questionnaire was long and the sample size was small, due to the inherent limitation of this type of studies. Moreover, we did not consider those software quality characteristics that were amended in the most recent version of the ISO standard.

Conclusion

We developed a model that relates common quality indicators coming from the two different worlds of healthcare and software. The fitness of the model was tested using different parameters. Since the most commonly concerned indicators in evaluating the effect of HIT on healthcare were used in the model, the model is in accordance with HIT evaluation objectives. Moreover, since the model is based on ISO standard definition of software quality, it can be extended to use in different healthcare settings. Considering that the characteristics/sub-characteristics from the ISO standard are clear concerning methods and metrics of measuring, the presented method can easily be tested in practice.

Conflict of interest

The authors have not received any external grant for the project. Neither do they have any competing interest, financial issue, or ethical concern to disclose.

Authors' contribution

All the authors provided substantial contributions to different parts of the study. HP and SA designed the research concept. SA and HP designed the data collection and interpretation methods. AA and AM had considerable contribution in designing data collection and analyzing methods. SA, HP, AA, and AM all contributed to data gathering, data analysis, drafting the manuscript and providing final approval of the version to be published.

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