Computers in Industry 74 (2015) 1–15

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

Analyze the healthcare service requirement using fuzzy QFD

C.K.M. Lee [a,*], Chloe Tan Ying Ru [b], C.L. Yeung [a], K.L. Choy [a], W.H. Ip [a]

[a] Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hong Kong, China
[b] School of Mechancial and Aeropsace Engineering, Nanyang Technological University, Singapore

ARTICLE INFO

Article history:
Received 29 November 2014
Received in revised form 8 August 2015
Accepted 12 August 2015
Available online 16 September 2015

Keywords:
Quality function deployment (QFD)
Fuzzy logic
Healthcare service quality
Service quality improvement
Singapore healthcare industry

ABSTRACT

Research on the adoption of fuzzy logic in healthcare diagnostic system to oversee the process performance and recognize certain predefined patterns has been conducted for associating the well-known problems using the rule-based approach technique. Even though a couple of medical applications such as those described above had shown generally proven results, the literature regarding applying fuzzy logic in healthcare delivery remains modest and the application of fuzzy logic to healthcare services had been rare. Applying fuzzy logic in healthcare services is still a mostly untapped region, especially collecting the voice of customer. Coupled fuzzy logic with QFD in healthcare services enables medical practitioners to understand customer requirements and include them for continuous improvement during the health service delivery. A fuzzy QFD approach for analyzing healthcare service requirement is proposed and realized through a case study. It is realized that the proposed approach can adjust service quality toward customer requirements.

1. Introduction

From recent national strategy in US, providing better care is one of the main aims for quality improvement in healthcare. Apart from improving the quality of healthcare, it attempts to convert healthcare to more patient-oriented, making it more reliable, accessible and safe [1]. This situation is not only prevalent in western developed countries, but also some Asian regions such as Singapore [2,3] and Hong Kong [4]. An increasingly dominating policy agenda of a developed country is to provide more than adequate healthcare services for its people. With the challenges of escalating healthcare cost due to improved technology and an aging population [5], a robust long-term healthcare system has to be developed. The rapidly growing demand for healthcare services is identified as a key challenge to the states. The necessity of getting "the economics of healthcare right" has been further emphasized [6]. The demand of healthcare services is increasing nowadays under the situation with restricted resource. This is an urgent need to investigate and identify the critical components of healthcare services and thus delivering the effective healthcare services to the recipients.

This study aims to explore and understand the customer requirements of the present healthcare services and then to decide the optimum portfolio of the healthcare services. By adopting Quality Function Deployment (QFD) and fuzzy logic, this study proposes a new approach to support the decision making process in healthcare industry. It provides a framework for analyzing the technical requirements that can lead to the synthesis of a customer-oriented system. It also transforms the inherent vagueness of the human perceptions to be as precise as possible so that they become valuable information for the analysis of the system. Due to the well development of Singapore's healthcare system in the world [2], this study is centered on healthcare system with focus on the quality of services provided by the hospitals in Singapore. As public hospitals in Singapore hold a central position in the health care system which is a key for understanding the country's performance in this sector, public hospitals in Singapore are then selected as the main area for investigation.

2. Research background

Nowadays medical treatments are no longer the only concern for patients in healthcare industry. Patients pay increasing attention in their safety and comfort [7,8]. Although many studies have been conducted in healthcare services, the term of healthcare service has yet clearly defined. A review of healthcare service definitions from [9–12] is conducted. Healthcare service can be summarized as the management or treatment of any health

* Corresponding author at: Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, EF617 The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China
E-mail address: ckm.lee@polyu.edu.hk (C.K.M. Lee).
URL: http://www.polyu.edu.hk/

http://dx.doi.org/10.1016/j.compind.2015.08.005
0166-3615/

problem through the services that might be provided by medical, nursing or any other relating health institutions. Its importance to the functionality of an individual, community or society as a whole cannot be undermined. The healthcare delivery is a patient-oriented service industry [7]. Hospitals are not only required to provide medical care but also expected to address the issue of improving customer satisfaction. These challenges are not only encountered by hospitals in the private sector. In fact, with heightening expectations from the citizens, public hospitals are also required to constantly upgrade and place themselves in the match for a truly reliable healthcare system for all. For hospitals in general, their aims are to ensure good service quality with high safety standard, increase healthcare service efficiency and competitive advantage to meet the ever increasing demand of patients and eventually increase customer satisfaction level.

Researchers developed different approaches in ensuring patients' safety and enhancing patients' comfort so as to provide quality services in healthcare industry. For example, different hardware, software and sensors are integrated into current healthcare processes to ensure accurate and prompt information can be obtained [13–17]. Recent studies in healthcare industry predominantly obtain positive results after adoption of Information Technology. It is not limited to computer-based diagnostic or monitoring systems [18]. Physical environment design in healthcare [19,20] and user satisfaction analysis [21,22] is also alternative approaches to facilitate the delivery of healthcare services. To support continuous quality improvement in healthcare industry, it is vital to pay attention to users' requirements and obtain feedback regarding their satisfaction [18]. Current user satisfaction analyses reply on conducting interview or survey to collect requirements or feedback from users or customers. [23,24] developed questionnaires and interviewed respondents in order to understand patient satisfaction in service quality in healthcare industry. It can identify what service quality dimensions affected user satisfaction. However, it cannot provide specific approaches or recommendations for improvement based on the degree of user satisfaction. Fuzzy AHP were adopted to evaluate the service quality in healthcare industry [25,26]. Domain experts or researchers are invited to participate in the evaluation. The voice of customer has not yet considered. [26,27] indicated that perceptions from service users are important to healthcare service quality improvement. Current approaches have limited support to convert qualitative user demands to quantitative parameters. This study attempts to investigate a method which can transform customer requests to specific requirements for quality improvement.

QFD has a long history and a wide range of application domains [28]. It is regarded as a useful tool for quality planning, continuous product improvement and decision making. It is a methodology with a systematic framework to convert the customer requests into design or engineering characteristics, and then into specific plans and production requirements, related to its manufacturing processes [29]. It can act as a conceptual map for inter-functional planning and communication [30]. QFD is capable of facilitating decision making approach. Apart from determining proper co-design systems for specific context in product design in SMEs [31], it also has the potential to assist the development of a structured and systematic method to facilitate the decision making process with appropriate adoption and extension and also aid its implementation [32]. As such, QFD found its applicability in the service industry as well, especially in healthcare domain [33]. The integration of QFD to design impressive qualities for healthcare service is done by translating customer perspectives into the regular service planning. Managerial staff in healthcare services can recognize and prioritize what customer needs through QFD [34,35]. The applications of QFD on hospital services unveil customer needs, therefore making modifications on vital services, and meeting customer satisfaction [35,36]. Existing QFD which is manual approach has several limitations such as long implementation time and subjective decision aid. Also customer opinions or preferences are presented in terms of numeric or linguistic which are subjective, vague and imprecise [37]. QFD is not adequate to interpret fuzzy human language and convert it to technical requirements. One of the quantitative methods, fuzzy logic can be integrated with QFD to generate a more precise and objective approach for the implementation.

Fuzzy logic has been widely used to handle real-life problems which are subjective, vague, and imprecise in nature [32,38]. Apart from handling challenges such as process control and optimization, scheduling and forecasting in manufacturing industry [39], fuzzy logic has different applications in rule-based expert systems. Compared with traditional rule based approach which selects one rule over another, fuzzy if-then rules provide rooms for redundant or overlapping rules to solve complicated human problems in the world [40]. Linguistic variables also can help computer to handle problems related to human language [41]. Compared to numerical variables whose values are numbers, the notion of linguistic variables can be regarded as a variable whose values are fuzzy numbers [42]. The application of linguistic variables had been tested as it was used to develop a non-structural fuzzy decision support for layout planning on site and has since shown its reliability even under the condition of insufficient precise information [43]. Fuzzy QFD has been used in supply chain industry since 2000. [44] adopted fuzzy QFD to change reliability consideration into fuzzy relationship. Fuzzy QFD was also used in supplier selection [45] and strategic selection [46]. In recent years, fuzzy QFD has been applied in licensor selection [47], manufacturing strategy development [48] and market segments evaluation and selection [49] respectively. Fuzzy QFD has demonstrated good performance in handling problems regarding human expressions, selections or decisions in different industries.

In the field of health services, research had been done on the adoption of fuzzy logic in healthcare diagnostic system to oversee the process performance and recognize certain predefined patterns that are related to well-known problems using the rule-based approach technique [40]. Fuzzy application has been applied for the epidemiology of sleep disorders [50] and intelligent patient monitoring system [40]. Both applications had proven the reliability of fuzzy logic and are capable of enhancing performance. It also provides the flexibility of maintenance [40]. Even though a couple of medical applications such as those described above had shown generally proven results, the literature regarding applying fuzzy logic in healthcare delivery remains modest and the application of fuzzy logic to healthcare services had been rare. Applying fuzzy logic in healthcare services is still a mainly untapped region, especially collect the voice of customer; it performs a great promise for increasing the efficiency and reliability of healthcare delivery [51]. As such, there exists a valuable area of research on using Fuzzy QFD on healthcare services to establish an effective service quality improvement project.

3. Fuzzy QFD approach to analyze the healthcare service requirement

The three major steps of conducting fuzzy QFD approach to analyze the healthcare service requirement are described below.

Step 1: Identify customer requirements and related technical requirements that influence the performance and satisfaction of the service.
Step 2: Understand current satisfaction levels and importance of the customer requirements by using fuzzy linguistic variables and fuzzy weighted average together with correlating customer requirements to technical requirements.
Step 3: Use fuzzy inference system to generate rules for service improvement.

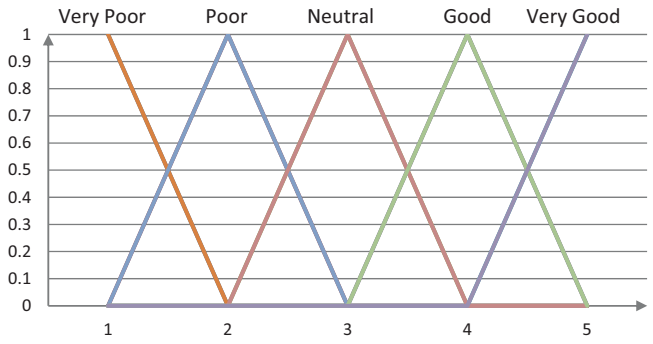


Fig. 1. Linguistic terms and the satisfaction value.

The proposed approach adopts one of the QFD tools, House of Quality (HOQ), to transfer customer requirements to technical requirements. The detailed steps of HOQ can be found in [52,53]. In step 1, customer requirements of the selected healthcare service are identified. Then, corresponding technical requirements which are the ways to satisfy customer needs are listed. In step 2, a survey is designed to collect customer perceptions regarding current satisfaction levels and importance of the customer requirements. Fuzzy linguistic variables are adopted to assign the importance of customer requirements and technical requirements. However, these linguistic variables are rather ambiguous and it can have a number of meanings to it. Therefore, the information obtained is converted to a range of fuzzy set. By adopting the triangular fuzzy numbers, the vagueness of fuzzy linguistic terms are captured, and the subjectivity and conflicting assessment of the numbers are represented. In the fuzzy QFD, the set of five-linguistic labels is used due to the convenience of allowing the observer to give us an insight of their perception in the survey. Linguistic terms such as "very poor", "poor", "neutral", "good", "very good" are used to determine the satisfaction level of the customer requirements as shown in Fig. 1. The linguistic terms are further translated into triangular fuzzy numbers as shown in Table 1.

After that, an average triangular fuzzy number from q fuzzy numbers is computed. The importance weightings of the customer requirements and technical requirements are being assessed by a sample of q individual members based on their experience. The q_j member gives the weighting for the ith customer requirements, $\tilde{w_{cij}} = (w_{c1}^{ij}, w_{c2}^{ij}, w_{c3}^{ij})$, and this member also gives the weighting for the ith technical requirements, $\tilde{w_{ti}} = (w_{t1}^{ij}, w_{t2}^{ij}, w_{t3}^{ij})$. Hence,

$$\tilde{w_{cij}} = \frac{\sum_{j=1}^{q} w_{cij}}{q} = \frac{\left(\sum_{j=1}^{q} w_{c1}^{ij}, \sum_{j=1}^{q} w_{c2}^{ij}, \sum_{j=1}^{q} w_{c3}^{ij}\right)}{q} = \left(w_{c1}^{i}, w_{c2}^{i}, w_{c3}^{i}\right) \quad (1)$$

$$\tilde{w_{ti}} = \frac{\sum_{j=1}^{q} w_{cij}}{q} = \frac{\left(\sum_{j=1}^{q} w_{t1}^{ij}, \sum_{j=1}^{q} w_{t2}^{ij}, \sum_{j=1}^{q} w_{t3}^{ij}\right)}{q} = \left(w_{t1}^{i}, w_{t2}^{i}, w_{t3}^{i}\right) \quad (2)$$

Table 1
Linguistic terms and corresponding fuzzy numbers on satisfaction value.

Linguistic term	Fuzzy number
Very Poor	(1, 1, 2)
Poor	(1, 2, 3)
Neutral	(2, 3, 4)
Good	(3, 4, 5)
Very Good	(4, 5, 5)

Where q is the total number of individual member, $\tilde{w_{cij}}$ is the importance weighting of the ith customer requirement, $\tilde{w_{ti}}$ is the importance weighting of ith technical requirement.

The strength of the contribution of jth technical requirement on ith customer requirement will be judged according to the individual member's perception. Each individual member will assign the degree of correlation of the technical requirements to the customer requirements, $\tilde{c_{ij}} = (c_{ij1}, c_{ij2}, c_{ij3})$. Hence,

$$\tilde{c_{ij}} = \frac{\sum_{k=1}^{q} c_{ij}^{k}}{q} = \frac{\left(\sum_{k=1}^{q} c_{ij1}^{k}, \sum_{k=1}^{q} c_{ij2}^{k}, \sum_{k=1}^{q} c_{ij3}^{k}\right)}{q} = (c_{ij1}, c_{ij2}, c_{ij3}) \quad (3)$$

where q is the total number of individual member, c_{ij} is the strength of contribution of jth technical requirement on ith customer requirement assigned by q individual members.

Triangular fuzzy numbers are retranslated into linguistic terms. For example, the fuzzy number $\tilde{B} = (b_1, b_2, b_3)$, can be transformed into the crisp number by the following equation [54]:

$$x = \frac{(b_1 + 2b_2 + b_3)}{4} \quad (4)$$

The linguistic term, A, can be represented as the fuzzy number, $\tilde{A} = (a, b, c)$ where $a \le b \le c$. The approximate linguistic term A is the fuzzy number $\tilde{B}$ and can be computed by Eq. (5), where x is the crisp number transformed by Eq. (3) and $\mu_A(x)$ represents the possibility of fuzzy number, $\tilde{B}$ as the approximate linguistic term A.

Supposed that the fuzzy set, $A = \left\{\sum_{i=1}^{n} \frac{\mu_A(x)}{A_i}\right\}$, represents the possibility that the fuzzy number $\tilde{B}$ is the approximate linguistic terms of $A1$, $A2$,..., An. The triangular fuzzy number $\tilde{B}$ can be translated into the linguistic terms Ak, where $1 \le k \le n$, when

$$\frac{\mu_{A_k}(x)}{A_k} = Max\left\{\sum_{i=1}^{n} \frac{\mu_{A_k}(x)}{A_i}\right\} \quad (5)$$

Fuzzy weighted average is used to calculate the customer satisfaction index ($\tilde{CSI}$), and technical requirement weightings for customer satisfaction ($\tilde{WCS}$) using the following equations.

$$\tilde{CSI} = \frac{\sum_{i=1}^{m} \tilde{cs_i} \tilde{W_{ci}}}{\sum_{i=1}^{m} \tilde{W_{ci}}} \quad (6)$$

$$\tilde{WCS} = \frac{\sum_{i=1}^{m} \tilde{W_{ci}} \tilde{c_{ij}}}{\sum_{i=1}^{m} \tilde{W_{ci}}} \quad (7)$$

where m: total number of customer requirements; $\tilde{cs_i}$: the strength of satisfaction degree of ith customer requirement; $\tilde{W_{ci}}$: importance weighting of the ith customer requirement; $\tilde{c_{ij}}$: the strength of contribution of jth technical requirement on ith customer requirement.

Correlating customer requirements to technical requirements are conducted. Detailed results are shown in Section 4. Several calculations are needed to facilitate the correlation. Improvement ratio in Planning Matrix is calculated by Eq. (8). The setting the Goal is a crucial strategic step in QFD. The more aggressive the Goal compared to the current Customer Satisfaction Performance, the larger will be the Improvement Ratio. The technical priorities in Technical Matrix are related to the raw score and the relative percentage. They can be directly computed from the weightings indicated in the planning and interrelationship matrix sections. Each interrelationship weighting is multiplied by the importance rating of the customer requirement. The raw score for each technical requirement are calculated by summation of the calculated values in the columns. The relative percentage is calculated based on the entire raw score obtained of the technical requirement. When the technical requirements have

been prioritized, the final step is to identify the importance rating of the technical requirements. The final section of the HOQ matrix attempts to summarize the conclusion drawn from the data contained in the entire matrix. QFD assists producers or providers to identify technical areas to focus on where the most customer satisfaction can be derived by setting the target specifications that should be achieved. At least, current performance standards should be maintained.

$$\text{Improvement Ratio} = \frac{\text{Goal}}{\text{Customer Satisfaction Performance}} \tag{8}$$

In step 3, fuzzy inference system is used to reason the strength of the overall component characteristics contributions to each customer requirement and each technical requirement. It formulates the mapping of a given input to an output using fuzzy logic. This process forms a foundation, from which decisions can be made, or patterns discerned, and it entails the complete workings of the Membership Functions, Logical Operations, and the If-Then Rules. To determine the applicability of rules in a rule-based system, either the composition or the compatibility modification inference method is employed [55]. The composition is a generalization of binary logical deduction to fuzzy logic, whereas, the compatibility modification is used to support the evaluation of rules by assessing the degree to which the input matches the antecedent of a rule from the output and then combined with the consequent of the rule to generate the output. In retrospect, Cross and Sudkamp [53] had come up with a suggestion that allows the introduction of a threshold τ for the compatibility modification inference system to determine the applicability of rules. As customers would only be satisfied only when the products or services achieve their requirements, this rationale can be applied to infer the strength of the overall contribution of each technical requirement to each customer requirement, and to allow the firing of only those technical requirements that achieve or surpass the customer requirements. Assume that there are n technical requirements responsible for fulfilling the ith customer requirement, the fuzzy set of technical requirements contribution on satisfying the ith customer requirement is represented as

$$\tilde{CS_i} = \left\{ \sum_{j=1}^{n} \tilde{cs_{ij}} \right\} \tag{9}$$

where n: total number of technical requirements; $\tilde{cs_i}$: the strength of satisfaction degree of ith customer requirement; $\tilde{cs_{ij}}$: the strength of contribution of jth technical requirement on ith customer satisfaction.

Based on this supposition, the inference system has to predetermine threshold $(\tilde{\tau})$. The predetermined threshold $(\tilde{\tau})$ is the fuzzy number $\tilde{3}$, which means that only the strengths of the technical requirements contributions to customer satisfaction $\tilde{cs_{ij}}$ which achieve or surpass the 'neutral' strength, are capable of improving the satisfaction of the ith customer requirement. Eq.(10) is then being stated. Then, it computes the strength of the overall technical requirements contributions to the ith customer requirement and translates the fuzzy numbers, $\tilde{cs_i}$ into linguistic terms.

The strength can be computed by Eq. (11).

$$\tilde{CS_i} = \left\{ \tilde{cs_{ij}} | \tilde{cs_{ij}} \geq \tilde{\tau}, \quad j = 1 \ldots . n \right\} \tag{10}$$

$$\tilde{cs_i} = \frac{\sum \tilde{cs_{ij}}}{n} \tag{11}$$

where n: total number of $\tilde{cs_{ij}}$ in the vector $\tilde{cs_{ij}}$; $\tilde{\tau}$: the predetermined threshold; $\tilde{cs_i}$: the strength of satisfaction degree of ith customer requirement; $\tilde{cs_{ij}}$: the strength of contribution of jth technical requirement on ith customer satisfaction; $\tilde{cs_{ij}}$: the strengths of the technical requirements contributions to customer satisfaction $\tilde{cs_{ij}}$ which achieve or surpass the 'neutral' strength.

4. Case study

The proposed method has been trial implemented into the healthcare services in Singapore. Due to the fact that public hospitals in Singapore play a key role in delivering healthcare services to citizens, it has been chosen as the main area for investigation. Data collection and analysis regarding patients requirements and expectations were conducted through literature review including World Health Organization Key Informant Survey, World Health Organization reports and healthcare publications [56–64,69]. Apart from understanding the healthcare performance in this sector in Singapore and other countries, it also helps to generate valuable lessons and insights for the world to improve their healthcare services. Information on the hospital service flows, and the various important aspects of services which would have significant influences on the customer satisfaction of healthcare services are identified and categorized into five main categories as shown in Table 2.

These five main categories are established based on the elements that can be defined from the customer experience in the hospital. Hence, the elements in the categories are the factors that patients are familiar with and can be judged easily by the patients or the public who used the healthcare services in the hospital before. Other factors such as the hospital environment, safety and cleanliness had been omitted because they had reached one of the world's highest standard in Singapore and are no longer the main concern of an even better healthcare system. All of which would make up the basis of customer requirements in search of a good healthcare service. After identifying customer requirements, technical requirements which are methods to improve the situations or meet the customer requirements are needed to be defined. As this project attempts to improve the healthcare service quality in terms of patients' perspectives, technical requirements are constructed based on the services or information that closely related to patient's experience in the hospital under the five main defined customer requirements [56–64,69]. The technical requirements which would affect the performance and satisfaction of the healthcare services are listed in Fig. 2. For example, the general expectations of patients regarding healthcare provider's professionalism are that the staff who provide treatment should be professional in their work, provide clear explanation and instructions about patients' conditions and show care or concern to patients [56,57,61]. Form the patients' perspectives, doctors, pharmacists and nurses are the healthcare providers who mainly deliver healthcare services to them in the hospital. Technical requirements which are defined based on patient's expectations are the important criteria that influence performance and satisfaction of the healthcare services. From customer perspectives, doctors should do interrogation enquiry and give treatment skillfully. They should be kind and explain the patients' condition at great length before giving treatment.

Table 2
Customer requirements in healthcare services.

Customer requirements	
1	Ease of navigation around the hospital
2	Pleasing attitude of staffs
3	Healthcare provider's professionalism; Doctor's professionalism Pharmacist's professionalism Nurse's professionalism
4	Speediness of healthcare services
5	Quality of healthcare services

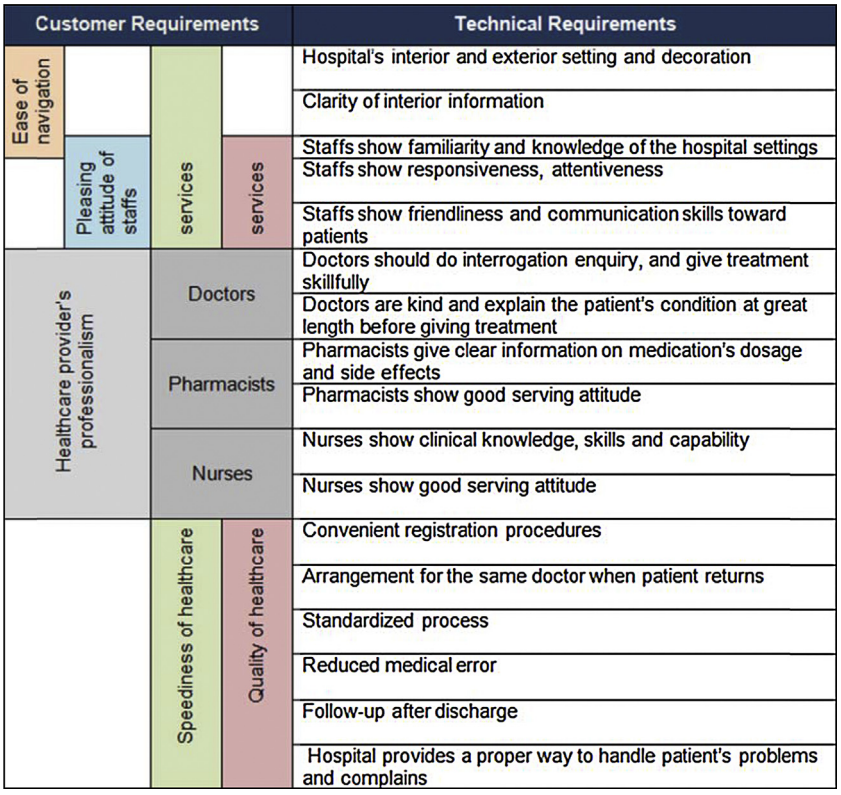


Fig. 2. Customer requirements and its corresponding technical requirements.

After identifying customer requirements and technical requirements, it is important to understand the current satisfaction of each customer requirement based on customer perspectives. Apart from this, individual customers have their own perspectives on the correlations between each customer requirement and technical requirement. Therefore, a group of service users of the hospital were invited to indicate current satisfaction level of each customer requirement and rate the correlations of each technical requirement to the corresponding the customer requirements. In order to facilitate the collection of users' perspectives regarding healthcare services in the hospital in Singapore, this study establishes a survey in the form of an online-questionnaire and Singapore residences are invited to participate in the survey so as to determine the perceptions of the citizens on healthcare services provided in Singapore's hospitals in general.

According to Department of Statistics Singapore, the total population in Singapore has been reached to 5 million including more than 3.7 million local residents since 2010 [65]. Based on the population size, 384 questionnaires are required to maintain 95% confidence level with 5% confidence interval. Apart from general public outside the hospital, this study invites healthcare service providers or staff in the hospital to randomly select the service users or visitors of the hospital to join the survey. Since the survey is conducted on a voluntary basis, the completion rate of the questionnaire is relative low (around 13%). After discarding incomplete questionnaires, fifty neatly completed questionnaires are obtained. The main objective of this survey is not to collect a large quantity of data. It attempts to find out the general perspectives from Singapore residents regarding current satisfaction level and importance of the customer requirements and the correlations of the technical requirements to the customer requirements. As the survey is conducted online, it implies that the respondents are capable of reading English and using computer so as to conduct the survey. The respondents would be Singapore residents with high educational level or the younger generation in Singapore. From the government statistics in Singapore in 2014, the proportion of Singapore residents with tertiary education increases from 36% to 51% over a decade [66]. This statistic will increase in the future as Singapore government encourages residents to have lifelong learning [67]. The better-educated residents will a higher knowledge of the healthcare services and lead to a higher expectation on the performance. They are also eager to express their views when compared with the elderly or persons with lower-educated profiles. For the younger generation, they are the future pillars of Singapore and will be the dominant groups who start to use the healthcare services in future 20 years. Their opinions are also valuable for long-term healthcare services improvement. Therefore, the perspectives from the highly educated residents and younger generation in Singapore are critical. This study attempts to conduct the first trial run of the proposed fuzzy QFD method to analyze the healthcare service requirements. Although the completion rate is low, the results of the survey are still appropriate for analyzing the healthcare services in the hospital in Singapore.

Background information regarding the respondents and whether the respondent had visited any hospital in the past twelve months are also inquired in the questionnaire. Thirteen questions including four questions which related to respondents' background and nine questions which related to individual's perception on healthcare services in Singapore's hospitals were set. Fifty respondents had completed the survey. The proportion of the male to female respondents for the survey is 3:2. As the survey was conducted online, respondents should have adequate English and computer skills in order to conduct the survey. This resulted in a relatively large portion of younger Singaporeans (86%) doing the survey and the education level of the respondents was mainly tertiary education (76%). It could mean they have a higher expectation on the performance and a higher knowledge of the

healthcare services. Of the fifty respondents, thirty-one had visited the hospitals while nineteen had not been to the hospitals in the past twelve months in Singapore. This indicates that the survey is mostly done by up of up-to-date respondents of the healthcare services in Singapore. Based on the results obtained from the survey, the weighted average satisfaction values (WASV) of the respondents are shown in Table 3. The respondents were also required to rank the importance of the customer requirements as shown in Table 4. The aim is to find out the more important factors that would affect the betterment of the healthcare service as a whole, and to give higher weighting for these factors. The quality of healthcare services and the professionalism of the doctors, pharmacists and nurses are important areas in the determinations of good healthcare services.

Respondents were required to rate the correlations of the customer requirements to the technical requirements. The information is useful in identifying the strength of the technical requirements on the customer requirements. Tables 5–8 show the correlations obtained from the survey. The mean values are the computed based on the result, and this value would signify the effect of each technical requirement on the customer requirement with a base value of nine. Respondents were also asked to select the more important factor when two options are given as shown in the Tables 9–11.

Table 3
Survey results (satisfaction level of healthcare services in Singapore).

Customer Requirements	Very Poor (1)	Poor (2)	Neutral (3)	Good (4)	Very Good (5)	Total	WASV
Ease of navigation around hospital	0%	0%	32%	62%	6%	100%	3.74
Pleasing attitude of staffs	2%	12%	38%	38%	10%	100%	3.42
Doctor's professionalism	2%	4%	20%	46%	28%	100%	3.94
Pharmacist's professionalism	0%	2%	32%	46%	20%	100%	3.84
Nurse's professionalism	0%	2%	24%	56%	18%	100%	3.90
Speediness of healthcare services	6%	34%	20%	36%	4%	100%	2.98
Quality of healthcare services	0%	2%	22%	52%	24%	100%	3.98

Table 4
Survey results (ranking of customer requirements).

Customer requirements	1	2	3	4	5	Total	Mean	Rank
Ease of navigation around hospital	64%	16%	2%	2%	16%	100%	1.90	1
Pleasing attitude of staffs	18%	40%	22%	16%	4%	100%	2.48	2
Healthcare provider's professionalism	4%	10%	31%	31%	24%	100%	3.61	4
Speediness of healthcare services	4%	28%	28%	26%	14%	100%	3.18	3
Quality of healthcare services	10%	6%	16%	26%	42%	100%	3.84	5

Scale: 1 – Least important; 5 – Most important.

Table 5
Survey results (correlations of technical requirement to ease of navigation around hospital).

Correlations of EASE OF NAVIGATION around the hospital to...	Not related (0)	Weak (1)	Medium (3)	Strong (9)	Total	Mean
Hospital's interior and exterior settings and decorations	10%	16%	56%	18%	100%	3.46
Clarity of interior information	0%	6%	34%	60%	100%	6.48
Staffs show familiarity and knowledge of the hospital settings	0%	6%	38%	56%	100%	6.24

Table 6
Survey results (correlations of technical requirements to pleasing attitude of staffs).

Correlations of the PLEASING ATTITUDE OF STAFFS to...	Not related (0)	Weak (1)	Medium (3)	Strong (9)	Total	Mean
Staffs show familiarity and knowledge of the hospital settings	6%	16%	54%	24%	100%	3.94
Staffs show responsiveness, attentiveness	0%	0%	38%	62%	100%	6.72
Staffs show friendliness and communication skills toward patients	0%	4%	22%	74%	100%	7.36

Table 7
Survey results (correlations of technical requirements to speediness of healthcare services).

Correlations of the SPEEDINESS of healthcare services to...	Not related (0)	Weak (1)	Medium (3)	Strong (9)	Total	Mean
Hospital's interior and exterior settings and decorations	22%	38%	36%	4%	100%	1.82
Clarity of interior information	12%	22%	46%	20%	100%	3.40
Staffs show familiarity and knowledge of the hospital settings	2%	20%	46%	32%	100%	4.46
Staffs show responsiveness, attentiveness	2%	16%	28%	54%	100%	5.86
Staffs show friendliness and communication skills toward patients	8%	24%	40%	28%	100%	3.96
Convenient registration procedures	0%	8%	28%	64%	100%	6.68
Arrangement for the same doctor when patients return	4%	22%	26%	48%	100%	5.32
Standardized process	0%	8%	38%	54%	100%	6.08
Reduce medical error	6%	18%	38%	38%	100%	4.74
Follow-up after discharge	4%	24%	42%	30%	100%	4.20
Efficiency in resolving complains	2%	22%	40%	36%	100%	4.66

Table 8
Survey results (correlations of technical requirements to quality of healthcare services).

Correlations of the QUALITY of healthcare services to...	Not related (0)	Weak (1)	Medium (3)	Strong (9)	Total	Mean
Staffs show familiarity and knowledge of the hospital settings	6%	18%	46%	30%	100%	4.26
Staffs show responsiveness, attentiveness	4%	8%	40%	48%	100%	5.60
Staffs show friendliness and communication skills toward patients	0%	6%	50%	44%	100%	5.52
Convenient registration procedures	0%	14%	48%	38%	100%	5.00
Arrangement for the same doctor when patients return	8%	10%	36%	46%	100%	5.32
Standardized process	2%	6%	50%	42%	100%	5.34
Reduce medical error	0%	4%	30%	66%	100%	6.88
Follow-up after discharge	0%	8%	42%	50%	100%	5.84
Efficiency in resolving complains	2%	10%	42%	46%	100%	5.50

After collecting and analyzing the survey data, HOQ is used to integrate the voices or opinions of the customer into the service provided. In HOQ, the correlations of customer and technical requirements at the interrelationship matrix are input according to the WASV in Table 3 and also based on the author's perception of whether the value gives a strong, medium, or weak correlation (Tables 5–8). The HOQ on healthcare services in Singapore is shown in Fig. 3. The relative percentage which is derived from the raw score gives a good overview of the role of every technical requirement in the HOQ, and these values are used to select the importance rating of the technical requirements. Thus, the focus of the HOQ is to find out the more significant technical requirements that would affect the overall quality of the healthcare service. At the planning matrix, the current satisfaction level is input from the data analysis which is a calculated average value of the results from the survey. The goal is based on the author's perceptions, and the improvement ratio is the output value. The improvement ratio features the proportion of the value of improvement to the value of the customer requirement.

Fuzzy inference system is utilized to achieve a more comprehensive analysis of the correlations of the technical requirements to the customer requirements based on the survey result. The Mamdani-type inference is the more widely used fuzzy methodology as it is based on Zadeh's research in 1973 regarding fuzzy algorithms related to complex systems and decision processes. This type of inference would first Fuzzify the inputs by determining the degree of fuzziness using the membership function, followed by applying the fuzzy operators which includes weighting the rules between 0 to 1, and finally it expects the output membership functions to be fuzzy sets in a single spike instead of a distributed

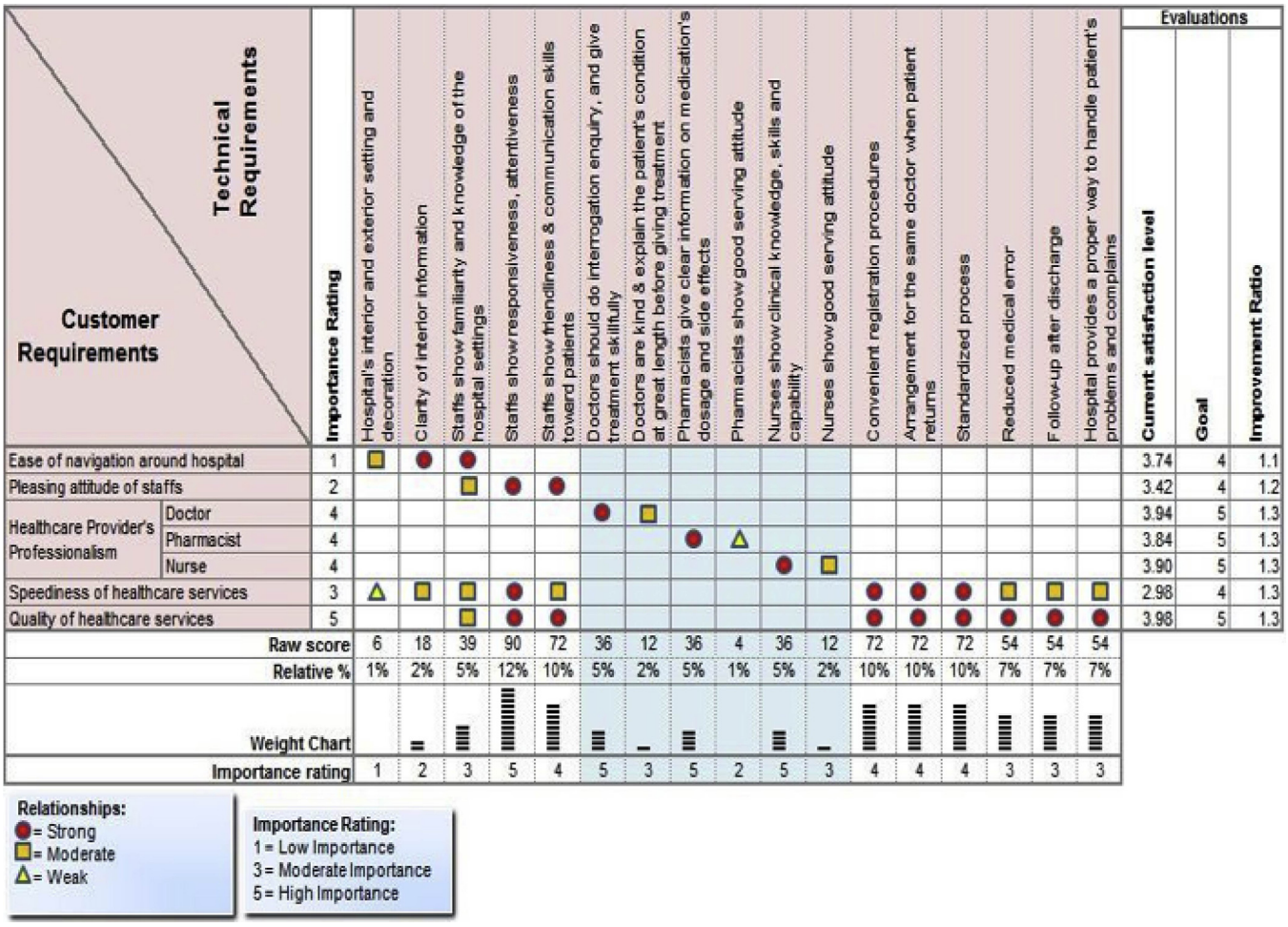


Fig. 3. HOQ on healthcare services in Singapore.

Table 9
Survey results (on professionalism of doctors).

Doctors should do interrogation enquiry and give treatment skillfully.	32	64%
Doctors explain the patient's condition at great length before giving treatment.	18	36%
Total	50	100%

Table 10
Survey results (on professionalism of pharmacists).

Pharmacists give clear information on medication's dosage and side effects.	48	96%
Pharmacists show good serving attitude.	2	4%
Total	50	100%

Table 11
Survey results (on professionalism of nurses).

Nurses show clinical knowledge skills and capability.	36	72%
Nurses show good serving attitude.	14	28%
Total	50	100%

fuzzy set, as it would improve the efficiency of the defuzzification process due to the great simplification of the computation requirement. In addition, it finds the centroid of a two-dimensional function rather than integrating across the two-dimensional function to identify the centroid. MATLAB is a high-end performance language interactive software which allows the user to perform complex computation, visualization, and to do programming in an user-friendly environment [68]. The Mamadani-type inference and MATLAB are used in this study. Fig. 4 shows the overview of fuzzy inference system. It includes three main components including membership function creation, rule generation and rule presentation.

In Fig. 4, different variables are required to define in fuzzy inference system. As the purpose of this project is to find out how the current healthcare services can be improved, the input would be the current satisfaction level of the customer requirement, and the output would be the technical requirements that affect the customer requirement. For example, the analysis of the satisfaction of customer requirement on the ease of navigation around the hospital and the corresponding technical requirements are hospital's interior and exterior setting and decoration, clarity of interior information and staffs show familiarity and knowledge of the hospital settings based on the HOQ as shown in Fig. 3. Table 12 shows the short forms of the technical requirements used in the fuzzy inference systems for convenience sake. The analysis of the rest of the customer requirements corresponding to their technical requirements is done in the same way.

The membership function creation displays and allows the creating of all the membership functions associated with the customer requirements and their related technical requirements. The range of the variables can be set, in which the satisfaction level of the customer requirement is set [0 5], whereas, the correlations

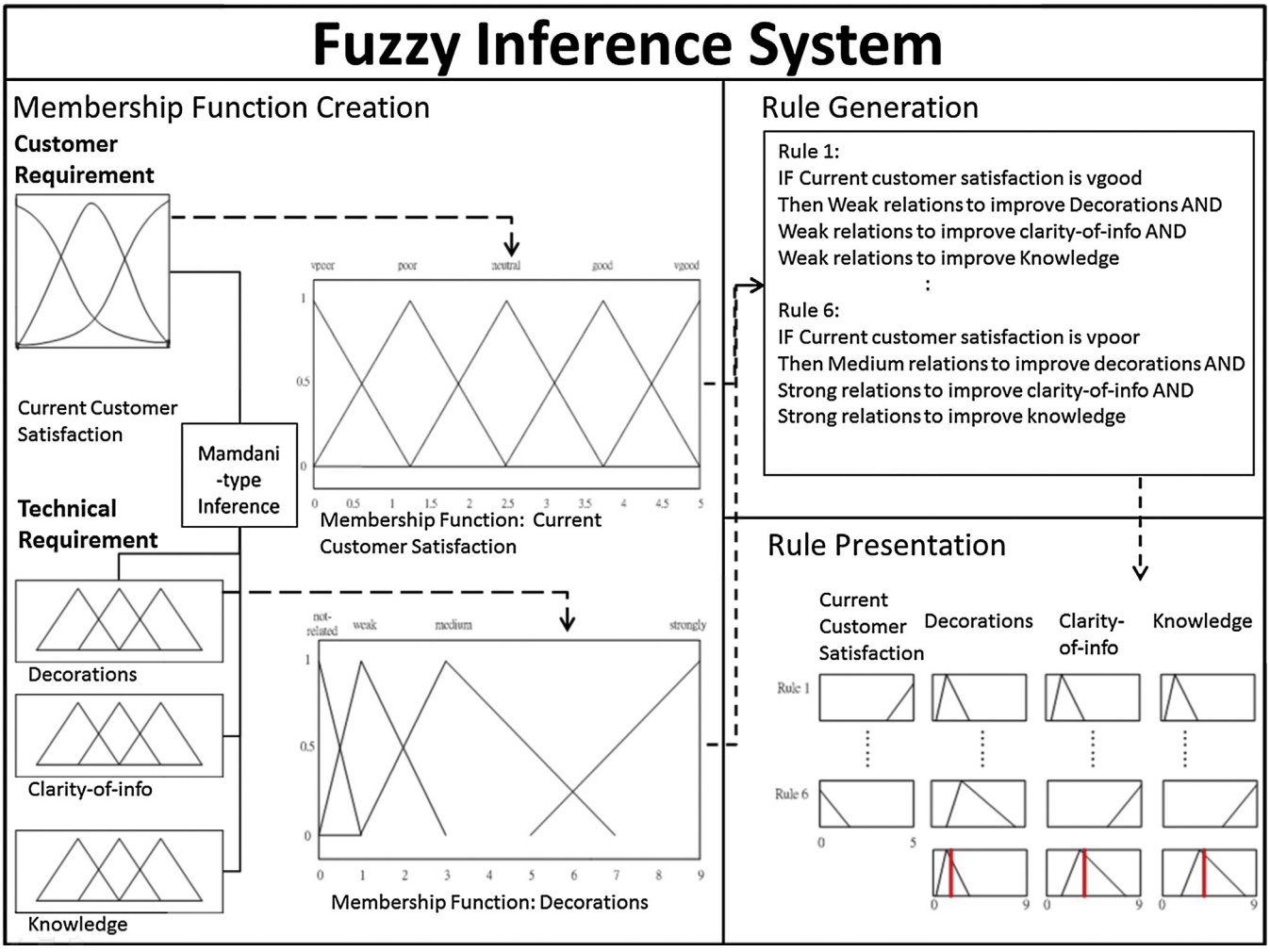


Fig. 4. Fuzzy Inference System.

of the customer requirements to the technical requirements is set [0 9]. Triangular membership function [trimf] is adopted in this project as it presents a clear and straightforward approach to the output. Fig. 4 shows that the customer satisfaction level in membership function creation part is divided into five different classes which are also the fuzzy sets with linguistic variables namely 'vpoor' for very poor, 'poor', 'neutral', 'good', and 'vgood' for very good. Each class has an equal standard deviation. On the other hand, the correlations of the customer requirement to the technical requirements are divided into four classes with linguistic variables namely 'not-related', 'weak', 'medium', and 'strong' which shows the strength of the correlations between each technical requirement and the customer requirement. The membership function of the hospital's interior and exterior's settings and decoration is shown in membership function creation in Fig. 4. However, the standard deviations of these classes are not equal, with the classes that indicate 'medium' and 'strong' spreading over a larger values about the mean. After setting the membership function, the degree of linguistics variable can be represented.

Rule generation in the fuzzy inference system allows rule construction using a series of If-Then rules based on the results of the membership function creation. These rules form the aggregate of all the possible cases together. Individual weights could be assigned for each rule to emphasize on the importance of the rule. Table 13 shows the fuzzy rules regarding the ease of navigation around hospital. Appendix A shows the rules for all the customer requirements, and how they should be interpreted in this study. These rules show how much each of the technical requirement are responsible for the satisfaction level of the customer requirement. The rules are set based on the survey results.

The rule presentation shows the roadmap of the entire fuzzy inference process. Each row of plots corresponds to each of the rule that were previously defined in the rule generation, and they represent the antecedent and consequent of the rule. The system is built on the aggregation of input/s and rules, which upon defuzzification would generate the output/s accordingly. The result from the fuzzy inference system on the ease of navigation around the hospital is shown in Fig. 5. It gives a good idea of which technical requirements in particular that has a higher possibility of impeding the current customer satisfaction level of the customer requirement. In the example of the customer requirement on the ease of navigation around the hospital, the clarity of interior information and the staff's familiarity and knowledge of the hospital's settings requires more attention than the hospital's interior and exterior's settings and decorations so as to improve the customer satisfaction level.

Table 12
Short-forms used for technical requirements.

Technical requirements	Short forms
Hospital's interior and exterior setting and decoration	Decorations
Clarity of interior information	Clarity-of-info
Staffs show familiarity and knowledge of the hospital settings	knowledge
Staffs show responsiveness, attentiveness	responsiveness
Staffs show friendliness and communication skills toward patients	communication
Doctors should do interrogation enquiry and give treatment skillfully	enquiry
Doctors explain the patient's condition at great length before giving treatment	explanation
Pharmacists give clear information on medication's dosage and side effects	information
Pharmacists show good serving attitude	attitude
Nurses show clinical knowledge skills and capability	knowledge
Nurses show good serving attitude	attitude
Convenient registration procedures	registration
Arrangement for the same doctor when patients return	same-doctor
Standardized process	standardize
Reduce medical error	medical-error
Follow-up after discharge	follow-up
Efficiency in resolving complains	resolve-complains

Table 13
Fuzzy rules regarding the ease of navigation around hospital.

Rule No.		
1	IF	Current customer satisfaction is vgood
	THEN	There is a weak relations to improve Decorations AND There is a weak relations to improve Clarity-of-info AND There is a weak relations to improve Knowledge
2	IF	Current customer satisfaction is vgood
	THEN	There is a weak relations to improve Decorations OR There is a medium relations to improve Clarity-of-info is OR There is a medium relations to improve Knowledge
3	IF	Current customer satisfaction is good
	THEN	There is a weak relations to improve Decorations AND There is a medium relations to improve Clarity-of-info AND There is a medium relations to improve Knowledge
4	IF	Current customer satisfaction is neutral
	THEN	There is a medium relations to improve Decorations AND There is a medium relations to improve Clarity-of-info AND There is a medium relations to improve Knowledge
5	IF	Current customer satisfaction is poor
	THEN	There is a medium relations to improve Decorations OR There is a strong relations to improve Clarity-of-info is strong OR There is a strong relations to improve Knowledge
6	IF	Current customer satisfaction is vpoor
	THEN	There is a medium relations to improve Decorations AND There is a strong relations to improve Clarity-of-info AND There is a strong relations to improve Knowledge

5. Results and discussions

Based on HOQ of the proposed approach, five technical requirements which have a greater impact on the customer satisfaction level are identified. 1. Staffs show responsiveness, attentiveness; 2. Staffs show friendliness and communication skills toward patients; 3. Convenient registration procedures; 4. Arrangement for the same doctor when patient returns; 5. Standardized process.

However, the relative percentage does not give a gratifying judgment to the technical requirements which are independent to the professionalism of the healthcare providers. This is because there are only two technical requirements for each of the profession and they are all disassociated from the rest of the customer requirements. As such, these independent technical requirements should be assessed differently. In addition, as the respondents in the survey are only asked to choose the more important item among the two technical requirements. Therefore, it does not mean that the other technical requirement is not important. A more thorough level of reasoning is required to make a good informed importance

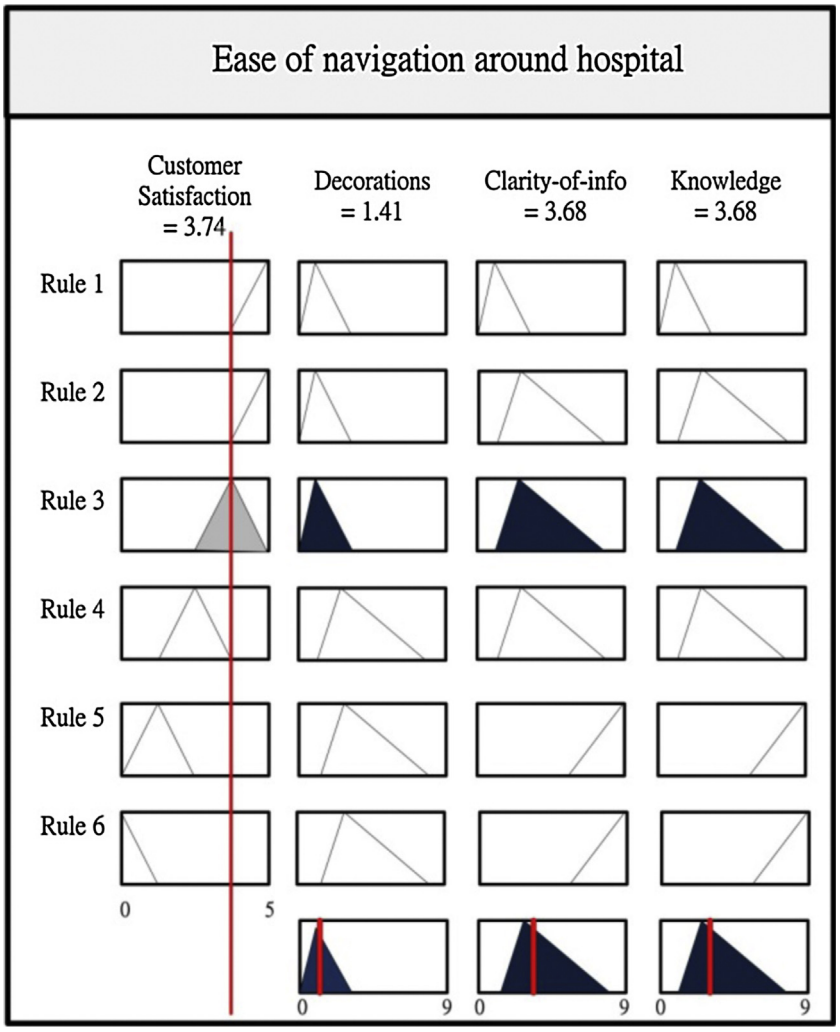


Fig. 5. Results from the fuzzy inference system on the ease of navigation around the hospital.

rating selection. The improvement ratios obtained gives a good gauge of the projected percentage of improvement that may result by making the changes to the technical requirements on each of the customer requirements which is shown in Table 14.

The results from the fuzzy inference system corresponding to each customer requirements with the current satisfaction level as input are shown in this section. Fig. 5 shows the results of the fuzzy inference system on the ease of navigation around the hospital. Based on the correlations of the ease of navigation around the hospital to its technical requirements and the current satisfaction level, it is found that there is a medium relationship to the clarity of interior information and the staff's familiarity and knowledge of the hospital settings, and a weak relationship to the hospital's interior and exterior settings and decorations. Thus, more emphasis should be taken into consideration on the interior signboards and clarity of information to navigate around the hospital and to train the staffs to be more familiar of the hospital's settings. These measures will ensure that navigation around the hospital is not stressful for the patients or visitors.

In terms of pleasing attitude of staffs, the responsiveness, attentiveness, friendliness and communication skill of the staffs would serve to play a bigger role in pleasing the customer or patients. Therefore, the staffs can do more to ensure that their patients would have a pleasant time in the hospital. For the speediness of healthcare services, there are many factors that could serve to improve the current average satisfaction level on the speediness of the healthcare services. However, more emphasis should be placed on the convenience of the registration procedure, and a standardize process.

Fig. 6 shows the results form fuzzy inference system on the healthcare provider's professionalism which includes professionalism of the doctors, pharmacists and nurse respectively. Patients generally prefer the doctors to do more enquiries and to have a thorough check on the patient's condition before giving treatment skillfully. This would serve to make the patients feel better than to explain the situation to the patients. This comparison serve to show that doctors should do more to ensure the best diagnosis is carried out. It would increase the patient's satisfaction level on the

Table 14
Percentage of improvement projected for customer requirements.

Customer requirements	Projected percentage of improvement
Ease of navigation around hospital	10%
Pleasing attitude of staffs	20%
Professionalism of doctors	30%
Professionalism of pharmacists	30%
Professionalism of nurses	30%
Speediness of healthcare services	30%
Quality of healthcare services	30%

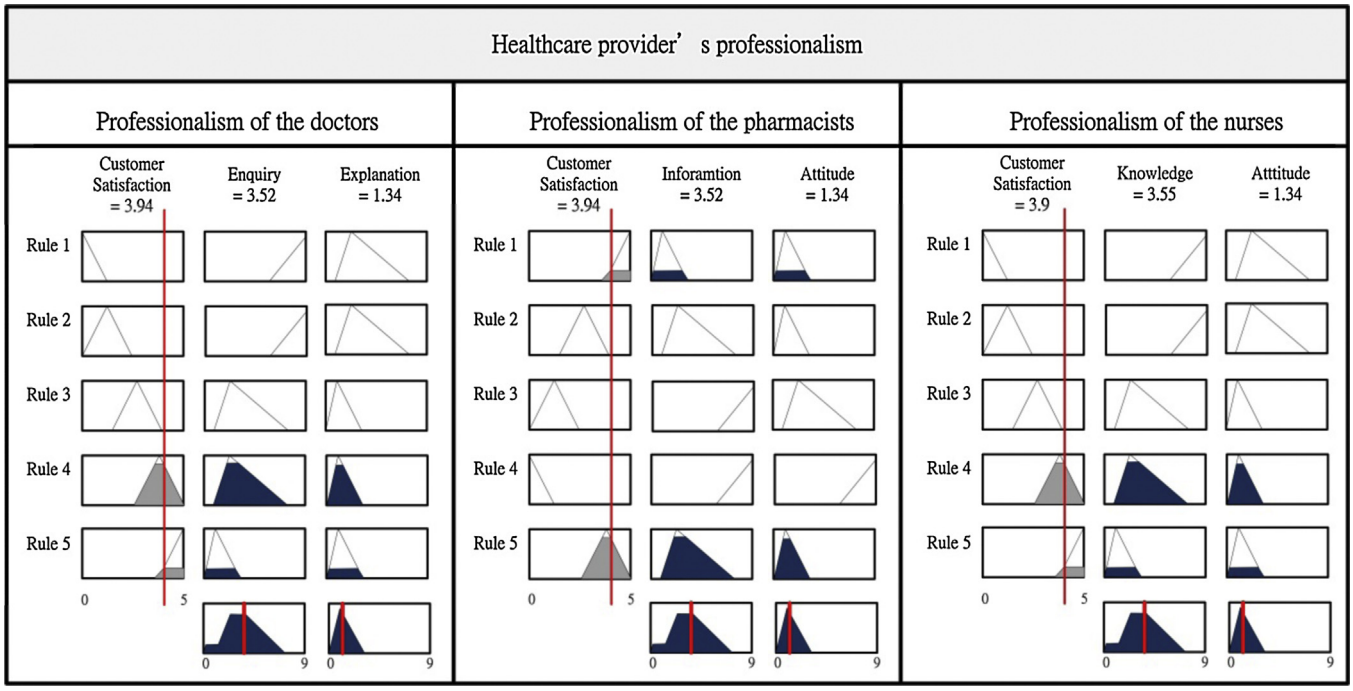


Fig. 6. Results from the fuzzy inference system on the healthcare provider's professionalism.

doctor's professionalism twice as much than to give explanation on the patient's condition in general. For the professionalism of pharmacists, this comparison serves to show that between giving the patients information on the medications and the pharmacist's attitude, the pharmacists should ensure that clear information is communicated effectively to the patients regarding the dosage and side-effects of the medication. This would serve to increase the satisfaction level of the pharmacists twice as much than having good serving attitude. However, a good serving attitude is still as important. In terms of the professionalism of nurses, the patients would be more satisfied when nurses are able to exhibit their clinical skills and show their capability. Thus, more emphasis on the nurses' skills and capability than their serving attitude would serve to improve the current satisfaction level of the patients.

Fig. 7 shows the results from fuzzy inference system on the quality of healthcare services. The average satisfaction level rated by the public on the quality of healthcare services is at the 'good' range. As per satisfaction level input, the result shows that the

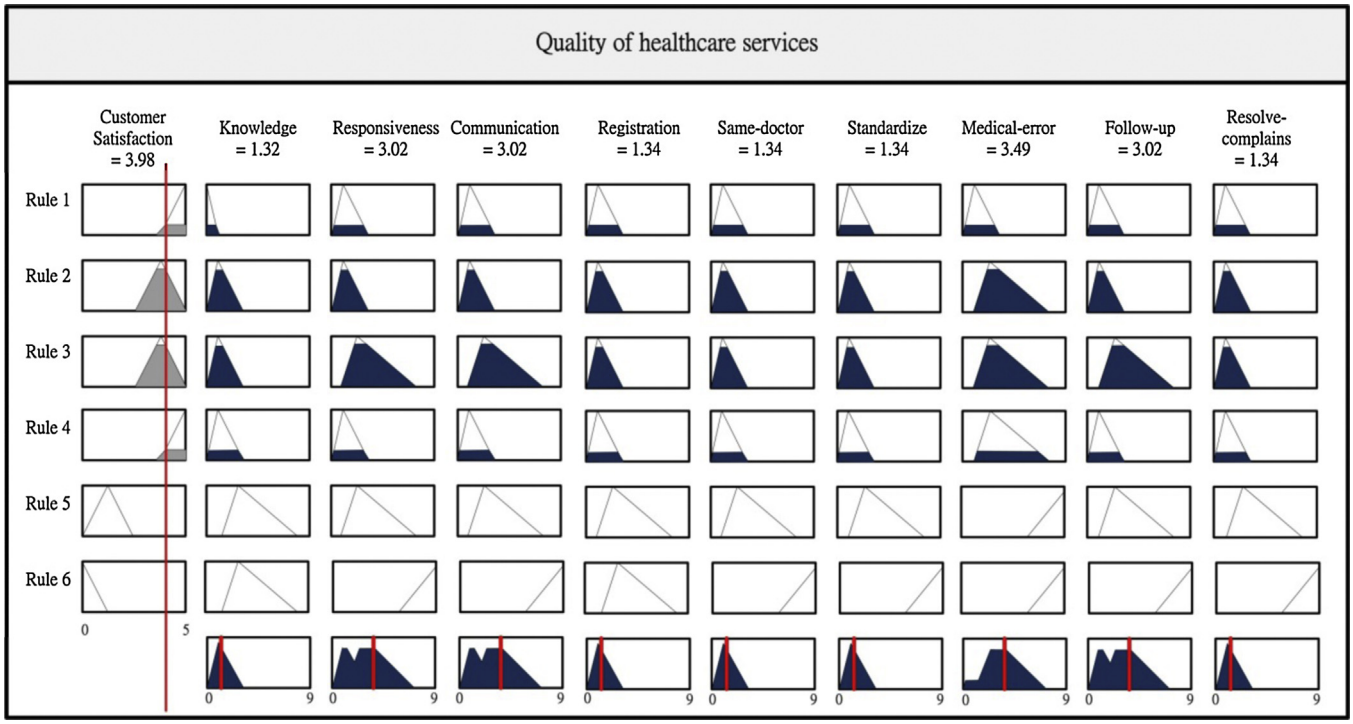


Fig. 7. Results from fuzzy inference system on the quality of healthcare services.

responsiveness, knowledge, and communications skills of staffs, reduction in medical errors, and to follow-up after patients discharge are seen as the considerably more important factors to determine further improvement in the quality of healthcare services. However, a larger portion of the possible improvement that can be made is on medical error. That means, given the good quality of healthcare services in Singapore, the utility to reduce medical error is much higher, and it would serve to enhance the quality of healthcare services more effectively. Thus, greater emphasis and stringent steps should be taken to even better, or at its minimum, maintain the current level of effort to reduce medical error.

6. Conclusions and future work

This paper demonstrates that fuzzy QFD approach is capable of providing a framework for analyzing the technical requirements that can lead to the synthesis of a customer-oriented system. Several managerial implications are provided in this study. In modern era, apart from healthcare services provided by the physicians or professional staff, patients pay increasing concern about the experience they gain during the healthcare services. For example, patients are paying attention in the areas such as ease of navigation, friendly facilities, speediness and efficiency of the healthcare services, quality of the staff and the services [69]. In current healthcare systems around the world, the costs of healthcare services are escalating. Under the tight financial condition, it is important for healthcare management staff to address important areas for improvement so as to increase customer satisfaction. This study provides us an insight that all the requirements are not always performed to the necessities which involve the efficacy of the healthcare services. Resources may not be adequate to ensure the tip-top condition of the healthcare services in reality. Thus, it is vital to identify the more important or more concerned requirements to ensure that resources are maximized and this forms the optimum portfolio of the healthcare service. The increasing demand on healthcare service quality may also result in an increasing difficulty in identifying areas of improvement. Therefore, the fuzzy QFD approach can be adopted to aid in the decision making process.

In this study, there are several limitations. The completion rate of the questionnaires is relatively low due to the reasons that the survey is conducted on a voluntary basis. To improve the situation, crowdsourcing method can be adopted in the future to ensure number of respondents and the quality of responses. Crowdsourcing is regarded as a general-purpose problem solving method. It makes use of a crowd of humans who are unknown to problem owner to solve a problem by using the Web as a medium [70]. As the participants can be selected based on their background or pervious crowdsourcing performance and they will get a small amount of reward after completing the crowdsourcing services, the number of sample, the completion rate of the questionnaire and the quality of responses can be ensured. Apart from this, one single trial study was conducted in this paper for improving the quality of healthcare services in public hospital in Singapore. For the whole healthcare system in Singapore, the generated results could be the important direction for future Singapore healthcare services. However, the results may not adequate or specific for individual hospital to conduct improvement. The proposed fuzzy QFD approach could narrow down to specific healthcare service institutions or hospitals or healthcare services in the future so as to address different improvement needs. Regarding the future research, it would be beneficial to extend this study into specific areas of the healthcare service such as on the prompt medication attention to the patients at the Accident & Emergency (A&E) department of the hospital. It can further understand the expectations of the patients in A&E. Service providers in hospitals can consider the findings and then establish different approaches to streamline the processes and also improve the patients' satisfaction in A&E department. To obtain more in-depth and precise information, the survey can target the more specific groups of personnel namely the healthcare providers or patients in the hospital so as to extract more accurate result.

Acknowledgments

The work described in this paper was fully supported by a grant from The Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University (Project No. G-UB97).

Appendix A

Customer Requirement		Rules
Ease of navigation around hospital	1	If (satisfaction is vgood) then there is a (weak relations to improve decorations) and a (weak relations to improve clarity-of-info) and a (weak relations to improve knowledge)
	2	If (satisfaction is vgood) then there is a (weak relations to improve decorations) or a (medium relations to improve clarity-of-info) or a (medium relations to improve knowledge)
	3	If (satisfaction is good) then there is a (weak relations to improve decorations) and a (medium relations to improve clarity-of-info) and a (medium relations to improve knowledge)
	4	If (satisfaction is neutral) then there is a (medium relations to improve decorations) and a (medium relations to improve clarity-of-info) and a (medium relations to improve knowledge)
	5	If (satisfaction is poor) then there is a (medium relations to improve decorations) or a (strong relations to improve clarity-of-info) or a (strong relations to improve knowledge)
	6	If (satisfaction is vpoor) then there is a (medium relations to improve decorations) and a (strong relations to improve clarity-of-info) and a (strong relations to improve knowledge)
Pleasing attitude of staffs	1	If (satisfaction is vgood) then there is a (weak relations to improve knowledge) or a (medium relations to improve responsiveness) or a (medium relations to improve communication)
	2	If (satisfaction is vgood) then there is a (weak relations to improve knowledge) and a (weak relations to improve responsiveness) and a (weak relations to improve communication)
	3	If (satisfaction is good) then there is a (weak relations to improve knowledge) and a (medium relations to improve responsiveness) and a (medium relations to improve communication)
	4	If (satisfaction is neutral) then there is a (medium relations to improve knowledge) and a (medium relations to improve responsiveness) and a (medium relations to improve communication)
	5	If (satisfaction is poor) then there is a (medium relations to improve knowledge) and a (strong relations to improve responsiveness) and a (strong relations to improve communication)
	6	If (satisfaction is vpoor) then there is a (strong relations to improve knowledge) and a (strong relations to improve responsiveness) and a (strong relations to improve communication)

Appendix A (*Continued*)

Customer Requirement		Rules
Professionalism of doctors	1	If (satisfaction is vgood) then there is a (weak relations to improve enquiry) and a (weak relations to improve explanation)
	2	If (satisfaction is good) then there is a (medium relations to improve enquiry) and a(weak relations to improve explanation)
	3	If (satisfaction is neutral) then there is a (medium relations to improve enquiry) or a(weak relations to improve explanation)
	4	If (satisfaction is poor) then there is a (strong relations to improve enquiry) or a(medium relations to improve explanation)
	5	If (satisfaction is vpoor) then there is a (strong relations to improve enquiry) and a(medium relations to improve explanation)
Professionalism of pharmacists	1	If (satisfaction is vgood) then there is a (weak relations to improve information) and a (weak relations to improve attitude)
	2	If (satisfaction is good) then there is a (medium relations to improve information) or a (weak relations to improve attitude)
	3	If (satisfaction is neutral) then there is a (medium relations to improve information) and a (weak relations to improve attitude)
	4	If (satisfaction is poor) then there is a (strong relations to improve information) or a (medium relations to improve attitude)
	5	If (satisfaction is vpoor) then there is a (strong relations to improve information) and a (medium relations to improve attitude)
Professionalism of nurse	1	If (satisfaction is vgood) then there is a (weak relations to improve knowledge) and a (weak relations to improve attitude)
	2	If (satisfaction is good) then there is a (medium relations to improve knowledge) and a (weak relations to improve attitude)
	3	If (satisfaction is neutral) then there is a (medium relations to improve knowledge) or a (weak relations to improve attitude)
	4	If (satisfaction is poor) then there is a (strong relations to improve knowledge) or a (medium relations to improve attitude)
	5	If (satisfaction is vpoor) then there is a (strong relations to improve knowledge) and a (medium relations to improve attitude)
Speediness of healthcare services	1	If (satisfaction is vgood) then there is a (no relations to improve decorations) or a (weak relations to improve clarity-of-info) or a (weak relations to improve knowledge) or a (weak relations to improve responsiveness) or a (weak relations to improve communication) or a (medium relations to improve registration) or a (weak relations to improve same-doctor) or a (medium relations to improve standardize) or a (weak relations to improve medical-error) or a (weak relations to improve follow-up) or a (weak relations to improve resolve-complains)
	2	If (satisfaction is good) then there is a (no relations to improve decorations) and a (weak relations to improve clarity-of-info) and a (weak relations to improve knowledge) and a (weak relations to improve responsiveness) and a (weak relations to improve communication) and a (medium relations to improve registration) and a (medium relations to improve same-doctor) and a (medium relations to improve standardize) and a (weak relations to improve medical-error) and a (weak relations to improve follow-up) and a (weak relations to improve resolve-complains)
	3	If (satisfaction is neutral) then there is a (weak relations to improve decorations) or a (medium relations to improve clarity-of-info) or a (medium relations to improve knowledge) or a (medium relations to improve responsiveness) or a (medium relations to improve communication) or a (strong relations to improve registration) or a (strong relations to improve same-doctor) or a (strong relations to improve standardize) or a (medium relations to improve medical-error) or a (medium relations to improve follow-up) or a (medium relations to improve resolve-complains)
	4	If (satisfaction is weak) then there is a (medium relations to improve decorations) or a (strong relations to improve clarity-of-info) or a (strong relations to improve knowledge) or a (strong relations to improve responsiveness) or a (strong relations to improve communication) or a (strong relations to improve registration) or a (strong relations to improve same-doctor) or a (strong relations to improve standardize) or a (strong relations to improve medical-error) or a (strong relations to improve follow-up) or a (strong relations to improve resolve-complains)
	5	If (satisfaction is weak) then there is a(medium relations to improve decorations) and a (medium relations to improve clarity-of-info) and a (medium relations to improve knowledge) and a (medium relations to improve responsiveness) and a (medium relations to improve communication) and a (strong relations to improve registration) and a (strong relations to improve same-doctor) and a (strong relations to improve standardize) and a (medium relations to improve medical-error) and a (medium relations to improve follow-up) and a (medium relations to improve resolve-complains)
	6	If (satisfaction is vweak) then there is a (medium relations to improve decorations) and a (strong relations to improve clarity-of-info) and a (strong relations to improve knowledge) and a (strong relations to improve responsiveness) and a (strong relations to improve communication) and a (strong relations to improve registration) and a (strong relations to improve same-doctor) and a (strong relations to improve standardize) and a (strong relations to improve medical-error) and a (strong relations to improve follow-up) and a (strong relations to improve resolve-complains)
Quality of healthcare services	1	If (satisfaction is vgood) then there is a (no relation to improve knowledge) and a (weak relations to improve responsiveness) and a (weak relations to improve communication) and a (weak relations to improve registration) and a (weak relations to improve same-doctor) and a (medium relations to improve standardize) and a (weak relations to improve medical-error) and a (weak relations to improve follow-up) and a (weak relations to improve resolve-complains)
	2	If (satisfaction is vgood) then there is a (weak to improve knowledge) or a (weak relations to improve responsiveness) or a (weak relations to improve communication) or a (weak relations to improve registration) or a (weak relations to improve same-doctor) or a (medium relations to improve standardize) or a (medium relations to improve medical-error) or a (weak relations to improve follow-up) or a (weak relations to improve resolve-complains)

Appendix A (*Continued*)

Customer Requirement		Rules
	3	If (satisfaction is good) then there is a (weak relations to improve knowledge) and a (weak relations to improve responsiveness) and a (weak relations to improve communication) and a (weak relations to improve registration) and a (weak relations to improve same-doctor) and a (medium relations to improve standardize) and a (medium relations to improve medical-error) and a (weak relations to improve follow-up) and a (weak relations to improve resolve-complains)
	4	If (satisfaction is neutral) then there is a (weak to improve knowledge) or a (medium relations to improve responsiveness) or a (medium relations to improve communication) or a (weak relations to improve registration) or a (medium relations to improve same-doctor) or a (medium relations to improve standardize) or a (medium relations to improve medical-error) or a (medium relations to improve follow-up) or a (medium relations to improve resolve-complains)
	5	If (satisfaction is weak) then there is a (medium relations to improve knowledge) and a (medium relations to improve responsiveness) and a (medium relations to improve communication) and a (medium relations to improve registration) and a (medium relations to improve same-doctor) and a (medium relations to improve standardize) and a (strong relations to improve medical-error) and a (medium relations to improve follow-up) and a (medium relations to improve resolve-complains)
	6	If (satisfaction is weak) then there is a (medium relations to improve knowledge) and a (strong relations to improve responsiveness) and a (strong relations to improve communication) and a (medium relations to improve registration) and a (strong relations to improve same-doctor) and a (strong relations to improve standardize) and a (strong relations to improve medical-error) and a (strong relations to improve follow-up) and a (strong relations to improve resolve-complains)

References

[1] U.S. Department of Health and Human Services, 2013 Annual progress report to congress: National strategy for quality improvement in health care [Internet], 2013 Available from: http://www.ahrq.gov/workingforquality/nqs/nqs2013annlrpt.htm.

[2] K. Feldscher, Singapore's health care system holds valuable lessons for U.S. [Internet], 2014 Available from: http://www.hsph.harvard.edu/news/features/singapores-health-care-system-holds-lessons-for-u-s/.

[3] M. Mccellan, S.J. Beales, S.I. Cohen, M. Macdonnell, A. Thoumi, M. Abdulmalik, et al., Accountable care around the world: a framework to guide reform strategies, Health Affair 33 (9) (2014) 1507–1515.

[4] P.Y. Leung, N. Tse, D. Yeung, Sustaining quality, performance and cost-effectiveness in a public hospital system, in: Proceedings of the 37th World Hospital Congress IHF Conference, Dubai, United Arab Emirates, 2011.

[5] O.P. Keown, G. Parston, H. Patel, F. Rennie, F. Saoud, H. Ai Kuwari, et al., Lessons from eight countries on diffusing innovation in health care, Health Affair 33 (9) (2014) 1516–1522.

[6] J. Lim, V. Joshi, Public perceptions of healthcare in Singapore, Ann. Acad. Med. Singap. 37 (2) (2008) 91.

[7] D.R. Graber, Organizational and individual perspectives on caring in hospitals, J. Health Hum. Serv. Adm. 31 (4) (2009) 517–537.

[8] C.L. Yeung, S.K. Kwok, H.C. Mui, An investigation of an RFID-based patient-tracking and mobile alert system, Int. J. Eng. Bus. Manag. 3 (1) (2011) 50–56.

[9] The Mcgraw-hill Companies, Inc, McGraw-Hill concise dictionary of modern medicine, Healthcare service [Internet], 2002 Available from: http://medical-dictionary.thefreedictionary.com/health+care+service.

[10] Oregonlaws.org [Internet] Health care services. 2013. Available from: http://www.oregonlaws.org/glossary/definition/health_care_services.

[11] Australian Government [Internet]. 62., The privacy act and health information, 2008 Available from: Australian Government, Australian Law Reform Commission Web site: http://www.alrc.gov.au/publications/62.%20The%20Privacy%20Act%20and%20Health%20Information/definition-%E2%80%98health-service%E2%80%99#_ftn30.

[12] World Health Organization, WHO centre for health development ageing and health technical report, [Internet], 2004 Available from: World Health Organization, WHO centre for health development web site: http://www.who.int/kobe_centre/ageing/ahp_vol5_glossary.pdf.

[13] T. Toshiyo, M. Sohichi, H. Takumu, K. Yutaka, K. Yuichi, Y. Masaki, et al., Assessment of participant compliance with a web-based home healthcare system for promoting specific health checkups, Biocybern. Biomed. Eng. 34 (1) (2014) 63–69.

[14] J. Barjis, G. Kolfschoten, J. Maritz, A sustainable and affordable support system for rural healthcare delivery, Decis. Support Syst. 56 (2013) 223–233.

[15] W.T. Sung, K.Y. Chang, Health parameter monitoring via a novel wireless system, Appl. Soft Comput. 22 (2014) 667–680.

[16] F. Andriopoulou, K. Birkos, D. Lymberopoulos, P2Care: a dynamic peer-to-peer network for collaboration in personalized healthcare service delivery, Comput. Ind. 69 (2015) 45–60.

[17] J. Caldeira, J. Rodrigues, P. Lorenz, S. Ullah, Impact of sensor nodes scaling and velocity on handover mechanisms for healthcare wireless sensor networks with mobility support, Comput. Ind. 69 (2015) 92–104.

[18] M.B. Buntin, M.F. Burke, M.C. Hoaglin, D. Blumenthal, The benefits of health information technology: a review of the recent Literature shows predominantly positive results, Health Affair 30 (3) (2011) 464–471.

[19] D. Pati, T. Harvey, C. Cason, Inpatient unit flexibility design characteristics of a successful flexible unit, Environ. Behav. 40 (2) (2008) 205–232.

[20] P. Mollerup, Wayshowing in hospital, Australas. Med. J. 1 (10) (2009) 112–114.

[21] N.H. Manaf, P.S. Nooi, Patient satisfaction as an indicator of service quality in Malaysian public hospitals, Asian J. Qual. 10 (1) (2009) 77–87.

[22] M.B. Bahari, Y.W. Ling, Factors contributing to customer satisfaction with community pharmacies in Malaysia, J. Public Health 18 (2010) 35–41.

[23] O. Kitapci, C. Akdogan, İ.T. Dortyol, The impact of service quality dimensions on patient satisfaction repurchase intentions and word-of-mouth communication in the public healthcare industry, Proc. Soc. Behav. Sci. 148 (2014) 161–169.

[24] A. Zarei, M. Arab, A.R. Froushani, A. Rashidian, S.M.G. Tabatabaei, Service quality of private hospitals: the Iranian Patients' perspective, BMC Health Serv. Res. 12 (2012) 31.

[25] G. Büyüközkan, G. Çifçi, A combined fuzzy AHP and fuzzy TOPSIS based strategic analysis of electronic service quality in healthcare industry, Expert Syst. Appl. 39 (3) (2012) 2341–2354, 2/15.

[26] G. Büyüközkan, G. Çifçi, S. Güleryüz, Strategic analysis of healthcare service quality using fuzzy AHP methodology, Expert Syst. Appl. 38 (8) (2011) 9407–9424.

[27] H. Lee, L.M. Delene, M.A. Bunda, C. Kim, Methods of measuring health-care service quality, J. Bus. Res. 48 (3) (2000) 233–246.

[28] L.K. Chan, M.L. Wu, Quality function deployment: a literature review, Eur. J. Oper. Res. 143 (3) (2002) 463–497.

[29] L.Y. Zheng, K.S. Chin, QFD based optimal process quality planning, Int. J. Adv. Manuf. Technol. 26 (7–8) (2005) 831–841.

[30] J.R. Hauser, D. Clausing, The house of quality, Harv. Bus. Rev. 1 (1988) 3–13.

[31] M. Cermani, M. Mengoni, M. Peruzzinin, A QED-based method to support SMEs in benchmarking co-design tools, Comput. Ind. 63 (2012) 12–29.

[32] Y.Q. Yang, S.Q. Wang, D. Mohammad, S.P. Low, A fuzzy quality function deployment system for buildable design decision-makings, Autom. Constr. 12 (4) (2003) 381–393.

[33] R. Radharamanan, P.G. Leoni, Quality function deployment as applied to a health care system, Comput. Ind. Eng. 31 (1996) 443–446.

[34] C.C. Chiou, Y.C. Cheng, An integrated method of Kano model and QFD for designing impressive qualities of healthcare service, Ind. Eng. Eng. Manag. (2008) 971–978.

[35] R. Radharamanan, L.P. Godoy, Quality function deployment as applied to a health care system, Comput. Ind. Eng. 31 (1–2) (1996) 443–446.

[36] C.Y. Kung, P.Y. Yang, T.M. Yan, Applying grey relational method to analyze the QFD process of medical service quality, in: IEEE International Conference on Systems, Man and Cybernetics 2006 SMC'06, vol. 1, 2006, 8–11.

[37] G. Büyüközkan, O. Feyzioğlu, D. Ruan, Fuzzy group decision-making to multiple preference formats in quality function deployment, Comput. Ind. 58 (5) (2007) 392–402.

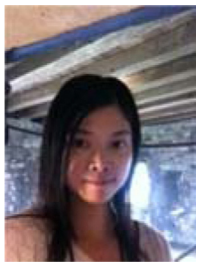
[38] H.H. Wu, Applying grey model to prioritize technical measures in quality function deployment, Int. J. Adv. Manuf. Technol. 29 (11–12) (2006) 1278–1283.

[39] A. Azadegan, L. Porobic, S. Ghazinoory, P. Samouei, A. Saman Kheirkhah, Fuzzy logic in manufacturing: a review of literature and a specialized application, Int. J. Prod. Econ. 132 (2) (2011) 258–270.

[40] T.T. Pham, G. Chen, Some applications of fuzzy logic in rule-based expert systems, Expert Syst. 19 (4) (2002) 208–223.
[41] L.A. Zadeh, The concept of a linguistic variable and its application to approximate reasoning—I, Inf. Sci. 8 (3) (1975) 199–249.
[42] W. Pedrycz, F. Gomide, An Introduction to Fuzzy Sets: Analysis and Design, MIT Press, Cambridge, MA, 1998.
[43] C.M. Tam, T.K. Tong, G.C. Chiu, I.W. Fung, Non-structural fuzzy decision support system for evaluation of construction safety management system, Int. J. Proj. Manag. 20 (4) (2002) 303–313.
[44] S.Y. Sohn, I.S. Choi, Q.F.D. Fuzzy, for supply chain management with reliability consideration, Reliab. Eng. Syst. Saf. 72 (3) (2001) 327–334, 6.
[45] M. Bevilacqua, F.E. Ciarapica, G. Giacchetta, A fuzzy-QFD approach to supplier selection, J. Purch. Supply Manag. 12 (1) (2006) 14–27.
[46] E. Bottani, A. Rizzi, Strategic management of logistics service: a fuzzy QFD approach, Int. J. Prod. Econ. 103 (2) (2006) 585–599.
[47] G.Z. Jia, M. Bai, An approach for manufacturing strategy development based on fuzzy-QFD, Comput. Ind. Eng. 60 (3) (2011) 445–454.
[48] L. Wang, Y. Juan, J. Wang, K. Li, C. Ong, Fuzzy-QFD approach based decision support model for licensor selection, Expert Syst. Appl. 39 (1) (2012) 1484–1491.
[49] L.Q. Dat, T.T. Phuong, H. Kao, S. Chou, P.V. Nghia, A new integrated fuzzy QFD approach for market segments evaluation and selection, Appl. Math. Model. 39 (13) (2015) 3653–3665.
[50] M.M. Ohayon, Improved decision-making processes with the fuzzy logic approach in the epidemiology of sleep disorders, J. Psychosom. Res. 47 (1999) 297–311.
[51] O. Castillo, P. Melin, O.M. Ross, Theoretical Advances and Applications of Fuzzy logic and Soft Computing, Springer, Heidelberg, 2007.
[52] J. Tapke, A. Muller, G. Johnson, House of quality: Steps in understanding the house of quality, IE, 2009.
[53] R.L. Armacost, D. Balakrishnan, J. Pet-armacost, Design for Remanufacturability Using QFD, in: Proceedings of the 11th Annual Industrial Engineering Research Conference: IERC-2002, 2002, pp. 1–5.
[54] C.H. Cheng, Evaluating weapon systems using ranking fuzzy numbers, Fuzzy Set Syst. 107 (1) (1999) 25–35.
[55] V. Cross, T. Sudkamp, Patterns of fuzzy rule-based inference, Int. J. Approx. Reason. 11 (3) (1994) 235–255.
[56] World Health Organization, World Health Organization Key Informant Survey, 2001 Available at: http://www.who.int/responsiveness/surveys/en/ (accessed 30.06.15).
[57] World Health Organization, The World Health Report 2000 Health Systems Improving Performance, 2000 Available at: http://www.who.int/whr/2000/en/whr00_en.pdf (accessed 30.06.15).
[58] World Health Organization, Quality of Care: A process for making strategic choices in health systems, 2006 Available at: http://www.who.int/management/quality/assurance/QualityCare_B. Def.pdf (accessed 30.06.15).
[59] World Health Organization, The World Health Report 2008 -primary Health Care (Now More Than Ever), 2008 Available at: http://www.who.int/whr/2008/en/ (accessed 30.06.15).
[60] M. Alameddine, S. Saleh, N. Natafgi, Assessing health-care providers' readiness for reporting quality and patient safety indicators at primary health-care centres in Lebanon: a national cross-sectional survey, Hum. Resour. Health 13 (37) (2015).
[61] J.K. Rao, M. Weinberger, K. Kroenke, Visit-specific expectations and patient-centered outcomes: a literature review, Arch. Fam. Med. 9 (10) (2000) 1148–1155.
[62] N. Valentine, C. Darby, G.J. Bonsel, Which aspects of non-clinical quality of care are most important? Results from WHO's general population surveys of "health systems responsiveness" in 41 countries, Soc. Sci. Med. 66 (9) (2008) 1939–1950.
[63] F. Lateef, Patient expectations and the paradigm shift of care in emergency medicine, J. Emerg. Trauma Shock 4 (2) (2011) 163–167.
[64] J.C. Pham, N.S. Trueger, J. Hilton, R.K. Khare, J.P. Smith, S.L. Bernstein, Interventions to improve patient-centered care during times of emergency department crowding, Acad. Emerg. Med. 18 (12) (2011) 1289–1294.
[65] Department of Statistics Singapore, Population and Population Structure, 2015 Available at: http://www.singstat.gov.sg/statistics/browse-by-theme/population-and-population-structure (accessed 29.06.15).
[66] Ministry of Manpower, Labour Force in Singapore, 2014, 2014 Available at: http://stats.mom.gov.sg/Pages/Labour-Force-In-Singapore-2014.aspx (accessed 30.06.15).
[67] Singapore Workforce Development Agency, Learning for Life: Singapore's Lifelong Learning Journey, 2015 Available at: http://www.wda.gov.sg/content/wdawebsite/L209-001About-Us/CET_Commemorative_Pub.html (accessed 30.06.15).
[68] MATLAB, MATLAB – The Language of Technical Computing, [Internet], 2012 Available from: http://www.mathworks.com/products/matlab/.
[69] J.R. Langabeer II., J. Helton, Health Care Operations Management: A Systems Perspective, Jones & Bartlett Publishers, 2015.
[70] A. Doan, R. Ramakrishnan, A.Y. Halevy, Crowd sourcing systems on the world-wide web, Commun. ACM 54 (4) (2011) 86–96.

C.K.M. Lee received the B.E. and Ph.D. degrees from The Hong Kong Polytechnic University, Hong Kong. She is currently an Assistant Professor with the Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hong Kong. She has authored and coauthored more than 100 journal and conferences papers. Her current research areas include logistics information management, healthcare system and data mining techniques. Dr. Lee was the recipient of the Bronze Award of 16th China National Invention Exhibition Award in 2006 and the Outstanding Professional Service and Innovation Award of The Hong Kong Polytechnic University in 2006.

Chloe Tan Ying Ru received B.E. degree in School of Mechanical and Aerospace Engineering from Nanyang Technological University, Singapore. Her research interests include healthcare service management, system modeling, and fuzzy logic.



C.L. Yeung is a research assistant and part-time PhD candidate in the Department of Industrial and Systems Engineering of The Hong Kong Polytechnic University. She has graduated in the same department with a Bachelor Degree in Industrial and Systems Engineering. Her research interests are knowledge management, knowledge-based system, computational narrative analysis and generation.

K.L. Choy is an Associate Professor in the Department of Industrial and Systems Engineering of The Hong Kong Polytechnic University. He gained his M.Sc. degrees in Manufacturing Systems Engineering and in Management Science and his M.Phil. in Engineering at the University of Warwick, UK in the 1990s and a Doctorate degree at The Hong Kong Polytechnic University in 2003. He has published more than 100 international journal papers in the areas of logistics information, data systems, supply chain management and technology management, as well as applying expert systems to industry.

W.H. Ip (M'10) received the M.Sc. degree from Cranfield University, Cranfield, UK, in 1983, the M.B.A. degree from Brunel University, Middlesex, UK, in 1989, and the Ph.D. degree in manufacturing engineering from Loughborough University, Loughborough, UK, in 1993. He is an Associate Professor with the Industrial and Systems Engineering Department, Hong Kong Polytechnic University. Over the span of 20 years of work in industry, education and consulting, he has authored and coauthored more than 170 international journal articles and over 80 conference articles in the areas of production system and management, supply chain and logistics management, and enterprise resource planning. His current research interests include the modeling and application of operations research, customer relationship dynamics, artificial intelligence techniques and wireless sensor network. Dr. Ip is a Fellow of the Hong Kong Quality Management Association (HKQMA) and a member of the Hong Kong Institution of Engineers (HKIE), the Institution of Engineering and Technology (IET), and the Institution of Mechanical Engineers (IMech).