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Assessing quality management system at a tertiary hospital in Oman using a hybrid knowledge-based system

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Abstract

The cost of medical care is snowballing at an alarming and unmaintainable rate universally. Consequently, the need for a trusted quality management (QM) system at healthcare organizations is a must. Such system will aid the healthcare governance to increase the effectiveness and decrease the cost. It will help in minimizing the risk and enhancing patient safety. Several challenges facing healthcare QM in Oman are creating computerizing monitoring tool and confirming commitment of decision makers at all levels. The Report of Quality and Patient Safety (RQPS) in Oman 2016 highlighted the low level of patient safety and quality culture among staff. It recommended to inaugurate a well-defined organizational chart based on each healthcare organization's vision and mission. Therefore, it is important to design a national accreditation system that is accredited by an international accreditation body. Such step will help in prioritizing the needs and minimizing the cost of maintaining and upgrading systems. To overcome these challenges, this article is presenting a novel methodology of hybrid knowledge-based (KB) system to assess QM in healthcare environment (QMHE) using gauging absence of prerequisites tool for benchmarking and analytical hierarchy process for prioritizing. The KB-QMHE model can be used as a standard to assess QM at any healthcare organization around the globe. The results showed that 852 questions were answered by the quality managers in a tertiary hospital in Oman; the percentage of bad points in this hospital was 32%. The KB-QMHE model has clearly shown that the priority 1, in level 0, is to focus on the patient-centered dimension in the healthcare quality dimensions submodule. Output, also, suggested a prioritized action plan covering healthcare governance module, healthcare leadership module and healthcare organization's resources module in level 1–3.

Keywords

Knowledge-based system, quality management in healthcare environment, gauging absence of prerequisites, analytical hierarchy process, Oman

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Introduction

Globally, the healthcare system is considered to be slow in adopting new quality initiatives compared with manufacturing industries.[1–3] The cost of medical care is growing at an alarming and unmaintainable rate universally. Consequently, the need for a trusted quality management (QM) system at healthcare organizations is a must.[4] Such system will aid the effectiveness of healthcare management and decrease the cost. It will help in minimizing the risk and enhancing patient safety.[5,6] In fact, there are several types

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of risks which could be minimized by implementing a durable QM system in the context of healthcare, such as identification patient, medication administration, acquired infection, and workplace violence.[7]

Thus, Oman's healthcare system has taken serious efforts since the 1970s to improve its QM services.[8] In 2000, World Health Organization (WHO) ranked Oman's healthcare system as one of the best 10 healthcare systems in the world, even better than those of Canada and America.[9] According to WHO, from 1990 till 2013, the mortality rate of under-five in Oman has decreased by 72%.[10] The same report showed that Oman's government expenditure on the health sector was 4.8% in 2012.

In May 2014, Ministry of Health (MoH) in Oman published the first edition of its Health Vision: 2050.[11] It was developed through a number of well-planned scientific activities. To implement this vision, the MoH has launched different quality improvement/management programs which use tools such as key performance indicators (KPIs), incidents reporting system, document controlling system, and best staff award. By the end of 2020, the MoH in Oman aims to establish central document management system, national accreditation system, risk management system, patient safety system, and staff motivation and patients engagement systems in the Ministry.[8]

Basically, this article shows the process of development and designing a knowledge-based system (KBS) which can assist healthcare managers and practitioners during decision-making in the context of achieving excellent benchmark QM. The model used for designing this KBS has integrated analytical hierarchy process (AHP) and gauging absence of prerequisite (GAP) methods. These two methods (AHP and GAP) are essentially required to optimize the solutions obtained for the decision-making. Hence, the aim of this article is to implement this hybrid KBS in a real healthcare QM system. As an example of real implementation, this article evaluates the current practice of QM in a tertiary hospital in Oman.

In fact, the selection of Oman to evaluate its healthcare system was because the study is funded by the Omani government which, as a result, was easy to conduct the evaluation process and build a road map for improvement. Nevertheless, the system can be validated and implemented in any healthcare system around the globe since its submodules were built based on international standards: Joint Commission International, Accreditation Canada International (ACI), and National Health Service (NHS). This system benchmarks global best practice to improve its performance. It will be integrated with GAP technique to facilitate decision-making processes. Moreover, the system will be embedded with AHP that will aid in prioritizing between KPIs.

Literature review

Due to the fast movement of the healthcare service around the world, various healthcare organizations now provide attention to the efficiency and effectiveness of their operations. In fact, the existing healthcare systems have several gaps that need to be filled to reach the standardized level. For example, almost £2 billion is paid in clinical negligence claims and adverse incidents in the United Kingdom per year.[12] To fill such gaps, healthcare organizations have tried several quality improvement methodologies such as total QM (TQM),[13–15] Six Sigma (6σ),[16–19] and Lean thinking.[20–23]

Basically, researchers do not agree on a particular definition for QM in Healthcare Environment (QMHE). Harteloh[24] discussed how difficult it was to standardize a definition for quality in healthcare. The patient's satisfaction has been used widely to measure the quality of services provided in healthcare facilities. Campbell et al.[25] defined quality of care in two ways: accessibility and effectiveness. They defined quality of care as the *ability of the patient to access effective care with the aim of maximizing health benefit in relation to need*. According to the Agency for Healthcare Research and Quality (AHRQ), QMHE is *doing the right thing for the right patient, at the right time, in the right way to achieve the best possible results*.[26] For the proposed system, authors have depended on AHRQ definition to develop and design the model used to build this system.

QM in healthcare environment

QMHE has used different tools to monitor and control its services. From literature, all the new QM tools were initiated by business and manufacturing sectors and used by healthcare organizations.[1–3] In the United Kingdom, the NHS has implemented a number of quality improvement concepts, most notably 6σ and, more recently, Lean.[27] In the United States, it was noticed that the popular quality initiative is 6σ.[1] At the beginning of this century, the 6σ philosophies were applied gradually and slowly in healthcare organizations.[1]

In fact, implementation of TQM concepts has shown a positive relationship with hospitals' performance.[13–15,28] However, most NHS managers in the United Kingdom are not interested in TQM as a tool for improving their organizational performance and enhancing patient care. They believe that TQM has failed to address the critical needs of hospitals especially on issues such as enhancing performance, efficiency, and effectiveness.[29] According to Mohammad Mosadeghrad,[30] the failure of TQM implementation could be due to non-holistic approach adopted in its implementation, managers' inadequate knowledge about TQM implementation, and frequent top management turnover.

In 2001, 6σ was used in medication delivery processes at Froedtert Hospital, USA. The results showed that by implementing 6σ methodology, a significant variability in the ordering and processing of intravenous drips was identified. In these areas, standards were created by a

multidisciplinary task force to reduce variation.[31] 6σ methodology has shown significant results by reducing patients' falls rate in an Academic Medical Centre of King Fahd Hospital in Saudi Arabia. The patients' falls rate decreased dramatically more than 70%.[32] Other examples of 6σ application in healthcare are decreasing turnaround time between general surgery cases,[33] improving processes and outcomes in hospitals,[19] improving microbiology laboratory processes,[18] and reducing incidence of catheter-related bloodstream infections in a surgical intensive care unit.[34]

QM in Oman's healthcare

Al-Mandhari[8] summarized the history of quality efforts in Oman starting from the year 2000 when the MoH recruited a QM consultant, passing through the development of *Quality Assurance Strategy* in 2005 and the establishment of the Department of Quality and Patient Safety in regional hospitals in 2007, and culminating in the establishment of the Directorate General of the Quality Assurance Centre in 2014.

According to the Report of Quality and Patient Safety (RQPS) which is part of Health Vision 2050,[35] the number of facilities implementing the quality system rose from 64 primary health centers in 2005 to 165 in 2012. It also states that the number of regional hospitals applying the system reached 10 compared to 0 in 2000, and the number of certified national auditors increased from 240 in 2005 to more than 800 in 2012. Starting from the year 2000, staff and user satisfaction surveys were implemented as tools of quality improvement at the MoH's facilities.

As a result of the above efforts, the output of patients' satisfaction survey conducted in a tertiary hospital in Oman showed that around 90% of the patients agreed that doctors and nurses explained the procedure before starting and listened carefully to their concerns and that nurses were cheerful and courteous.[35]

Challenges of Oman's healthcare QM

Despite the above remarkable achievements, the absence of national accreditation body for healthcare organizations in the country is considered to be one of the biggest challenges in Oman's healthcare QM. In fact, adopting an international accreditation system (whether ACI or ISO or any other) may not achieve the desired results. The reason is that countries' experience in implementing the accreditation system shows negative results because it was not a one-size-fit-all solution. Issues of compatibility, cost, and sustainability were among the main obstacles facing successful adaptation of any accreditation system.[36] Therefore, it is important to design a national accreditation system that is accredited by an international accreditation body. Such step will help in prioritizing needs and minimizing the cost of maintaining and upgrading systems.[35]

In 2016, the Omani Minister of Health promulgated a decree forming a national committee that represents all healthcare organizations in Oman, including independent hospitals in order to create national guidelines for healthcare accreditation and maintain them frequently. This committee follows up the implementation of national standards at Omani healthcare organizations, train national auditors, issue accreditation certificates, collaborate with international accreditations bodies, and create knowledge base of all national standards.[37]

According to the RQPS, there are several challenges facing QMHE in Oman, such as creating computerizing monitoring tool and confirming commitment of decision makers at all levels. The report highlighted the low level of patient safety and quality culture among staff. It recommended the inauguration of a well-defined organizational chart based on each healthcare organization's vision and mission.

To overcome these challenges, this article is presenting a novel methodology of hybrid KBS to assess QMHE using GAP tool for benchmarking and AHP for prioritizing. The KB-QMHE model can be used as a standard to assess QM at any healthcare organization around the globe.

Methodology

The model

Basically, the authors have developed a framework to act as a foundation for the model of the proposed system. This framework has been introduced in a conference[38] and the feedback received has been used to refine and improve it. Furthermore, the refined framework was further improved into a model and presented again in another conference[39] for further improvement. After that, the authors conducted several knowledge acquisition sessions with experts in the field of QMHE, as shown in Appendix 1. The revised KB-QMHE model in Figure 1 was used to build the KBS. Moreover, the model has been tested for its ability to interact with users and for its contents harmony. The results of this test were published by authors.[40]

A model consisting of strategic and operational levels is presented in Figure 1. It is the development process of KB-QMHE which covered the main strategic and operational issues affecting the QMHE. The aim of the developed system is to identify the gap in healthcare practice compared to the standardized one. This includes four levels: *level 0 – healthcare organization's environment*; *level 1 – healthcare governance*; *level 2 – healthcare leadership;* and *level 3 – healthcare organization's resources*.

The feedback received from the mentioned peer-reviewed publications and conferences was used to improve the model and, therefore, the related development steps as part of the verification process.[41,42] In addition, extensive discussion has been carried out between authors and healthcare quality managers. The discussion with these

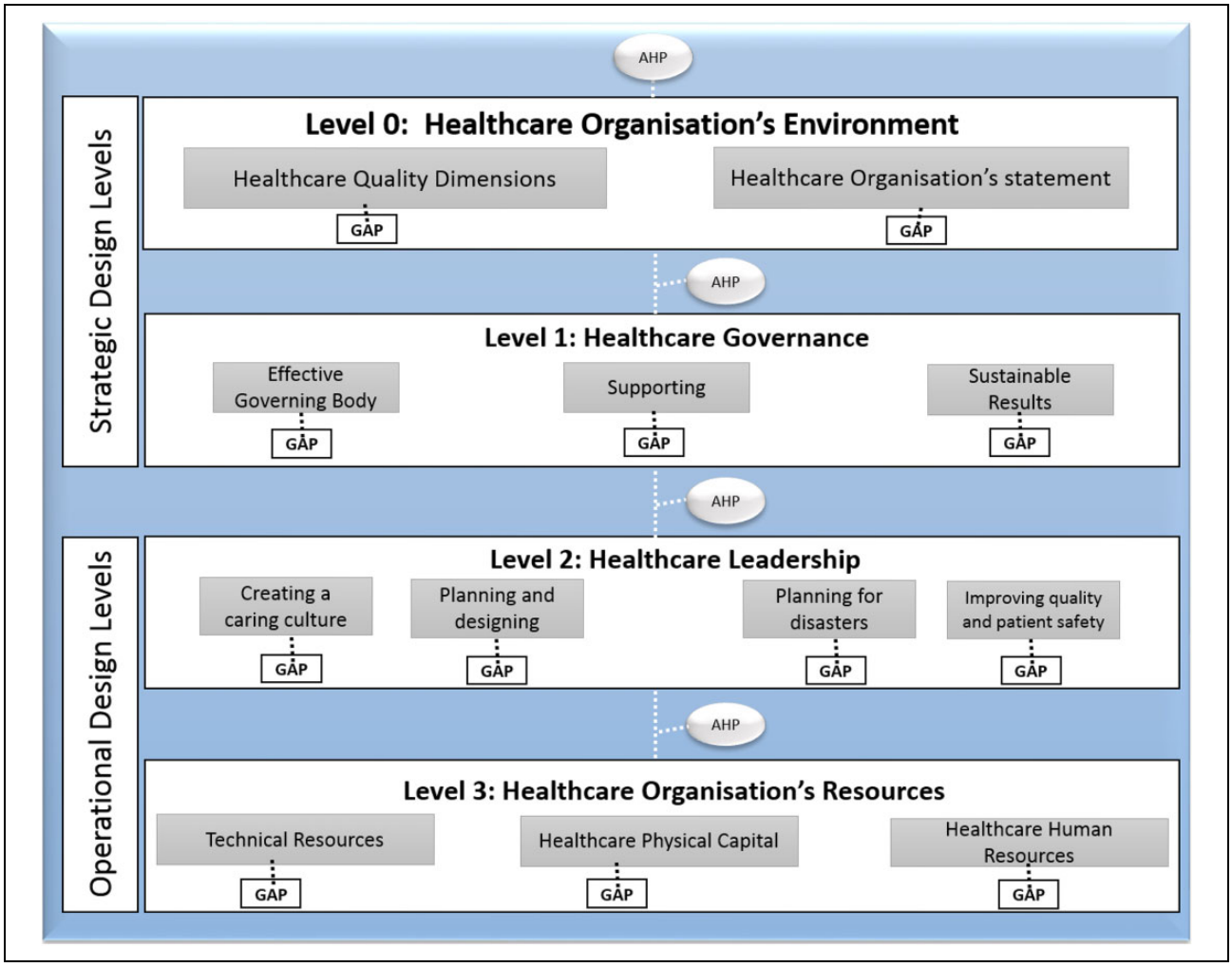

Figure 1. Structure of QMHE model. QMHE: quality management in healthcare environment.

experts helped to assure the critical selection of the KPIs of each module. As an example, *level 0 – healthcare organization's environment is consisting of two submodules: healthcare quality dimensions and healthcare organization's statement*. These submodules are consisting of dimensions (KPIs) which were used later to produce the KB rules for different variables of QMHE based on different levels of decision-making at each organizational hierarchy. In fact, the process of building and referencing each dimension has been elaborated in three published papers.[38–40]

Knowledge-based system

KBS is a computer software that can use a knowledge base to support decision-making to solve real-world problems.[43] The actual work of this system is to save experts' knowledge in its inference engine to be used by the user at any time. It consists of knowledge base, inference engine, scheduler, and user interface. Actually, KBS is a branch of artificial intelligence which has many examples in healthcare environment such as patient-focused and continues performance improvement in healthcare,[44] evaluating healthcare waste disposal alternatives,[45] relationship between healthcare professionals and knowledge management,[46] and exploration of healthcare quality indicator.[47]

The knowledge base contains actual knowledge acquired from the human expert in any field. This knowledge is represented in the form of IF . . . . THEN type rules, facts, and assumptions about the problem the system is designed to solve. For example,

IF: *Home state is Muscat.*

THEN: *Home country is Oman.*

The inference engine is the main processing element of KBS which draws conclusions of available knowledge.[48] It is a group of computer programs that organize the reasoning and inferencing based on the rules of the knowledge base to come up with a solution.[49] The third component of KBS is scheduler which explains exactly how the KBS arrived at the solution. This explanation works as a useful

instructional aid and builds a trust between KBS and users. Finally, the user interface enables all communication between the user and the system. Without user interface, the KBS becomes 'black box' incapable of seeking any additional information required.

Consequently, authors have acquired the knowledge rules and related knowledge structure for each module of the above model based on a literature review, healthcare QM experts, standards, publications, feedback, and so on. Several experts in the field of QMHE have been interviewed from 26 June 2017 to 3 September 2017 in Oman. The knowledge obtained from them during the interview with the other knowledge acquisition's ways has used to create rules. These rules are reformatted into structured questions for easy interaction with the user. However, how can the user know if his/her answer was right or wrong? And how can he/she measure the distance of the answer from the desired one? The next paragraph will answer these two questions.

Gauge absence perquisite

In fact, the questions of KBS are designed to capture both qualitative and quantitative information for the current situation across all aspects, bearing in mind the identification of GAP analysis in each aspect. In fact, to apply GAP as part of this system, the knowledge could also be acquired from users via the developed questionnaire implanted in the KBS. GAP is defined as a method of assessing the gap between the manufacturer's (services at healthcare organizations) necessary prerequisites for benchmark employment related to its existing position level.[50] GAP is consisting of problem categories (PCs) that measure how far is a particular performance from the standardized one. In this PCs' report, good points (GPs) and bad points (BPs) should be written in two separated reports.[51] As an example, the following rule will be converted to a question in the KBS:

IF: *When updating the mission statement, the governing body and the organization's leaders seek input from organization staff (Yes: GP; No: BP-PC-1).*

Q: *Does the governing body seek input from the organization staff when updating the mission statement? (Yes or No)*

If the user selected Yes, it means a GP and if he/she selected No, it means BP. This BP is ranged from PC-1 which indicates a very serious problem to PC-5 which indicates a minor problem.

In fact, reviewing literatures have shown several examples of using GAP with hybrid KBS as a benchmarking method. These examples can be seen in supply chain management,[52] performance measurement,[53] maintenance strategy and operation,[54] and sustainable maintenance.[55] To wrap up this part, the GAP analysis report (good and bad) will help the user to see how far is he/she from the standard but it will not help in prioritizing the actions need to be taken to deal with these problems. The prioritizing process is the job of the next tool of this hybrid system.

Table 1. Example of PV calculation at level 0.

Level 0	Healthcare organizational statement	Healthcare quality dimensions	PV
Healthcare organizational statement	1	1/2	0.333
Healthcare quality dimensions	2	1	**0.667**

PV: priority vector.

Table 2. Example of PV calculation at healthcare quality dimensions.

Healthcare quality dimensions	Accessibility	Patient-centered	Effectiveness	PV
Accessibility	1	3/2	3/2	0.245
Patient-centered	2/3	1	2	**0.463**
Effectiveness	2/3	1/2	1	0.292

PV: priority vector.

Analytical hierarchy process

Now the KBS has benchmarked each KPI and it needs to determine which aspect has priority over the others in order to achieve the KB-QMHE benchmark standard by applying the AHP technique. Saaty[56] defined AHP as a systematic analysis method established for multi-criteria decision.

To make it clear on how to apply AHP in this KBS, *level 0* will be taken as an example. In this level, there are two submodules and it is needed to prioritize between them. AHP will compare between *healthcare organizational statement* and *healthcare quality dimensions.* Table 1 shows that *healthcare organizational statement* equals half *healthcare quality dimensions and healthcare quality dimensions* equals double *healthcare organizational statement.* In fact, experts can decide the weight of each factor. Because of the long process of AHP calculations, authors have used *Super Decision Software* that supported in the calculation of priority vector (PV) for each pair-wise comparison matrix in each dimension as it will be shown in the results.

As a result from Table 2, PV of *healthcare quality dimensions* considered to be the highest which means that it should take the priority in action plan. Moving deeper in *healthcare quality dimensions* submodule which has three dimensions: *accessibility*, *patient-centered*, and

Table 3. Summary of GAP analysis results.

					BPs				
					PC				
Level	Submodule	Number of KB rules	GP	BPs	1	2	3	4	5
Level 0: Organization's environment	Organization's statement	52	26	26	13	5	8	0	0
	Quality dimensions	63	1	62	0	14	9	39	0
	Subtotal	115	27	88	13	19	17	39	0
	Percentage (%)		23.5	76.5	27.8			48.7	
Level 1: Healthcare governance	Effective governing body	93	81	12	8	4	0	0	0
	Supporting	54	44	10	10	0	0	0	0
	Sustainable results	65	27	38	8	22	8	0	0
	Subtotal	212	152	60	26	26	8	0	0
	Percentage (%)		71.7	28.3	24.5			3.8	
Level 2: Healthcare leadership	Creating a caring culture	112	70	42	0	9	17	16	0
	Planning and designing	160	133	27	0	8	16	3	0
	Planning for disasters	44	44	0	0	0	0	0	0
	Improving quality	68	57	11	0	5	3	3	0
	Subtotal	384	304	80	0	22	36	22	0
	Percentage (%)		79.1	20.9	5.7			15.2	
Level 3: Healthcare resources	Human resources	54	22	32	0	4	11	17	0
	Physical capital	43	39	4	0	2	0	2	0
	Technical resources	44	35	9	0	0	1	8	0
	Subtotal	141	96	45	0	6	12	27	0
	Percentage (%)		68.1	31.9	4.3			27.6	
Grand total		852	579	273	39	73	73	88	0
Percentage (%)			68.0	32.0	13.1			18.9	

GAP: gauging absence prerequisite; GP: good point; BP: bad point; PC: problem category.

effectiveness. Again each variable has to be compared with other as it shows in Table 2. The highest priority is for *patient-centered* as it has the highest PV. In summary, all modules, submodules, and dimensions in this model will be prioritized using the same process as Table 4 illustrates.

Summary of the methodology

1. KB-QMHE model has generated by the authors and verified, tested and validated by three published papers.
2. The model is consisting of four modules (levels); each module is consisting of submodules and each submodule is consisting of dimensions (KPIs).
3. These KPIs have generated based on literature reviews, experts' interview, and publications' feedback.
4. The authors have used KBS to embed the KPIs and build the model.
5. The KPIs have converted to be in IF . . . . .THEN rules.
6. These rules have converted to be questions for easy communication with the user.
7. GAP tool has selected to benchmark (Assign a PC 1–5) each and every question in the KBS.
8. AHP technique has used to prioritize each module, submodule, and dimension based on its questions' weights.
9. The final hybrid KB-QMHE system has used to evaluate QMHE.

For the complete KB-QMHE system (levels 0–3), over 2000 KB rules have been developed and structured. For demonstration purposes, and due to the large number of KB rules involved, the discussion of each module will be followed by key rules only. The following KB rules set illustrates a generic example of a typical rule-based structure in QMHE:

IF: *The governing body works in collaboration with the organization's leaders to develop the organization's mission statement (Yes: GP; No: BP-PC-1).*

AND: *The governing body works in collaboration with the organization's leaders to implement the organization's mission statement (Yes: GP; No: BP-PC-1).*

AND: *When developing the mission statement, the governing body and the organization's leaders seek input from organization staff (Yes: GP; No: BP-PC-1).*

AND: *When updating the mission statement, the governing body and the organization's leaders seek*

Table 4. Summary of AHP-PV values.

Level	Submodule	PVs	Dimensions with PVs			
Level 0: Organization's environment	Organization's statement	0.333	Vision (**0.50**)	Mission (0.25)		Values (0.25)
	Quality dimensions	**0.667**	Accessibility (0.245)	Patient-centered (**0.463**)		Effectiveness (0.292)
Level 1: Healthcare governance	Effective governing body	0.297	Roles and responsibilities (**0.571**)	Membership (0.286)		Decision-making (0.143)
	Supporting	0.163	Evaluating the CEO (0.20)	Financial planning (0.20)		Supporting patient safety culture (0.60)
	Sustainable results	**0.540**	Relations with community (0.124)	Promoting quality improvement (**0.517**)		Monitoring performance (0.359)
Level 2: Healthcare leadership	Creating a caring culture	**0.467**	Decisions according values (0.143)	Promoting a safe work environment (0.286)		Promoting a quality culture (**0.571**)
	Planning and designing	0.277	Planning for a community needs (0.249)	Understanding community health status change (**0.594**)		Developing operational plans (0.157)
	Planning for disasters	0.095	Preparing for disasters and emergencies			
	Improving quality	0.160	Managing risk (0.141)	Improving client flow (0.263)	Improving client safety (0.141)	Implementing a QM system (0.455)
Level 3: Healthcare resources	Human resources	**0.50**	Training of healthcare providers			
	Physical capital	0.25	Financial efficiency (**0.667**)			Physical environment (0.333)
	Technical resources	0.25	Using equipment (**0.667**)			Information management (0.333)

AHP: analytical hierarchy process; PV: priority vector; QM: quality management.
Note: The bold was made for the highest PV value among each module and sub-module.

input from organization staff (Yes: GP; No: BP-PC-1).

AND: *When developing the mission statement, the governing body and the organization's leaders seek input from partners (Yes: GP; No: BP-PC-2).*

AND: *The governing body consults regularly with the government to confirm the appropriateness of the organization's mandate and core services (Yes: GP; No: BP-PC-1).*

AND: *The governing body, with the organization's leaders, reviews the mission statement to reflect changes in the environment (Yes: GP; No: BP-PC-3).*

THEN: *The governing body works with the organization's leaders to develop the organization's mission statement.*

OR: *The governing body needs to work with the organization's leaders to develop the organization's mission statement.*

The above KB rules are reformatted into questions, where GP is Good Point, BP is Bad Point and PC is Problem Category, as mentioned before. It is very important for the questions to be clearly defined in a logical order. The KB rules are fired based on user response for a particular question and related subsequent questions. Another key aspect in KB-QMHE is the accurate categorization (*PC*) of each rule which has been determined through literature review and discussion with healthcare QM experts.

Results

Using the above methodology, the study was conducted in a tertiary hospital in Oman based on the KB-QMHE model requirements from December 13, 2017 to January 10, 2018. The study involved the healthcare quality managers at a tertiary hospital in Oman to answer these questions.

Based on the KB-QMHE model analysis, Table 3 illustrates the summarized results for the targeted hospital; 852 KB rules were triggered in these modules. Output shows 579 GPs representing the GPs of the hospital in implementing QMHE; however, 273 BPs were identified by the model based on the hospital user feedback, which demonstrates the overall organization performance is about 32.0% lower than the designed benchmark standard. Yet, the KB-QMHE model has considered categories PC-1 and PC-2 as the major problematic areas, whereas category PC-3 and above

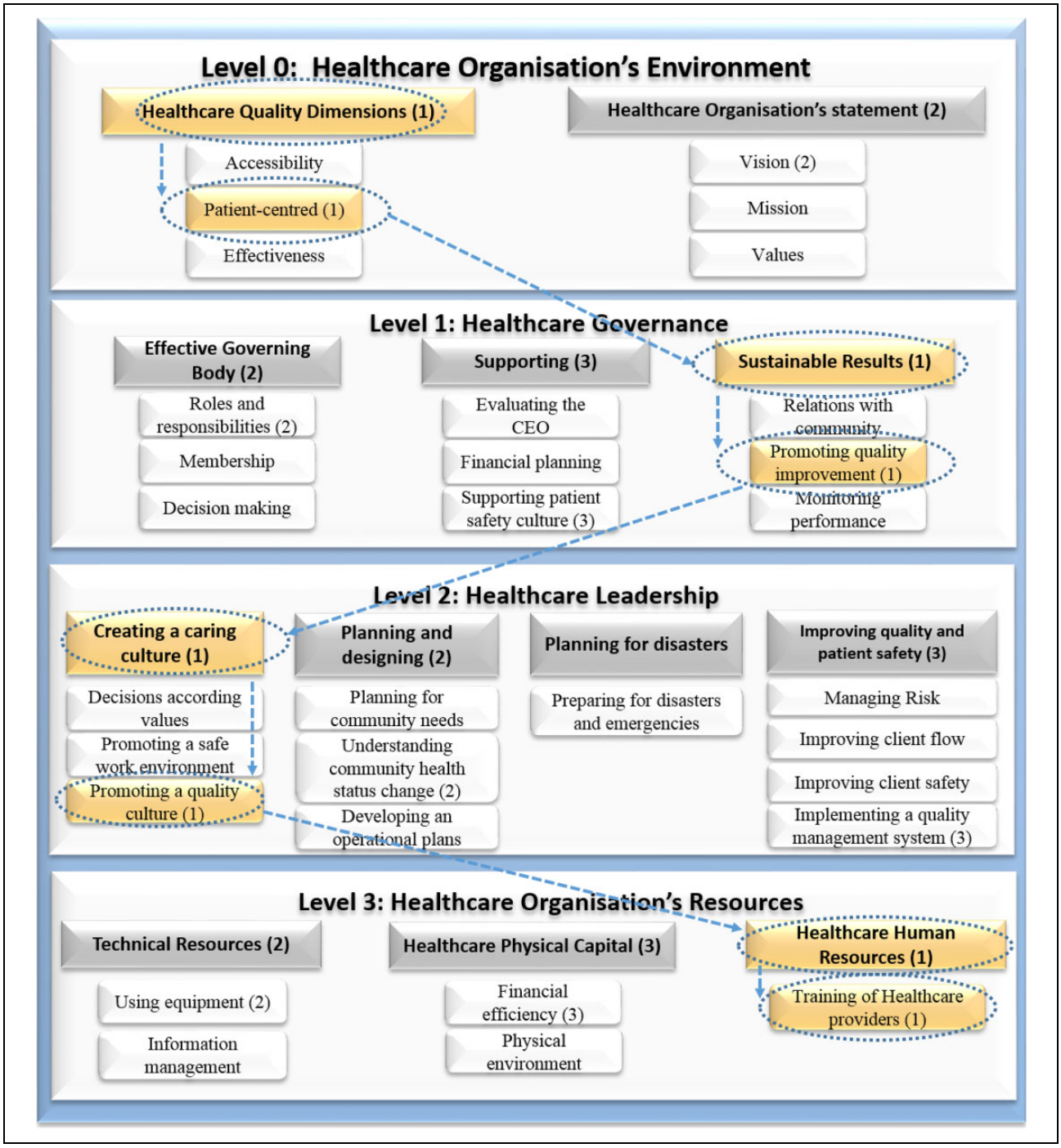

Figure 2. Priority 1: developed QMHE framework. QMHE: quality management in healthcare environment.

are minor problems. Obviously, it can be seen from Table 3 that this hospital has 13.1% of the BPs as major problematic areas and 18.9% of the BPs as minor problems. The detailed breakdown of the modules' (levels 0–3) BP percentages can be highlighted in ratios (serious:unserious) as 76.5% (27.8:48.7), 28.3% (24.5:3.8), 20.9% (5.7:15.2), and 31.9% (4.3:27.6), respectively.

As Table 3 shows, at *level 0 – healthcare organization's environment*, the most serious problems were identified in the *healthcare quality dimensions* submodule and specifically in the *patient-centered* dimension. The second problematic submodule is the *healthcare organization's statement*, where lack of records has been triggered in the *vision* aspect with regard to identifying time frames for achieving the strategic goals of the organization. This has caused a gap in the governing body's overseeing a strategic planning process to develop the organization's vision and set the strategic plan, goals, and objectives.

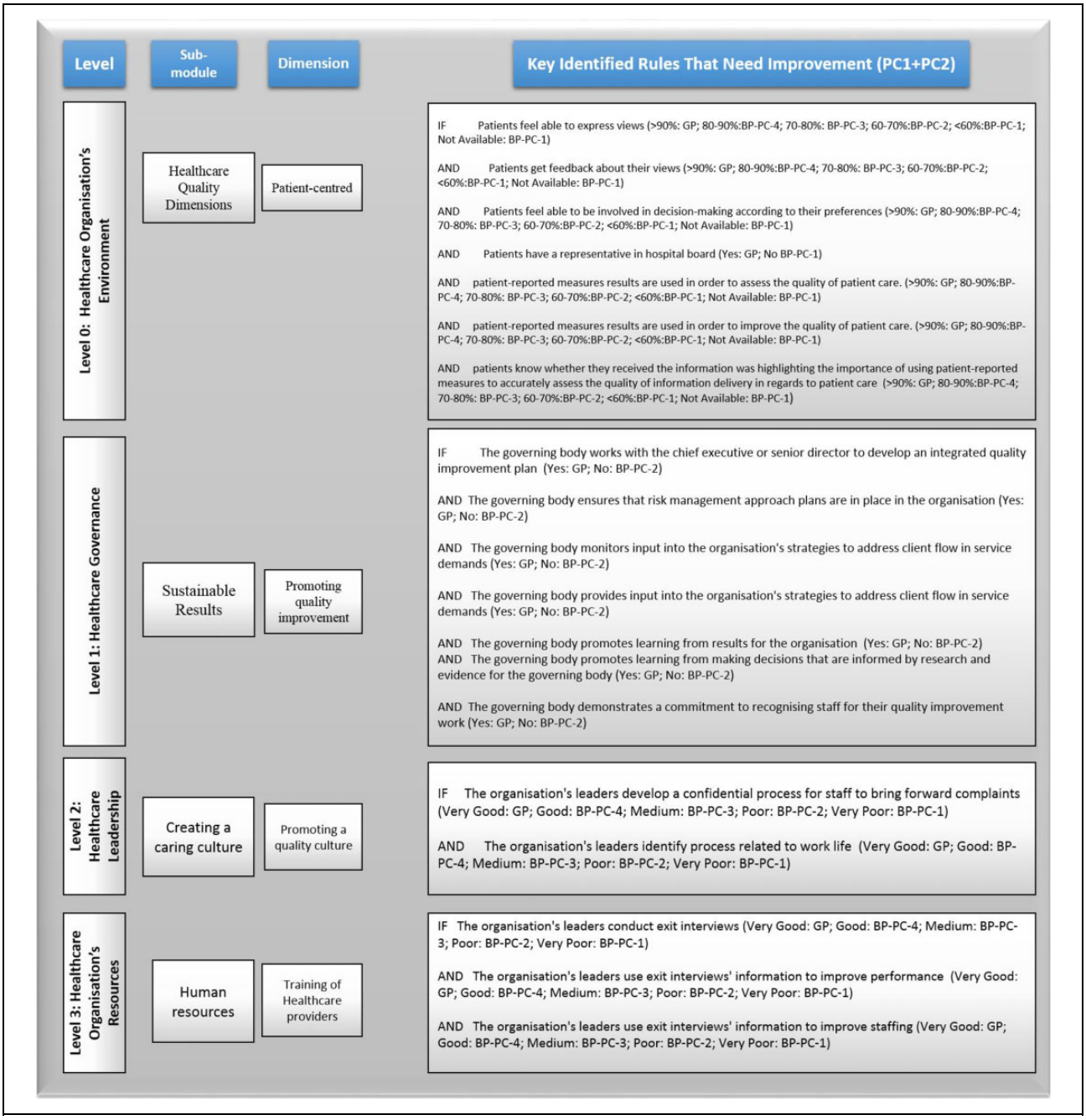

Figure 3. Priority I improvements actions identified by KB-QMHE system. KB-QMHE: knowledge-based quality management in healthcare environment.

Based on the output results of *level 1 – healthcare governance*, the most critical part was the *sustainable results* submodule. The *promoting quality improvement* dimension has proved that governing body of this hospital does not ensure that risk management approach plans are in place in the organization. The second serious submodule at *level 1* is *effective governing body*. The analysis shows that the governing body does not regularly review its roles and responsibilities. The least important submodule at this level is *supporting*. The analysis has shown a gap in reviewing the frequency of adverse events and near misses as part of the organization's quarterly client safety reports.

At *level 2 – healthcare leadership*, the most serious problems were identified in *creating a caring culture* submodule and specifically in the *promoting of a quality culture* dimension. The second problematic submodule is the *planning and designing*, where lack of *understanding community health status change* has shown to be part of the user's output. This has caused a gap between the governing body and the organization's leaders in exchanging

information about the community. The next important submodule at this level is *improving quality.* The analysis has shown a gap in implementing QM system in terms of monitoring service, unit, or program areas to monitor their own process and outcome measures which aligns with the broader organizational strategic goals and objectives. In *planning for disasters* submodule, the hospital has achieved 100% of the KB-QMHE model requirement in accordance with the user's output.

Last, at *level 3 – healthcare organization's resources*, the most critical part was the *human resource* submodule. Some gaps were identified in the training of healthcare providers, defining their roles for client safety and writing and using exit interviews' information to improve performance. *Physical capital* and *technical resources* dimensions are equally the second serious submodules at *level 3*. However, *technical resource* has more BPs compared to *physical capital.* The analysis shows that hospital's leaders do not manage the physical environment to promote client and staff health and safety. They do not have a process to evaluate the effectiveness of the preventive maintenance program in the organization.

The KB-QMHE is embedded with AHP, which also supports the hospital in prioritizing the decision, by facilitating the PV values for each and every part of the model. Table 4 illustrates the PV values for each perspective (levels 0–3), which are used to formulate the developed KB-QMHE framework as shown in Figure 2 with critical areas highlighted.

Priority 1 improvements

The developed KB-QMHE framework shown in Figure 2 illustrates a priority 1 visual improvement road map for the hospital prioritized by the KB-AHP-GAP system. Starting from the strategic levels, the AHP aspect of the KB system has the highest priority (1) at *level 0 – healthcare organization's environment* that hospital should improve on. Within this module, the submodule *healthcare quality dimensions* has been identified as the key where the *patient-centered* dimension plays a major role.

Thereafter, at *level 1 – healthcare governance*, the KB system has identified the submodule *sustainable results* as priority 1, specifically within the dimension of *promoting quality improvement* (by ensuring that risk management approach plans are in place in the organization). Then, at level *2 – healthcare leadership*, the KB system recommends the hospital to start improvements with *creating a caring culture* submodule, in which the *promoting a quality culture* dimension has identified unavailability of monitoring service processes and outcome measures which aligns with the broader organizational strategic goals and objectives.

Next, at *level 3 – healthcare organization's resources*, the KB system has identified the submodule *human resource* as priority 1, where the hospital should give more attention for training healthcare providers and defining their roles in relation to client safety in writing. One of the important aspects of this developed KB system is to have a complete audit trail of the KB rules that have identified prioritized actions for improvement by the AHP and GAP methodologies in order to achieve benchmark standards. Hence, Figure 3 shows the KB system's prioritized audit trail (priority 1) in detail, which can be used to assist with decision-making and to develop an action plan for this hospital across the whole organization's levels (levels 0–3) to achieve the benchmark.

In this case, it is recommended to start with the *patient-centered* dimension in level 0, followed by the *promoting quality improvement* dimension in level 1, followed by the *promoting a quality culture* dimension in level 2, and completed by the *training healthcare providers* dimension in level 3. It can be treated in a step-by-step manner as shown and described above, bearing in mind the immediate actions to be taken for the most serious problems which represent 13.1% of the BPs.

In terms of the KB system, AHP priority 1, and the audit trail of the rules, Figure 3 illustrates the key submodules, dimensions, and priority rules across all levels for improvements to achieve benchmark standards at the hospital. For the sake of briefness, only PC-1 and PC-2 are shown; however, the KB system shows an audit trail for all of the rule-based PCs identified and which need action.

The above figure of the identified key rules shows that hospital has to involve patients and their families in the decision-making process in accordance with their preferences. Besides not promoting quality improvement effectively, this may give an indication that the organization's culture is below the standard of promoting a patient safety and quality culture among its staff. In the same vein, the hospital should focus on training healthcare providers and defining their roles for client safety in writing.

Conclusions

The KB-QMHE system has been developed to assess QMHE using a GAP tool for benchmarking and AHP for prioritizing. This approach can help in detecting issues affecting quality of healthcare systems and to overcome their challenges. It also can be used as a standard to assess QM at any healthcare organization around the globe. Moreover, it suggests primary and secondary solutions based on experts' opinions and functional priorities.

Eight hundred and fifty-two questions were answered by the quality managers in a tertiary hospital in Oman. Output shows 579 GPs representing the GPs of this hospital in implementing QMHE; however, 273 BPs were identified by the model based on the hospital user feedback, which demonstrates that the overall organization performance is about 32.0% lower than the designed benchmark standard. Yet, the KB-QMHE model has considered categories PC-1 and PC-2 as the major problematic areas, whereas category

PC-3 and above are minor problems. Obviously, the targeted hospital has 13.1% of the BPs as major problematic areas and 18.9% of the BPs as minor problems.

The KB-QMHE model has clearly shown that the priority 1, in *level 0*, is to focus on the *patient-centered* dimension in the *healthcare quality dimensions* submodule. Based on the hospital's results, the KB-QMHE model has clearly shown that the priority 1, in *level 1*, needs to focus on the *sustainable results* submodule, especially in the dimension of *promoting quality improvement*. For *level 2*, the analysis shows that hospital has to concentrate on the dimension of *promoting a quality culture* within the *creating a caring culture* submodule. In *level 3*, the KB system suggested that hospital needs to focus on the *human resources* submodule, especially in the dimension of *training healthcare providers* dimension. These results will be used practically by the hospital's governors to identify the gap of the current practice compared to the standardized one and to prioritize their work based on the results of AHP.

Although the developed KB-QMHE model has demonstrated potential in recommending and suggesting improvements for QMHE, the system is still at the prototype development stage. Thus, some limitations are still valid as described below:

- The development of the KB rules only focuses on the important areas to be improved within the QMHE context. Nevertheless, there are unlimited rules that could be implemented in QMHE environment, which become impossible to include in such a limited scope.
- This system used the explanation facility to overcome the uncertainty instead of using fuzzy logic or Bayesian logic. Thus, the assumption that the organization's participant understands the system's questions with related explanations must be taken into account.
- The developed KB-QMHE system is considered similar to other non-healthcare KBS initiatives. A KBS is considered to be a "black box" in the validation process, where the user can see only the output as a result of a set of inputs evaluated. This is because the model is built by the knowledge engineer with the assistance of human experts in the field of QMHE. Therefore, the organization's management level may not appreciate the working effort in developing the KBS as it is difficult to let them visualize the reasoning process inside the system.

For the future work, it is recommended that:

- The system contained over 850 KB rules forming the KB-QMHE system. Thus, for the above suggested areas of expansion, another 1000 rules be added to the developed KB system.
- The system was focusing more on non-clinical healthcare rules to cover QM aspects; hence, for each field (clinical, technical, and administrative), healthcare needs to build its own system to enhance the performance by identifying gaps and prioritize them accordingly.
- Since the implementation process was performed in an Omani healthcare environment, which differs from many other countries in terms of regulations, practice, and culture, there is need for the model to be validated in other countries, which have different culture, and strict policies, and regulations with respect to QMHE.

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References

1. Black K and Revere L. Six Sigma arises from the ashes of TQM with a twist. *Int J Health Care Qual Assur* 2006; 19(3): 259–266.
2. Langabeer JR, DelliFraine JL, Heineke J, et al. Implementation of Lean and Six Sigma quality initiatives in hospitals: a goal theoretic perspective. *Operat Manag Res* 2009; 2(1-4): 13–27.
3. Vest JR and Gamm LD. A critical review of the research literature on Six Sigma, Lean and Student Group's Hardwiring Excellence in the United States: the need to demonstrate and communicate the effectiveness of transformation strategies in healthcare. *Implement Sci* 2009; 4(1): 35.
4. Ferlie EB and Shortell SM. Improving the quality of health care in the United Kingdom and the United States: a framework for change. *Milbank Q* 2001; 79(2): 281–315.
5. Gillies RR, Chenok KE, Shortell SM, et al. The impact of health plan delivery system organization on clinical quality

and patient satisfaction. *Health Serv Res* 2006; 41(4p1): 1181–1191.
6. Donaldson MS, Corrigan JM, and Kohn LT. *To err is human: building a safer health system*. National Academies Press: Washington (DC), 2000.
7. ACI. *Required Organizational Practices Handbook*. Canada: ACI, 2017.
8. Al-Mandhari A. Implementing the patient safety and quality agenda in Oman. In: Al-Mandhari A (ed) *Inter-Regional Technical Consultation on Best Practices in Patient Safety and Quality of Care in the African and Asia Pacific Region*. Muscat, Oman Muscat, Oman, 2016.
9. WHO. *The World Health Report 2000*. WHO, 2000. ISBN: 92 4 156198 X.
10. WHO. *World Health Statistics 2015*. WHO, 2015.
11. Ministry of Health. *Oman's Health Vision 2050*. Muscat: Ministry of Health, 2014. Report No: 08/03/2016.
12. UK DoH. *Report of an Expert Group on Learning from Adverse Events in the NHS*. 2001. Report No: 11/1/2017.
13. Sweis RJ, Al-Mansour A, Tarawneh M, et al. The impact of total quality management practices on employee empowerment in the healthcare sector in Saudi Arabia: a study of King Khalid Hospital. *Int J Product Qual Manag* 2013; 12(3): 271–286.
14. Ali KAM and Alolayyan MN. The impact of total quality management (TQM) on the hospital's performance: an empirical research. *Int J Serv Operat Manag* 2013; 15(4): 482–506.
15. Ju KJ and Park B. An empirical study of total quality management and its influences on nurses' attitude and service performance in healthcare organizations. *Int J Serv Operat Manag* 2016; 24(2): 147–166.
16. Koning H, Verver JP, Heuvel J, et al. Lean Six Sigma in healthcare. *J Healthcare Qual* 2006; 28(2): 4–11.
17. Tolga Taner M, Sezen B, and Antony J. An overview of Six Sigma applications in healthcare industry. *Int J Health Care Qual Assur* 2007; 20(4): 329–340.
18. Elder BL. Six Sigma in the microbiology laboratory. *Clin Microbiol Newsl* 2008; 30(19): 143–147.
19. De la Lama J, Fernandez J, Punzano J, et al. Using Six Sigma tools to improve internal processes in a hospital center through three pilot projects. *Int J Health Care Manag* 2013; 6(3): 158–167.
20. Kollberg B, Dahlgaard JJ, and Brehmer PO. Measuring lean initiatives in health care services: issues and findings. *Int J Product Perform Manag* 2006; 56(1): 7–24.
21. Lummus RR, Vokurka RJ, and Rodeghiero B. Improving quality through value stream mapping: a case study of a physician's clinic. *Total Qual Manag* 2006; 17(8): 1063–1075.
22. Brandao de Souza L. Trends and approaches in lean healthcare. *Leadership Health Serv* 2009; 22(2): 121–139.
23. Suárez-Barraza MF, Smith T, and Dahlgaard-Park SM. Lean service: a literature analysis and classification. *Total Qual Manag Bus Excell* 2012; 23(3–4): 359–380.
24. Harteloh PP. The meaning of quality in health care: a conceptual analysis. *Health Care Anal* 2003; 11(3): 259–267.
25. Campbell SM, Roland MO, and Buetow SA. Defining quality of care. *Social Sci Med* 2000; 51(11): 1611–1625.
26. Assurance NCFQ. *The essential guide to health care quality*. Assurance NCFQ: USA, 2016.
27. Proudlove N, Moxham C, and Boaden R. Lessons for Lean in healthcare from using Six Sigma in the NHS. *Public Money Manag* 2008; 28(1): 27–34.
28. Alolayyan MNF, Mohd Ali KA, Idris F, et al. Advance mathematical model to study and analyse the effects of total quality management (TQM) and operational flexibility on hospital performance. *Total Qual Manag Bus Excell* 2011; 22(12): 1371–1393.
29. Nwabueze U. Organizational improvement: one hospital's experience of implementing TQM. *Int J Bus Perform Manag* 2016; 17(4): 466–487.
30. Mohammad Mosadeghrad A. Why TQM does not work in Iranian healthcare organizations. *Int J Health Care Qual Assur* 2014; 27(4): 320–335.
31. Buck C (ed). Application of Six Sigma to reduce medical errors. *ASQ World Conference on Quality and Improvement Proceedings*. American Society for Quality, 2001.
32. Kuwaiti AA and Subbarayalu AV. Reducing patients' falls rate in an Academic Medical Center (AMC) using Six Sigma "DMAIC" approach. *Int J Health Care Qual Assur* 2017; 30(4): 373–384.
33. Adams R, Warner P, Hubbard B, et al. Decreasing turnaround time between general surgery cases: a Six Sigma initiative. *J Nursing Admin* 2004; 34(3): 140–148.
34. Frankel HL, Crede WB, Topal JE, et al. Use of corporate Six Sigma performance-improvement strategies to reduce incidence of catheter-related bloodstream infections in a surgical ICU. *J Am Coll Surg* 2005; 201(3): 349–358.
35. Ministry of Health. *Quality and Patient Safety: Health Vision 2050*. Ministry of Health O, 2016.
36. Hinchcliff R, Greenfield D, Westbrook JI, et al. Stakeholder perspectives on implementing accreditation programs: a qualitative study of enabling factors. *BMC Health Serv Res* 2013; 13(1): 437.
37. Ministry of Health. *Forming committee to create national healthcare standards*. Ministry of Health, 2016.
38. Al Khamisi YN, Khan MK, and Hernandez EM (ed). A conceptual model for a hybrid knowledge-based system for quality management at healthcare environment. In: *Proceedings international conference on industrial engineering operations management*. 2017, pp. 22–34.
39. Al Khamisi YN, Khan MK, and Hernandez EM (ed). New methodology for improving quality management in healthcare environment using a hybrid knowledge-based system. In: *Proceedings World Congress Engineering*. 2017, pp. 692–696.
40. Al Khamisi Y, Khan MK, and Munive JE. Knowledge-based lean Six Sigma system for enhancing quality management performance in healthcare environment. *Int J Lean Six Sigma* 2018; 10(3).
41. Al Khamisi YN, Hernandez EM and Khan MK (ed). Developing a Knowledge-Based Lean Six Sigma Model to Improve Leadership's Performance in Healthcare Environment. In: *Proceedings SQM XXVI*. 2018, pp. 31–42.

42. Al Khamisi YN, Khan MK and Hernandez EM (ed). Evaluating Healthcare Governance using Knowledge-Based System to Enhance Quality Management. In: *Proceedings the World Congress on Engineering*. 2018, pp. 426–428.
43. Quinn K. Expert system shells: what to look for. *Ref Serv Rev* 1990; 18(1): 83–86.
44. Büyüközkan G, Çifçi G, and Güleryüz S. Strategic analysis of healthcare service quality using fuzzy AHP methodology. *Exp Syst Appl* 2011; 38(8): 9407–9424.
45. Dursun M, Karsak EE, and Karadayi MA. A fuzzy multi-criteria group decision making framework for evaluating health-care waste disposal alternatives. *Exp Syst Appl* 2011; 38(9): 11453–11462.
46. Chen YH, Liu CF, and Hwang HG. Key factors affecting healthcare professionals to adopt knowledge management: the case of infection control departments of Taiwanese hospitals. *Exp Syst Appl* 2011; 38(1): 450–457.
47. Chae YM, Kim HS, Tark KC, et al. Analysis of healthcare quality indicator using data mining and decision support system. *Exp Syst Appl* 2003; 24(2): 167–172.
48. Giarratano JC and Riley G. *Expert systems*, 4th ed. Australia: Thomson, 2005.
49. Awad EM and Huntington D. *Building expert systems: principles, procedures, and applications*. USA: West Publishing Co., 1996.
50. Mohamed N. *The Development of a Hybrid Knowledge-Based System for Designing a Low Volume Automotive Manufacturing Environment*. UK: The Development of A Hybrid Knowledge-Based (KB)/Gauging Absences of Pre-Requisites (GAP)/Analytic Hierarchy Process (AHP) System for the Design and Implementation of a Low Volume Automotive Manufacturing (LVAM) Environment: University of Bradford, 2013.
51. Khan M. Development of an expert system for implementation of ISO 9000 quality systems. *Total Qual Manag* 1999; 10(1): 47–59.
52. Udin Z. A hybrid knowledge-based approach for planning and designing a collaborative supply chain management system. *School Eng Design Technol* 2004.
53. Khan M and Wibisono D. A hybrid knowledge-based performance measurement system. *Bus Proc Manag J* 2008; 14(2): 129–146.
54. Milana M, Khan MK, and Munive JE, (ed). A framework of knowledge based system for integrated maintenance strategy and operation. *Appl Mech Mater(Trans Tech Publ)* 2014, pp. 619–624.
55. Aldairi J, Khan M, and Munive-Hernandez JE. Knowledge-based lean Six Sigma maintenance system for sustainable buildings. *Int J Lean Six Sigma* 2017; 8(1): 109–130.
56. Saaty TL. *The analytic hierarchy process: planning, priority setting, resources allocation*. New York: McGraw, 1980.

Appendix 1

List of experts in healthcare QM interviewed by the researcher from July 10 to August 20, 2017 and from December 13, 2017 to January 10, 2018

	Expert's name	Position	Organization
1	Dr Ahmed Al Mandhari	Director-General of National Quality Assurance Centre	MoH Oman
2	Dr Rashid Al Abri	Associated Professor, Head of Medical Education, College of medicine and Health sciences	Sultan Qaboos University Oman
3	Dr Maha Al Shuaibi	Director of Development and Quality	Sultan Qaboos University Hospital Oman
4	Dr Yasmeen Al Hatmi	Deputy Director of Development and Quality	Sultan Qaboos University Hospital Oman
5	Mr Hamdan Al Siyabi	Head of Quality Monitoring	Sultan Qaboos University Hospital Oman
6	Dr Ismail Al Rashdi	Director of Quality and Patient Safety	Royal hospital Oman
7	Ms Khalsa Al hinai	Head of Quality Department	Khoula Hospital Oman