Ranking and Evaluating CT Departments by Quality Function Deployment

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ABSTRACT
Rankings have a great value in providing necessary information to take the appropriate decision in various fields. In the healthcare sector, ranking systems have a vital and important role in the development of each hospital. The aim of this paper is to design mathematical ranking model based on quantitative parameters and sub parameters using quality function deployment to rank the computed tomography (CT) departments in hospitals. The proposed model is based on parameters extracted from both the hospitals and the CT scan devices. The output of the system from 30 different hospitals has been compared with experts' opinions showing an average error of 2.04 % ±1.9%.

Keywords
Ranking, computed tomography(CT), QFD

1. INTRODUCTION
From a consumption standpoint, there is considerable evidence that individuals find ranked lists informative and influential. Consumers often choose goods and services based on a product's inclusion in a ranked list[1]or on its direction of movement on the list[2].In the health care sector, there are considerable ranking organizations for benchmarking and evaluating hospitals such as United States and world news (U.S. News & World Report) [3], Go Local Worcester Contributor [4],Axial Exchange and Becker's Hospital [5] and The Medical Travel Quality Alliance (MTQUA)[6].

Most of these ranking sites depend on the opinion of patients and doctors taking into considerations criteria such as medical quality and outcomes, value for safety, patient safety and security, website and management. Such method are very common but are not accurate.Go Local Worcester[4]Contributor conducted a survey through asking a random sample of patients to give feedback about topics involving how well nurses and doctors communicated, how responsive hospital staff were to patient needs, how well the hospital controlled patients' pain, and the cleanliness and quietness of the hospital environment.Axial Exchange and Becker's Hospital Review[5]ranked 3,077 U.S hospitals' based on statistical analysis collected from patient engagment data. They used four main criteria ;Readmissions (25%), Patient satisfaction (25%), Patient education and self care tools (25%) and Social media engagement (25%).theMedical Travel Quality Alliance (MTQUA) [6]provides tourists with international hospital ranking for tourists through an extensive review of each hospital's programs and protocols that affects medical tourists including the quality and effectiveness of their international and internal patient communication, marketing, website and social media activities; their external partnerships and alliances; internal care management protocols; and attention to patient safety, security and privacy. The aim of this paper isto design a mathematical system for ranking and evaluating the CT departments in hospitals based on qualitative as well as quantitative measurements from both the hospital and department itself. The direct impact of this system is improving the healthcare sector in developing countries.

There are several decision making approachsthat are considerabliy used in ranking such as analytic hierarchy process (AHP), fuzzy logic and Quality Function Deployment QFD [7-14].In a recent work we have showed that fuzzy logic approach is efficient in ranking hospitals [our fuzzy paper[15]]. However, theuse of QFD in the healthcare ranking is very rare. It is used in fields outside the field of healthcare; such as auto companies; to determine the requirements that the consumers need to achieve. However, it can be used to carefully connect the hospital requirements and the requirements of the patient in order to achieve them. Therefore, this decision making technique was used to build the proposed ranking model. The model output was verified by relevant expertise. In the proposed model, the four main quantitative criteria power stability, device performance, specifications and safety in a CT department were used..

2. METHODOLOGY
Quality Function Deployment was developed by Professor Yoji Akao Emeritus of the Tokyo Institute of Technology in Japan in 1966. By 1972 the power of the approach had been well demonstrated at the Mitsubishi Heavy Industries Kobe Shipyard[16]and in 1978 the first book on the subject was published in Japanese and then later translated into English in 1994[17] .QFD consists of four phases; Phase 1, Product Planning (house of quality), Phase 2, Product Planning , Phase 3, Process Planning and Phase 4, Process Control). Phase one (house of quality) is the main phase and is the most important one.

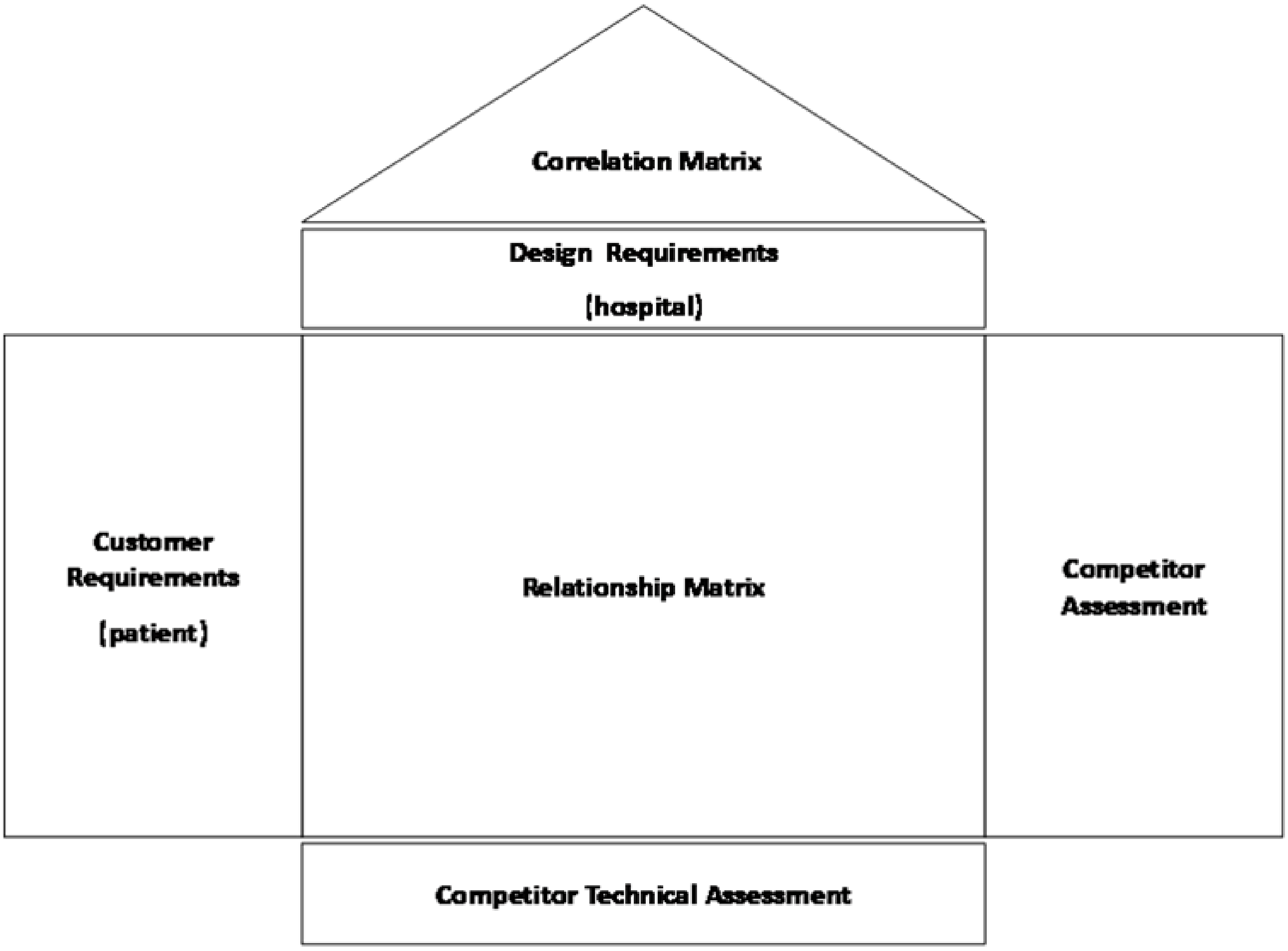

Figure 1 House of quality

3. HOUSE OF QUALITY

House of quality is the primary planning tool used in QFD. The QFD matrix consists of six parts as shown in Figure 1. It uses a matrix format to link between the customer requirements (patient requirements) and designer requirements (hospital requirements) to achieve the patient requirements by assigning values between 0 and 10(the standard values for the QFD technique).

The simplest but widely used QFD model contains only (four phases); the customer requirements and their relative importance, designer measures and their relationships with the customer requirements and Competitor Technical Assessment. Some models include also Competitor Assessment and Correlation Matrix.

Generally, the patient requirements starts with constructing a list of product claimant as voiced of the patient. In our proposed model, the customer requirements include 8 main criteria; power stability, specifications, level of care, professionalism, environment, device, safety and level of cleanness, with customer importance ratings from 1 to 5.

The hospital requirements are the requirements needed by hospital to achieve the requirements of patients in CT department. In our model, the hospital requirements include mainly quantitative parameters such as power line resistance, ground resistance, area, location, lighting, leakage and down time. The relationship matrix is used to represent graphically the degree of influence between each technical descriptor (hospital) and each customer requirement (patient) by using values between 0 and 10 according to the strength of the relationship between each of the patient requirement and hospital requirement.

4. CONSRTUCTING THE MODEL

The proposed model is mainly constructed from two stages : first stage includes three phases(customer requirements, designer requirements and relation matrix) and second stage include one phase(Competitor Technical Assessment); In the first stage we set the matrix linking the customer's requirements and the requirements of the designer as shown in Figure 2.

Customer Requirements (What):	Customer Importance Rating	Functional Requirements (How): ground resistance	UPS	main cable material	power line voltage	power line resistance	Area	flooring	Door	Window	Corridors	Location	Lighting	O2 line	crash cart	Anesthesia machine	PACS	RIS	Technicians	Air condition	Tests before installing	Maintenance	Calibration	Filtration	Soft ware tools	Leakage	Fire alarm system	Emergency switch	Infection control	[illegible]	down time
Power stability	4	10	10	10	10	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
specifications	3	1	1	1	1	1	10	10	10	10	10	10	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Level of care	3	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
professionally	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	1	1	1	1	1	1	1	1	1	1	1	1
Environment	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	10	1	1	1	1	1	1	1	1	1	1	1
Device	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	10	10	1	1	1	1	1	10
safety	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	10	10	10	10	1	1
level of cleaness	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	10	1

Figure 2.Part one of the model

4.1 Custmer requirements for CT departments

In this proposed model we put the (customer) requirement (patient requirements) were put to cover all the needs of the client (these needs determined by 57 experts, each expert put weight value from 0to five for each requirement then we take average for each requirement). One of the most important requirement issues is the power stability of the department which protects which is important to keep the device from any sudden increase in electricity. In addition, it continues the operation of the device in the event of a power failure using uninterruptible power supply (UPS). Specifications of the department include the requirements in and dimension of the room as well as access to the department and accommodation patient's trolley. The level of care term means to what extent the department is well prepared for taking care of patients. This include the existence of anesthesia or anesthesia cart and emergency oxygen line in the room[18, 19]. Experience and professionalism of subjects operating the CT devices is very important criteria in ranking. It is, also, a crucial point to have a system of transferring and archiving patient information. Environmental criteria is concerned about the heat exchange and air flow within the department to ensure that the CT devices are working well and providing good atmosphere for patients and technicians. Device is a major element in the Department of CT scan. Several factors affect the efficiency of the device such as filtration, and regular maintenance for the device. Safety concern is the most important requirement of the client's requirements as it relates to patient, device and personal working in the department so it takes the highest rating value of importance. The safety criteria include how well the department is isolated and protected from leak of radiation and the emergency fire-fighting system.

The weights of Patients needs are determined by surveying the opinions of 57 experts from diverse of ray technicians and radiologists and biomedical engineers specialize in CT devices working in 30 hospitals. Participants have been asked to give a weight value for each requirement and the average weights are calculated and used in our model as shown in table 1.

Table 1. Customer requirements and its importance rating.

Customer Requirements	Customer Importance Rating
Power stability	4
Specifications	3
Level of care	3
Professionalism	3
Environment	2
Device	4
Safety	5
Level of cleanness	2

4.2 Designer Requirements For CT Department

In this model, designers are considered to be the hospitals which have requirements that must be connected and consistent with the patient requirements. In such aspect, 57 experts from diverse of ray technicians and radiologists and biomedical engineers specialized in CT devices have been asked to put the hospital requirements. Table 2 shows these requirements for the hospitals. The 57 experts were, then, asked to put values for the relation matrix that link between the patient and hospital requirements.

Table 2. The designer requirements and the description of them.

Designer requirement	Description
Ground resistance	Ground resistance is opposition of the earth to the flow of current through it; its standard value is 0.1 Ohm [20].
Uninterruptible Power Supply (UPS)	UPS is an electrical device that provides power when the input power suddenly stop[21, 22]. The power of the UPS should be consistent with the power of the device
Main cable material	A main cable is made up of copper [20].
Power line voltage	It is the power supply line to the CT device which should be 400 volts [20].
Power line resistance	Power line resistance is the impedance that is present in the line which hinders the passage of electric current in the cable; its standard value equal 0.17 Ohm [20].
Area	Area of the department is an important sub-criteria; its standard value is $30m^2$.
Flooring	The floor of the CT's room should have standard specifications and strong enough to support device and table of the device which can carry patients weighing more than 200 kg [20].
Door	The door of the department should not be centered with the table end but offset in order to allow direct entrance of a stretcher along a line parallel to the table, its standard value equal 140 cm.[20].
Window	Windows in CT department should have built-in lead protection equivalent to that of the surrounding walls. ; Its standard value is function of the window dimension and its angle.
Corridors	Corridors leading to the department should allow easy and safe access of all patients, including handicapped or injured. Its standard value equal 150 cm (calculated from the survey Which was conducted from57 expert).
Location	The location of the department should be on the ground floor and with good access to all departments.
Lighting	Lighting should cover the entire area of the CT department.
O2 line	The existence of oxygen line in the CT scan room is important and necessary to care patients that need anesthesia.
Crash cart	The existence of crash cart is essential for emergencies and patients in ICU [23, 24].
Anesthesia machine	Anesthesia device in the CT scan room is important and necessary especially for patients in intensive care and kids.
PACKs	Packs are system for storage and transfer of CT images [25].
Radiology Information System (RIS)	RIS is software system for storing patient information and set up a file for each patient[26, 27].
Technicians	Radiology technicians a very important element in the Department.
Air condition	Keeping the CT device at low temperature value (normally 20° C) is very essentials for better performance.

Tests before installing	All CT devices should go through many tests to accept its operation. [28].
Maintenance	Regular preventive maintenance is crucial to maintain the device working efficiently [28].
Down time	It is the total time during the course of the year that the CT device is working efficiently.
Calibration	Calibrating the device according to the manufacturers' recommendations is very important for better performance [28].
Filtration	Filtration is filtering the image from any noise affecting the image quality and purity[29].
Soft ware tools	Software packages provided with the CT device facilitate the calculations and examinations to the CT technicians. [30].
Leakage	Leakage is radiation leakage that seeps from the walls of a CT scan device room[31, 32].
Fire alarm system	The existence of fire alarm system and keeping it working properly is very important issue in providing safety for the department.[20].
Emergency switch	Emergency switches and the distribution of them in the department is very essential and crucial for safety concerns.
Infection control	Infection control units responsible for the protection of patients and employees from any transmission of infection [33, 34].
Finishes/walls	Finishes and walls and the cleanliness of the CT department are very important for ranking.

The ranking value of the hospital is calculated by summing up the raw score values shown in Table 3. Raw score calculated by multiplying the values of customer importance rating by the values in each box of the matrix then summing up the values in each column.

The maximum value that can any hospital reaches is equal to 1743 points (The sum of the numbers in the top row in Table 3.). Based on that, so the grade of the hospital's CT department would be:

$$\text{Grade of department}=\frac{measuredvalueindepartmentpoints}{1743\ points}\ \%\quad(1)$$

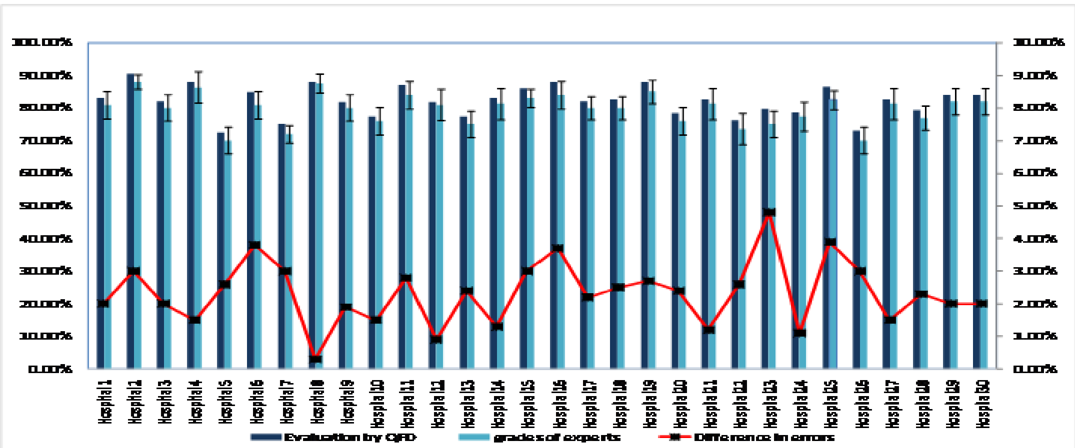

Figure 3. Model assessment by experts grades for 30 CT departments and the percentage of error between them.

Table 3. Part two of the mode

Rank	Raw score
5	62
5	62
5	62
5	62
5	62
16	53
16	53
16	53
16	53
16	53
16	53
16	53
16	53
16	53
16	53
16	53
16	53
16	53
29	44
5	62
5	62
5	62
5	62
5	62
1	71
1	71
1	71
1	71
29	44
5	62
	1743

5. RESULTS AND DISSCUSION

The proposed model have been applied on 30 CT departments at different hospitals in Egypt. To validate the output of the proposed QFD system, we compared it with the experts evaluation for these departments. To validate the output of the proposed QFD system, we compared it with the experts evaluation for these department (Figure 3). 150 experts participated in the evaluation process, in average 5 for each hospitals. 30 out of these participants have been chosen to be doctors with an average of 8±1.287 years of experience in the radiology field, 60 to be clinical engineers working in the radiology field with an average experience of 13±2 years and 60 to be CT scan technician working in the radiology field with and average experience of 18±2 years.

The results shows an average error in the difference between our system output and the experts ranking is 2.04 ±1.9 with maximum error of 4.8%.The reason for this peak error in hospital No. 23 is that experts assigned less value for infection control criterion than the value set by the QFD model. This small error differences verifies the reliability of our proposed model and approves the generated rules of the system which conform to opinions and suggestions of experts.

Also we can see that the standard deviation of the averaged experts' decisions did not exceed 5% which indicates the seriousness and quality of experts involved in the evaluation.

6. CONCLUSIONS

A mathematical model based on quantitative and qualitative measurements using QFD methodology have been provided. The model links between the patient's needs and the hospital needs to provide better higher quality medical service to the patient. The model, also, helps both the patient and the hospital. It helps the hospital to know the shortcomings in CT department to work on its improvement. It helps the patient to make a better CT department selection. This model is scalable and can be implemented for different departments in any hospital and especially in developing countries where there is no systems to sort and evaluate hospitals, leading to the development and improvement of the health sector.

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