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QUALITY MODEL OF CLOUD HEALTHCARE SERVICES: A PAIRWISE COMPARISON APPROACH

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Abstract. *Measuring software quality is one of the success keys in healthcare organizations, so this research work is conducted to study the quality functional and technical factors in cloud healthcare systems. For a successful implementation of cloud healthcare systems, the providers should offer superior services that meet customers' expectations. The quality models can be employed to present and evaluate the quality of the services or products provided by such providers, in which the cloud healthcare systems' stakeholders can establish concreted understanding. In this research work, a novel quality model is proposed to help the providers of cloud healthcare services and healthcare organizations provide and implement systems that meet stakeholders' expectations. The proposed quality model includes seven quality characteristics, namely, functionality, reliability, efficiency, usability, maintainability, portability, and marketability. After conducting a survey on 50 cloud healthcare system stakeholders, the Analytic Hierarchy Process has been applied to evaluating the validity of the proposed model. The results of this research work arrange the quality characteristics of the proposed model according to its importance (weights) as follows: functionality, reliability, efficiency, usability, maintainability, marketability, and portability.*
Keywords: Software quality, Healthcare quality model, Quality characteristics, Healthcare quality characteristics

1. **Introduction.** Over the last few years, cloud computing has emerged as an important revolutionary technology in the information technology field. Most of the leading organizations (Microsoft, Google, IBM) have entered the cloud computing market to obtain additional customers and expand their businesses. Cloud computing is an effective computing paradigm where the software functions, hardware, and other resources are offered as services in Internet-based environments with little human interaction [1,2]. Thus, cloud computing providers should provide preferable services that meet the customers' expectations to succeed in a competitive market.

Similarly, cloud services have significantly been adapted in the healthcare industry, and the coronavirus has reinforced this trend [3]. According to [4], healthcare enterprises will spend approximately USD 25.25 billion in 2020-2024 on cloud services. Healthcare enterprises implement cloud computing not only to break down the location barriers restricting access to healthcare but also to cut down the operational expenses; to take advantage of big data analytics methods, accessibility, and scalability of the system; and to provide high-quality services and personalized care [5]. Cloud services have successfully been adopted in many areas. However, many of them have failed to achieve the objectives and expectations behind implementing such services [5,6]. This failure could have several reasons, but the most evident one is the poor quality of cloud computing resources [6].

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Therefore, the availability of a guideline for designing and implementing high-quality healthcare cloud services is crucial.

Although a few research works have been conducted on the quality of cloud healthcare services, the quality factors of cloud healthcare services have not been well defined. Furthermore, most of the prior quality models are of western origin and consistent with developing countries' cultures and economies [6]. Such studies provided scales similar to the general measures of service quality, which could be not completely suitable for measuring the perceived quality of cloud healthcare services [7]. In addition, prior research works had considered a functional aspect and ignored other leading quality factors, such as functional and technical factors [6-9]. These results offer much cause for failure.

Therefore, this research work aims to propose a quality model for healthcare services including the leading quality characteristics. This quality model leads to creating a quality framework for healthcare systems development. Such framework is considered as the process to assess evidence for determining whether the healthcare organizations maintain its quality to become an asset; to offer better services; to effectively support goals of healthcare organizations; to efficiently consume resources. The main contributions of this research work are proposing a quality model for healthcare services including seven quality characteristics and 29 sub-characteristics; conducting in the developing countries environment; applying the Analytical Hierarchy Process (AHP) to validate the proposed model.

A few quality models have been proposed in the literature to assess the quality of healthcare services including HospitalQual, HEALTHQUAL, Donabedian, and SERVQUAL [7,10-14], where others proposed to measure the cloud and software quality [15-18]. Such quality models are generic quality models and developed according to the contexts of particular healthcare services. Furthermore, they did not consider the functional and technical aspects of the healthcare services. Notably, no quality model has been proposed to measure the quality of cloud healthcare services.

The rest of this research work is organized as follows. Section 2 addresses the proposed quality model including the leading quality characteristics of cloud healthcare services. Section 3 describes the method of data collection, analyzing technique, and research results. Finally, Section 4 concludes this research work.

2. Quality Model of Cloud Healthcare Services.

By reviewing and synthesizing the prior literature on the quality of healthcare services, a variety of models are identified, namely, HEALTHQUAL, SERVQUAL, HospitalQual, and PubHosQual models. However, such models provided generic measuring for service quality, which may not be completely appropriate to evaluate the quality of healthcare services. Additionally, they paid too little attention to the functional and technical aspects of the services. They were also conducted in developed countries, thereby unnecessarily conforming to measuring the quality of healthcare services in developing countries [6,19].

With the same respect, cloud services are provided in Internet-based environments. Thus, they have some characteristics not only of traditional services delivered in human-based environments but also of e-services conducted in Internet-based environments [20].

To this end, this research work has been conducted to bridge the gap in the literature on the quality of cloud healthcare services. That is, this work proposes a Quality Model of Cloud Healthcare Services (QMCHS) for providing a comprehensive framework for measuring the quality of cloud healthcare services in developing countries. This quality model involves a set of functional and technical quality characteristics including functionality, reliability, efficiency, usability, maintainability, portability, and marketability. Figure 1 shows the QMCHS.

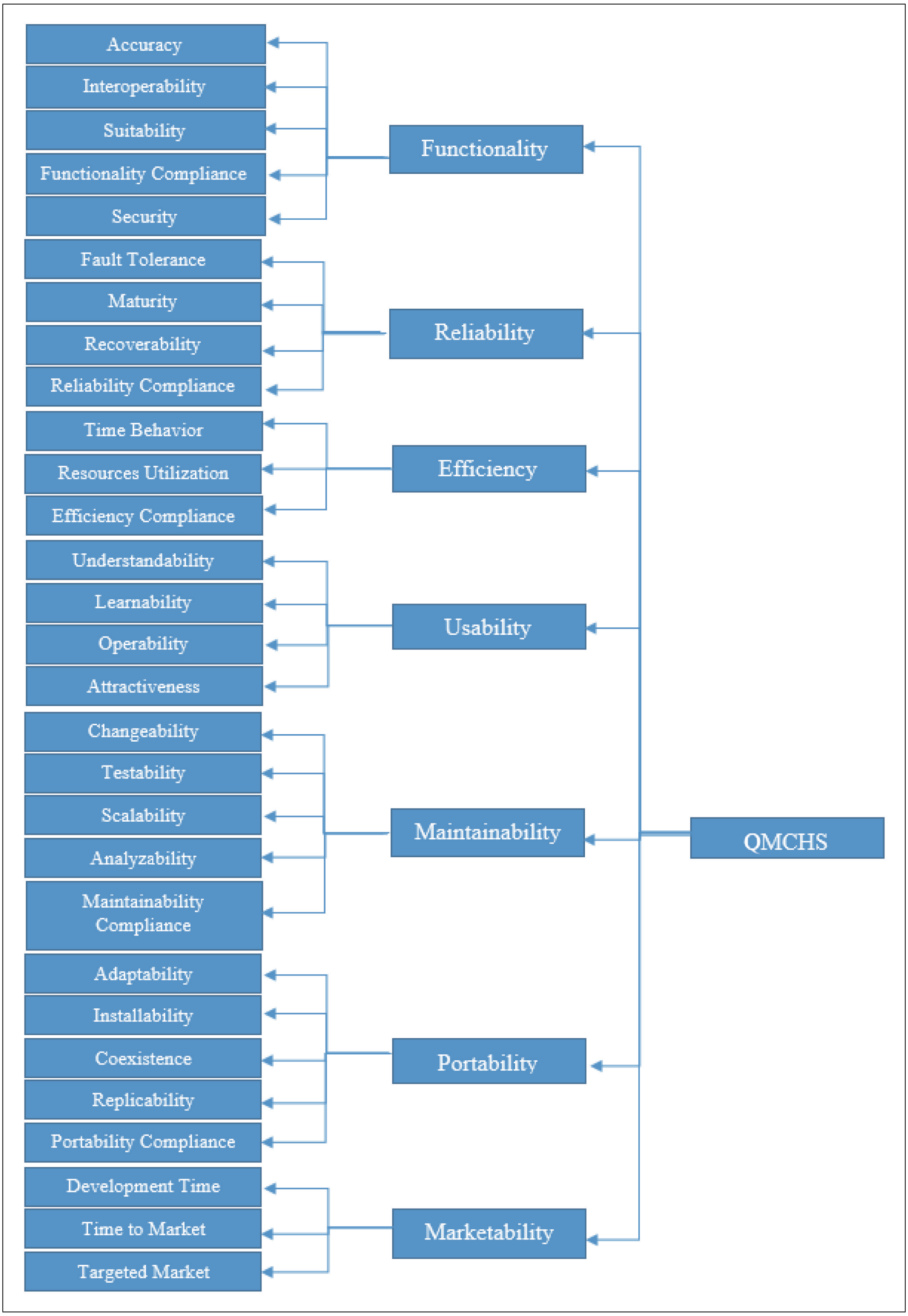

Figure 1. Quality Model of Cloud Healthcare Services (QMCHS)

Functionality is defined as the capability of a software system to offer functions that meet the users' needs under specified conditions of usage [21]. To measure such characteristics, functionality has been divided into a variety of sub-characteristics, namely, accuracy, interoperability, suitability, functionality compliance, and security [21,22]. Adapting the functionality to the cloud healthcare services involves that the cloud healthcare software should provide functions and services as per the needs of users when used under specific conditions.

Reliability is defined as the capability of software systems to preserve their level of performance under stated conditions for a specific interval of time [17]. The reliability characteristic includes a set of sub-characteristics, namely, fault tolerance, maturity, recoverability, and reliability compliance [17]. Adapting this characteristic to the cloud healthcare software reveals the capability of cloud healthcare software to maintain its level of performance under specific conditions for a specific period of time.

Efficiency is the capability of a software system to offer desired performance relative to the number of resources used under specific conditions [23]. This quality characteristic has been divided into three sub-characteristics, namely, time behavior, resources utilization, and efficiency compliance [23,24]. The efficiency characteristic is employed in this study to suggest that the cloud healthcare software should pay attention to the used resources when providing its functions.

Usability refers to the capability of a software system to learn, understand, use, and attract users [25]. The usability characteristic is divided into some sub-characteristics including understandability, learnability, operability, and attractiveness [25]. In terms of cloud healthcare services, the usability characteristic refers to the capability of cloud healthcare software to learn, understand, use, and attract users under specific conditions [29].

Maintainability refers to the capability of a software system to be modified. The modification involves corrections, improvements, and adaptations of a software system [30,31]. The maintainability characteristic consists of a set of sub-characteristics including changeability, testability, analyzability, scalability, and maintainability compliance [25]. In terms of cloud healthcare services, any component in the software of cloud healthcare should be modifiable. Moreover, defining the causes of a system failure and validating the modified cloud healthcare system should not need much time and effort.

Portability is the capability of the software system to be conveyed from one environment (hardware or software) to another [21]. Five sub-characteristics have been used to measure portability including adaptability, installability, coexistence, replicability, and portability compliance [21]. The cloud healthcare software should be employed using different operating systems and a variety of hardware.

Marketability refers to the capability of a software system to be bought and sold [26]. Three sub-characteristics have been used to evaluate the marketability characteristic, namely development time, time to market, and targeted market (cost) [26]. Marketability is adopted in this research to suggest that the cloud healthcare software should be developed and available to the stated markets at the appropriate time.

3. **Evaluating CHQM Using Analytic Hierarchy Process.**

The evaluation of the Cloud Healthcare Quality Model (CHQM) is based on the Analytic Hierarchy Process (AHP). [27] proposed the AHP, which applies the pair-wise matrix to measuring the ambiguity in multi-criteria decision-making problems. For instance, once n elements to be compared exist, $C_1, C_2, C_3, \ldots, C_n$ represent the relative weight (priority) of Criteria (C). C_i and C_j are represented as a_{ij} in a square matrix $A = [a_{ij}]$ of order n as shown in Equation (1).

$$A = [a_{ij}] = \begin{array}{c|cccc} & C_1 & C_2 & \cdots & C_n \\ C_1 & 1 & a_{12} & \cdots & a_{1n} \\ C_2 & \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_n & \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{array} \tag{1}$$

Human judgments in the square matrix are more or less inconsistent. In the case of consistency, vector (ω) must satisfy Equation (2) [28].

$$A.\omega = \lambda_{\max}.\omega, \text{ and } \lambda_{\max} \geq n \tag{2}$$

where ω denotes eigenvector, $\lambda_{\max}$ denotes the eigenvalues, and n is the elements to be compared. The difference, if any, between $\lambda_{\max}$ and n indicates inconsistency of the judgment. Equations (3) and (4) show a Consistency Index (CI) and Consistency Ratio (CR) proposed by [27] to verify the consistency of the comparison matrix.

$$\text{CI} = (\lambda_{\max} - n)/(n-1) \tag{3}$$

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

where RI represents the average of CI over numerous random entries of the same order reciprocal matrices. Furthermore, CR should be less than or equal to 0.1, which means that the judgment is consistent to be reliable [27].

3.1. **Allocating the weights of characteristics and sub-characteristics.** To allocate weights to the quality characteristics and sub-characteristics of the proposed model, a survey on 50 participants from developing countries (Jordan, United Arab Emirates, Saudi Arabia) has been conducted. Of these participants, 30 are hospital employees who have a good knowledge of using cloud healthcare systems. The remaining 20 participants are customers (patients) who are also working on cloud healthcare systems. Each survey form includes eight tables for filling pair-wise relative weights of seven characteristics and 29 sub-characteristics. The means of collected pair-wise relative weight values of seven characteristics including functionality (C_1), reliability (C_2), efficiency (C_3), usability (C_4), maintainability (C_5), portability (C_6), and marketability (C_7) have been filled in the square matrix $A = [a_{ij}]$ see Equation (5), which is prepared based on Equation (1). Similarly, the means of pair-wise relative weight values of sub-characteristics of each characteristic have been filled in the square matrix $A = [a_{ij}]$. In the next sub-section, the eigenvector and eigenvalues are calculated.

$$A = [a_{ij}] = \begin{array}{c|ccccccc} & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 \\ C_1 & 1 & 3.91 & 3.78 & 3.54 & 3.49 & 3.41 & 3.33 \\ C_2 & 0.256 & 1 & 3.50 & 3.00 & 2.33 & 2.51 & 2.40 \\ C_3 & 2.650 & 2.860 & 1 & 2.93 & 2.45 & 2.34 & 2.11 \\ C_4 & 0.282 & 0.333 & 0.345 & 1 & 2.94 & 2.32 & 1.80 \\ C_5 & 0.287 & 0.429 & 0.408 & 0.340 & 1 & 3.71 & 1.79 \\ C_6 & 0.293 & 0.398 & 0.427 & 0.431 & 0.27 & 1 & 1.47 \\ C_7 & 0.300 & 0.417 & 0.474 & 0.556 & 0.560 & 0.680 & 1 \end{array} \tag{5}$$

3.2. **Calculating eigenvector and eigenvalue.** One of the methods to find the eigenvector is calculating the nth root for the results of multiplying together the entries in each row of matrix A. Consequently, the nth roots are summed, and then, the sum is employed to normalize the eigenvector elements to be added to 1.000. For the matrix in Table 1, the 7th root of the first row is 2.977 and then divided by 8.457 to give 0.352 as the first value in the eigenvector (ω). The eigenvector values for C_1-C_7 are 0.352, 0.199, 0.136, 0.103, 0.087, 0.056, and 0.067, respectively. These eigenvector values represent the

TABLE 1. Eigenvector and eigenvalues of main characteristics

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	7th root	ω	$A.\omega$	$\lambda_{\max}$
C_1	1	3.910	3.780	3.540	3.490	3.410	3.33	2.977	0.352	2.727	7.748
C_2	0.256	1	3.500	3.000	2.330	2.510	2.400	1.679	0.199	1.580	7.957
C_3	0.265	0.286	1	2.930	2.450	2.340	2.110	1.151	0.136	1.075	7.899
C_4	0.282	0.333	0.341	1	2.940	2.320	1.800	0.876	0.103	0.823	7.939
C_5	0.287	0.429	0.408	0.340	1	3.710	1.785	0.732	0.087	0.692	7.999
C_6	0.293	0.398	0.427	0.431	0.270	1	0.98	0.478	0.056	0.431	7.623
C_7	0.300	0.417	0.474	0.556	0.560	1.020	1	0.567	0.067	0.483	7.215
TOTAL								8.457	1.000		Mean 7.769

weights of the main quality characteristics including functionality (C_1), reliability (C_2), efficiency (C_3), usability (C_4), maintainability (C_5), portability (C_6), and marketability (C_7).

Next, the eigen ($\lambda_{\max}$) values have been calculated by employing $\lambda_{\max} = (A.\omega/\omega)$, where $A.\omega = \lambda_{\max}.\omega$. Thus, the seven values of eigen are 7.748, 7.957, 7.899, 7.939, 7.999, 7.623, and 7.215. All such values of eigen are greater than or equal to 7, as the 7th order matrix, which meet the condition of $\lambda_{\max} \geq n$ [25]. The mean of eigenvalues is 7.769.

Therefore, the values of CI could be calculated by applying Equation (3).

$$\text{CI} = (\lambda_{\max} - n)/(n - 1) = (7.769 - 7)/(7 - 1) = 0.128.$$

Finally, the CR has been calculated for the set of judgments by applying Equation (4). The statistical results showed the CR < 0.1 for all matrices of main characteristics. Therefore, all estimates are acceptable.

$$\text{CR} = \text{CI}/1.32 = 0.128/1.32 = 0.097.$$

Similarly, all steps of AHP have been applied to all the sub-characteristics of the main characteristics. Table 2 presents the eigenvectors for the set of sub-characteristics. As shown in the table, 29 sub-characteristics are weighed as follows: sub-characteristics of C_1 are accuracy (SC_{11}) (0.138), interoperability (SC_{12}) (0.138), suitability (SC_{13}) (0.123), functionality compliance (SC_{14}) (0.258), and security (SC_{15}) (0.343); fault tolerance (SC_{21}) (0.314), maturity (SC_{22}) (0.246), recoverability (SC_{23}) (0.260), and reliability compliance (SC_{24}) (0.189) for sub-characteristics of C_2, and others.

Finally, the results show that the values of CR for all sub-characteristics are less than 0.1, indicating that all estimates are acceptable.

4. **Conclusions.** This research work aims to propose a new quality model for cloud healthcare services. This quality model involves seven main quality characteristics, namely, functionality (C_1), reliability (C_2), efficiency (C_3), usability (C_4), maintainability (C_5), portability (C_6), and marketability (C_7); and 29 sub-characteristics including the following: accuracy (SC_{11}), interoperability (SC_{12}), suitability (SC_{13}), functionality compliance (SC_{14}), and security (SC_{15}) for the functionality (C_1); fault tolerance (SC_{21}), maturity (SC_{22}), recoverability (SC_{23}), and reliability compliance (SC_{24}) for the reliability (C_2); time behavior (SC_{31}), resources utilization (SC_{32}) and efficiency compliance (SC_{33}) for the efficiency (C_3); understandability (SC_{41}), learnability (SC_{42}), operability (SC_{43}), and attractiveness (SC_{44}) for the usability (C_4); changeability (SC_{51}), testability (SC_{52}), scalability (SC_{53}), analyzability (SC_{54}), and maintainability compliance (SC_{55}) for the maintainability (C_5); adaptability (SC_{61}), installability (SC_{62}), coexistence (SC_{63}), replicability (SC_{64}), and portability compliance (SC_{65}) for the portability (C_6); development time (SC_{71}), time to market (SC_{72}), and targeted market (SC_{73}) for the marketability (C_7). All these characteristics and sub-characteristics have been selected based on the features of cloud healthcare services. The AHP has been applied to evaluating the validity of the proposed quality model. To generate the pair-wise relative weights of the main quality

Table 2. Eigenvector and eigenvalues of sub-characteristics

Characteristics	ω of characteristics	Sub-characteristics	ω of sub-characteristics	$\lambda_{\max}$ of sub-characteristics
C_1	0.352	SC_{11}	0.138	5.360
		SC_{12}	0.138	5.017
		SC_{13}	0.123	5.152
		SC_{14}	0.258	5.230
		SC_{15}	0.343	5.371
C_2	0.199	SC_{21}	0.314	4.010
		SC_{22}	0.246	4.050
		SC_{23}	0.260	4.060
		SC_{24}	0.189	4.040
C_3	0.136	SC_{31}	0.319	4.298
		SC_{32}	0.338	4.159
		SC_{33}	0.220	4.190
		SC_{34}	0.122	4.349
C_4	0.104	SC_{41}	0.094	3.079
		SC_{42}	0.661	3.079
		SC_{43}	0.245	3.079
C_5	0.087	SC_{51}	0.436	5.597
		SC_{52}	0.243	5.405
		SC_{53}	0.119	5.041
		SC_{54}	0.092	5.076
		SC_{55}	0.110	5.178
C_6	0.060	SC_{61}	0.401	5.209
		SC_{62}	0.298	5.231
		SC_{63}	0.130	5.340
		SC_{64}	0.090	5.017
		SC_{65}	0.081	5.273
C_7	0.063	SC_{71}	0.667	3.098
		SC_{72}	0.194	3.098
		SC_{73}	0.139	3.098

characteristics and sub-characteristics, the data from 50 health organizations' employees and customers who have good knowledge of the healthcare systems. The results of this research work arrange the quality characteristics based on weight as follows: functionality, reliability, efficiency, usability, maintainability, marketability, and portability.

Therefore, the health organizations that want to apply cloud healthcare systems should choose the systems that include such characteristics according to their importance (weights). Furthermore, the developers of cloud healthcare systems should also pay more attention to such quality characteristics when developing such systems.

Future work should concentrate on incorporating more quality characteristics and evaluating the proposed model with more experts.

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