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## Knowledge-Based Lean Six Sigma System for Enhancing Quality Management Performance in Healthcare Environment

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Quality Management Performance in Healthcare  
Environment**

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# Knowledge-Based Lean Six Sigma System for Enhancing Quality Management Performance in Healthcare Environment

## Abstract

**Purpose**– This paper presents the development of a Knowledge-Based System (KBS) to support the implementation of Lean Six Sigma (L6 $\sigma$ ) principles applied to enhance Quality Management (QM) performance within a healthcare environment.

**Design/methodology/approach**– The process of KBS building has been started by acquiring knowledge from experts in field of L6 $\sigma$  and QM in healthcare. The acquired knowledge has been represented in a rule-based approach for capturing L6 $\sigma$  practices. These rules are produced in IF....THEN way where IF is the premise and THEN is the action. The produced rules have been integrated with Gauging Absence of Pre-requisites (GAP) technique to facilitate benchmarking of best practice in a healthcare environment. A comprehensive review of the structure of the system is given, detailing a typical output of the KBS.

**Findings**– Implementation of L6 $\sigma$  principles to enhance QM performance in a healthcare environment requires a pre-assessment of the organisation's competences. The KBS provides an enhanced strategic and operational decision making hierarchy for achieving a performance benchmark.

**Research limitations/implications**– The KBS needs validation in real healthcare environment which will be done in Oman's hospitals.

**Practical implications**–The paper is intended to benefit quality management practitioners in the healthcare sector during decision making to achieve performance improvement against a best practice benchmark.

**Originality/value**– This research presents a novel application of a hybrid KBS with GAP methodology to support the implementation of L6 $\sigma$  principles to enhance QM performance in a healthcare environment.

**Keywords**- Lean Six Sigma (L6 $\sigma$ ), Quality Management in Healthcare Environment (QMHE), Knowledge-Based System (KBS), Gauge Absence Prerequisites (GAP)

**Paper type**- Research paper

## 1. Introduction

In similar way that different business organisations have been concerned with improving quality of service and becoming more efficient and effective in the use of resources in order to be more competitive and achieve long-term success, healthcare organisations have also understood the importance of quality improvement. Quality in healthcare is concerned with the service provided to patients, safety, performance of internal operations, healthcare procedures and the supply chain, etc. In the last four decades, healthcare organisations have attempted the implementation of different initiatives to improve their quality performance, such as Total Quality Management (TQM), Six Sigma (6 $\sigma$ ) and Lean Thinking, with different levels of success.

Although, the Quality Management (QM) aims and methodologies are very comprehensive, the failures of organisations trying to implement a successful QM program have been well noted (Mi Dahlggaard-Park et al., 2006). 6 $\sigma$  has been implemented gradually in healthcare institutions since early 2000 (Black and Revere, 2006). Although, the principles of 6 $\sigma$  can be

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3 found in the work of quality pioneers like Deming in the 1980s, Revere et al. (2004) claimed  
4 that  $6\sigma$  emerged from the fertile environment created by the TQM movement in US  
5 healthcare organisations. There was a key need in those organisations for significant,  
6 continuous improvement in the quality of patient care outcomes, processes, and services.  
7 Some operational inefficiencies in healthcare are related to the direct healthcare service  
8 delivery process, while others are associated with the administrative and operational  
9 healthcare system (Koning et al., 2006).  
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14 Lean, as a quality improvement tool, is a process of re-engineering philosophy that  
15 includes strategic principles and tools at operational level. Lean system focuses on  
16 eliminating wastes by focusing on the value chain, doing more with less, doing things better,  
17 and achieving an improved performance. Sloan et al. (2014) defined categories of readiness  
18 factors for the successful launch of Lean principles in healthcare such as: strong leadership  
19 support, understanding value and customer groups in healthcare, undertaking an end-to-end  
20 process view, staff training, establishing measurement and reward systems aligned to Lean  
21 objectives. Similarly to  $6\sigma$ , healthcare institutions adopted Lean system values from the  
22 manufacturing industry (Vest and Gamm, 2009). Much of the attention is focused specifically  
23 on work processes, quality, and efficiency.  
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30 In fact the current healthcare systems around the globe has several gaps that need to be  
31 filled. For example, the UK's Department of Health mentioned that almost £400 million was  
32 paid in clinical negligence claims and adverse incidents, causing nearly £2 billion per year of  
33 losses (UK 2001). As a result, the National Health Service (NHS) implemented a number of  
34 quality improvement concepts, most recently  $6\sigma$  and Lean (Proudlove et al. 2008). In the  
35 USA, the National Committee of Quality Assurance estimated that US \$3.6 billion had been  
36 paid as a result of preventable hospitalization, which could have been avoided had the total  
37 health care system operated at appropriate benchmark levels (Feng and Manuel, 2008).  
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44 In Oman, where the KBS will validated, Health Vision 2050 (2016) Report highlighted  
45 a number of challenges for enhancing and developing healthcare research which will have an  
46 impact on QM performance. These challenges included: insufficient funds, lack of research  
47 prioritization accordingly to the national plan, poor coordination between Ministry of Health  
48 and other healthcare Organisations within Oman, poor dissemination of research results,  
49 insufficient follow up of the outcomes, and immature research culture among health care  
50 providers (Ministry of Health, 2016).  
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3 To overcome these challenges, the proposed Knowledge-Based System (KBS) can  
4 provide such lead aid support. The implementation of the KBS clearly defines the integration  
5 of Lean Six Sigma (L6 $\sigma$ ) principles as an advanced performance improvement philosophy for  
6 QM in a Healthcare Environment (QMHE). The hybrid L6 $\sigma$ -QMHE system also captures the  
7 benchmarking with international best practice to enhance performance. It will be embedded  
8 with Gauging Absence Pre-requisites (GAP) technique to support such benchmarking and  
9 facilitating decision making processes.  
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15 KBS will provide new ways of sharing and distributing knowledge in fast time and  
16 reliable way. Increasing productivity, consistency and output are the most important benefits  
17 of KBS. According to Giarratano and Riley (2005), KBS increase confidence that the correct  
18 decision was made by providing a second opinion to a human expert. They added that KBS  
19 can explain in details the reasoning that led to a conclusion. Furthermore, KBS are considered  
20 to be steady, unemotional, and provide complete responses at all times.  
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26 The originality of this research is to integrate the use of KBS with GAP methodology  
27 to design an integrated KBL6 $\sigma$ -QMHE system to be used as decision-making tool in  
28 healthcare environment. This will accomplish the necessities of investigating quality  
29 problems and recommend effective solutions according to international benchmarks.  
30 Consequently, this paper presents a novel approach to the design a KBL6 $\sigma$ -QMHE system  
31 through the application of KBS that has not been carried out in the past in this field. The  
32 hybrid KBS and GAP method is selected based on the reasons that firstly, a large number of  
33 Key Performance Indicators (KPIs) are usually involved in successful implementation of  
34 QMHE and the relationships between them are somewhat difficult. Secondly, the GAP  
35 analysis will identify the gap between each KPI and the desired point.  
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43 The proposed KBS will benchmark the current position with the ideal framework  
44 resulting from extensive evaluation of international L6 $\sigma$  quality concepts for healthcare  
45 organisations, and will conclude by recommending practical solutions to overcome the  
46 identified gaps. Thus, the research will provide an active decision support system that will  
47 assist senior management, quality managers, and practitioners in the healthcare organisations  
48 to arrange and monitor their performance and enhance their productivity comparing to  
49 benchmark standards.  
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## 2. Literature Review

The main elements of the proposed conceptual system are QMHE, L6 $\sigma$ , KBS, and GAP, and these will be discussed in this section in the light of current research.

### 2.1 *Quality Management in Healthcare Environment (QMHE)*

Across all disciplines, at all levels, and throughout the world, healthcare is becoming more complex (Plsek and Greenhalgh, 2001). Despite that, the healthcare industry is considered to be slow in adopting new quality improvement practices compared to manufacturing industries, although anecdotal evidence suggests they are now being gradually diffused throughout hospitals on an increasing basis (Langabeer et al., 2009). The cost of medical care is increasing at an alarming and unsustainable rate worldwide. Admittedly, a significant percentage of this cost increases can be attributed to an aging population and technological advances (Koning et al., 2006). Till now, there is no agreement among reserachers to define QMHE. Harteloh (2003) discussed how difficult it was to standarise a definition for quality in healthcare. The patient's satisfaction has been used widely to measure the quality of services provided in healthcare facilities. The Agency for Healthcare Research and Quality (AHRQ) defines it as "*doing the right thing for the right patient, at the right time, in the right way to achieve the best possible results*" (Assurance, 2016). In the UK, NHS's definition of quality is consisting of three components; effectiveness of the treatment, care provided to patients and experience patients have of the treatment (Darzi, 2007).

Basically, healthcare systems have been under accumulative pressure to advance performance by controlling healthcare costs, ensuring high-quality, patient services and better access to care at the same time (Chilingerian and Sherman, 2011). If a healthcare system is not working to improve health, there would be no reason for it (WHO, 2000). According to Irfan and Ijaz (2011) the high level of patients' expectations about the service quality has pressured the healthcare service providers to detect the key factors that are essential to raise healthcare services that improve patients' satisfaction and decrease time and money involved in managing a patients' complaints.

Brown and Patterson (2001) raised a major controversy in the famous report, *To Err is Human*. The report recognised healthcare errors as a major public health subject leading to the death of at least 44,000 and perhaps as many as 98,000 each year in US hospitals.

The NHS distributed a report in 2000 detecting the important effect of adverse events in the NHS (Baker and Norton, 2002) and (Vincent et al., 2001). Integrated health systems

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3 are commonly considered to run trustable performance in terms of quality and patient safety  
4 as a result of effective communication and standardized protocols within hospitals (Gillies et  
5 al., 2006).  
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8 In fact, healthcare leadership plays a critical role in any quality management system  
9 success. To overcome these challenges Stefl and Bontempo (2008) introduced five  
10 competency domains common among all practicing healthcare managers: communication and  
11 relationship management, professionalism, leadership, knowledge of the healthcare system,  
12 and business skills and knowledge. Effective healthcare leadership, as a pillar of this  
13 research's system, begins with understanding the various responsibilities and authority of  
14 individuals in the organisation and how these individuals work together (JCI, 2010).  
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## 20 *2.2 Lean, Six Sigma ( $6\sigma$ ) and Lean Six Sigma ( $L6\sigma$ ) in healthcare*

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22 Lean as an independent terminology can be defined as a way to specify value, line up  
23 value-creating actions in the best sequence, conduct these activities without interruption  
24 whenever someone requests them, and perform them more and more effectively (Womack  
25 and Jones, 2003). It helps to reduce work lead times, remove all practices of waste, reduce  
26 setup times, and map the value stream. It seeks to prevent sub-optimisation by its  
27 concentration on the whole value chain. Consequently, the success of Lean's implementation  
28 depends on organisational infrastructure, deployment plans, analytical tools, and control  
29 (Koning et al., 2006).  
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35 The term Lean Healthcare, which is considered to be quite new, is concentrating on  
36 efficiency and patient satisfaction (Brandao de Souza, 2009). Bridges (2006) proposed that  
37 Lean can be used not only to sleek waste from the healthcare environment, but as a method  
38 of producing real motivations for innovation and value creation. Another example has been  
39 introduced by Lummus et al. (2006) when they have implemented Lean in a physician's  
40 clinic and the results showed that the capacity of that office has increased without adding  
41 people or equipment, lower waiting times for people with scheduled appointments, increase  
42 the opportunity for patients without appointments to be seen at the last minute, and lower the  
43 stress levels for the clinic's staff.  
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50 In the UK, no one before 2005 in the NHS had tried to implement Lean principles  
51 through entire hospital (Fillingham, 2007). It has launched in releasing time to care (RTC)  
52 programme which was designed to utilise Lean improvement techniques, the intrinsic  
53 motivators of social movement theory and the front line engagement theories of large-scale  
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3 change in a healthcare environment (Waring and Bishop, 2010). According to Suárez-  
4 Barraza et al. (2012) it is important to study the dynamics which are present when Lean  
5 service is applied, such as understanding if the management approach is given gradually, in  
6 evolving phases over time, or not.  
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10 Moving to  $6\sigma$ , it can be defined as a powerful strategy developed to accelerate  
11 improvement in product, process and service quality by relentlessly focusing on reducing  
12 variation and eliminating waste (Antony and Coronado, 2001). It is deployed by carrying out  
13 improvement projects that selected based on a translation of the company strategy into  
14 operational goals (Pyzdek, 2004). In the previous twenty years, healthcare organisations such  
15 as Baxter Health and Mount Carmel Hospital have shown success through  $6\sigma$  implementation  
16 (Koning et al., 2006). In 2001,  $6\sigma$  was used in medication delivery processes at Froedtert  
17 Hospital, USA. The results showed that by implementing  $6\sigma$  methodology, a significant  
18 variability in the ordering and processing of Intra-venous drips was identified. In these areas,  
19 standards were created by a multidisciplinary task force to reduce variation (Buck, 2001).  
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28 In fact,  $6\sigma$  adds value to Lean by utilizing of data in decision-making and using  
29 methodologies that enhance a scientific method to achieving quality (Arnheiter and Maleyeff  
30 2005). The integration of Lean and  $6\sigma$  happened in the late 1990s and early 2000s (George,  
31 2003). This integration aims to target each and every opportunity for improvement in  
32 particular organisation and attempts to provide empowerment even at the higher-level  
33 process analysis stages (Pepper and Spedding, 2010). According to Snee (2010),  $L6\sigma$  can be  
34 defined as *'a business strategy and methodology that increases process performance  
35 resulting in enhanced customer satisfaction and improved bottom line results'*. It is a  
36 business improvement methodology that aims to maximise shareholders' value by improving  
37 quality, speed, customer satisfaction, and costs: it achieves this by merging tools and  
38 principles from both Lean and  $L6\sigma$  (Laureani and Antony, 2011). When an Organisation  
39 plans to construct a new framework for  $L6\sigma$ , this framework should be strategic and process  
40 focused, balanced between the two philosophies, balanced between complexity and  
41 sustainability and structured around the type of problem experienced (Pepper and Spedding,  
42 2010).  
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53 Antony (2006) has summarised the benefits of  $L6\sigma$  from the literature in both  
54 manufacturing and service as; ensuring services/products conform to what the customer  
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3 needs, removing non-value adding steps (waste) in business processes, reducing cost of poor  
4 quality, reducing the incidence of defective products/transactions, shortening the cycle time  
5 and delivering the correct product/service at the right time in the right place.  
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9 Pepper and Spedding (2010) concluded their paper by saying if Lean is applied without  
10  $6\sigma$ , then there is a lack of tools to force improvement to its full potential and if  $6\sigma$  is  
11 implemented without Lean thinking, then there would be a lack of tools for the continuing  
12 improvement. Hence, the union of Lean and  $6\sigma$  improvement methods is necessary to  
13 facilitate the reduction of the cost of complexity (George, 2003).  
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18 The process needed as a tool to improve L $6\sigma$  process in the healthcare organisation is  
19 called DMAIC, explained as: *Define* which process or product that needs improvement,  
20 *Measure* data that help set priorities and criteria, *Analyze* carefully the recorded  
21 measurements, *Improve* result of analysis accordingly and *Control* if the implementation was  
22 successful and make sure that improvement is continuous over time (Lin et al., 2013). This  
23 methodology is repeated if it is not successful the first time. The implementation strategy in  
24 this research is built on extensive investigation of DMAIC key success and failure factors.  
25 This implies a DMAIC cycle as a screen type approach in which the project or issue must be  
26 tested against some main conditions to decide whether it can be structured to meet the  
27 DMAIC criteria.  
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34 As an example of L $6\sigma$  implementation at healthcare can be seen in Mayo Clinic  
35 Rochester in the USA. In 2011 the use of Lean and  $6\sigma$  approaches in this organisation has  
36 increased operation theatre efficiency and financial performance. The operation room  
37 efficiency was enhanced by process mapping, top management support, staff involvement,  
38 and sharing performance metrics (Cima et al., 2011). Kuo et al. (2011) examined L $6\sigma$   
39 application in post anaesthesia care unit workflow. They found that L $6\sigma$  in healthcare system  
40 closed the service gaps between healthcare workers and patients, balanced the needs of health  
41 care managers, and provided health care services to patients by combining the Lean speed  
42 and  $6\sigma$  high-quality principles.  
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49 Another example of L $6\sigma$  approach implementation can be seen in joint replacement  
50 surgical procedures at the Richard L. Roudebush Veterans Affairs Medical Centre, Indiana.  
51 Perioperative processes for patients undergoing total joint replacement were redesigned to  
52 fulfil the L $6\sigma$  requirements. A multidisciplinary team including the orthopaedic surgeons,  
53 frontline staff, and executive management identified waste in the current processes and  
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3 initiated changes to reduce waste and increase efficiency. The results showed that length of  
4 stay decreased 36% overall, decreasing from 5.3 days during the pre-project period to 3.4  
5 days during the 20-month sustainment period. Moreover, the centre's returns has increased  
6 by \$1 million annually comparing with baseline cost and volumes (Gayed et al., 2013).  
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9 Despite the above implementation examples, Glasgow et al. (2010) emphasised that  
10 L6 $\sigma$  approach is hard to be evaluated, given that the lack of difficult estimation or obviously  
11 sustained enhancements offers little evidence supporting broad adoption. According to Snee  
12 (2010), resistance due to lack of understanding of L6 $\sigma$  and a lack of belief that it will work,  
13 and lack of roadmaps to follow are the most critical challenges that face L6 $\sigma$  implementation.  
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17 It is more likely to have a successful and sustainable process improvement by joining  
18 L6 $\sigma$  implementation with the concept of realistic evaluation that considers individual and  
19 environmental characteristics (Black, 2009). To summarise, Lean, 6 $\sigma$ , or L6 $\sigma$  are not for the  
20 faint of heart. They need hard work, self-reflection, the willingness to learn, and the  
21 willingness to change (Bliss, 2009).  
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### 26 27 *2.3 Knowledge Based Systems (KBS)*

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29 The goal of Artificial Intelligence (AI) as a science is to make machines think things  
30 that would need intelligence if done by humans. According to Munakata (2008), although  
31 there is no standard definition of AI, one could be: *'the study of making computers do things*  
32 *that the human needs intelligence to do'*. AI has several techniques and methods used for  
33 implementation. One of the widely used techniques of AI is the Knowledge Based (KBS) or  
34 Expert Systems (ES). Quinn (1990) defined an Expert System as *'an interactive computer*  
35 *program that asks the same questions a human expert would ask, and from the information*  
36 *given to it by the user, provides the same answer the expert would provide'*.  
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44 According to Khan et al. (2011), the terms ES and KBS have similar meaning;  
45 therefore, most scholars use them synonymously. In the early years of AI, there was a  
46 realisation that the ES were not truly reaching the knowledge, experience and wisdom of  
47 human experts and it was a misnomer to call them ES. However, since they contained a  
48 strong element of knowledge, they were later re-named (more accurately) as KBS. The final  
49 goal of ES is to capture the experts' experience into a single knowledge base (Chapman and  
50 Pinfeld, 2001). It is the input from various sources such as human expert, research papers,  
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3 and books (Benavides, 2002) as the authors of this paper have done to acquire knowledge  
4 from L6 $\sigma$  and QM in healthcare.  
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7 Sunnapwar and Kodali (2006) emphasized that KBS should be implemented carefully  
8 because it is expensive and relative investments are not reversible. Failures of KBS range  
9 from selecting the wrong problem domain, chasing the wrong talent to develop the KBS,  
10 poor verification and validation of the system, a lack of understanding of the expert's  
11 knowledge, and other causes. Currently, KBS are widely applied in business organisations to  
12 facilitate the decision making process (Udin, 2004; Moud Nawawi, 2009; Milana et al., 2014;  
13 Aldairi, 2015) because they are an accurate and effective decision-making tool. Hence,  
14 healthcare organisations have adopted and applied different quality tools and systems in  
15 recent times, with some even developing their own quality-based initiatives. However, the  
16 nature and complexity of healthcare environment which directly impact on humans requires  
17 leaders/managers to carefully apply appropriate QM systems suitable for this critical  
18 environment. Consequently, the authors desire to use KBS in healthcare environment to  
19 facilitate the decision making process that leads to minimise the risk and enhance patient  
20 safety.  
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#### 31 *2.4 Gauging Absence Pre-requisite (GAP)*

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34 GAP analysis is a method to assess the gap between the manufacturer's (services at  
35 healthcare Organisations) benchmark implementation compared with current status level  
36 (Mohamed, 2013). In any type of application, an audit should be conducted to assess the gap  
37 between what actually exists in a specific environment and the essential or desirable  
38 prerequisites for effective implementation. The information needed to apply GAP could be  
39 also collected from the users through a designed questionnaire embedded in the KBS. After  
40 the GAP analysis audit or questionnaire, the Problem Categories (PCs) can be recorded into  
41 two reports: all positive elements and procedures (Good Points – GPs) already existing in  
42 report and all negative elements (Bad Points – BPs) representing non-existence of data, poor  
43 systems in the other report (Khan, 1999).  
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51 GAP methodology has been integrated with hybrid KBS as a benchmarking tool in  
52 different fields, such as supply chain management (Udin, 2004), performance measurement  
53 systems (Khan and Wibisono, 2008), maintenance strategy and operation (Milana et al.,  
54 2014) and in sustainable maintenance (Aldairi, 2015).  
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Therefore, this research will integrate the GAP methodology within a KBS system to the area of QMHE in order to measure the differences between existing practices and the desired (benchmark) ones. It will focus on internal and external benchmarking.

### 3. Development of KBL6 $\sigma$ System to support Quality Management of Healthcare Environment (KBL6 $\sigma$ -QMHE)

To develop a KBS, a process starting from knowledge acquisition, followed by knowledge representations, followed by GAP methodology integration and concluding by verifying its structure and contents.

#### *Knowledge acquisition*

Actually, knowledge acquisition refers to the process of acquiring, processing, understanding, and recalling information via interviewing, observation, brainstorming or any other technique. Awad and Huntington (1996) defined it as a process of arresting expert's thought and experiences. They added that knowledge acquisition is a demanding process in which a knowledge engineer cooperates with the expert to transform expertise into coded program by elicit information from the expert, interpreting the information and build rules that represent the expert's solutions. As a pre-requisites for acquisition, knowledge engineer must take in consideration the problem domain, selecting the right expert and preparing well for the knowledge acquisition.

In this paper, an extensive knowledge acquisition process has been carried out with healthcare quality managers, L6 $\sigma$  Black Belt and Master Black Belt practitioners. The in-depth meetings with these experts have been carried out to capture the knowledge and assure the critical selection of the KBS Key Performance Indicators (KPIs). In order to formulate the L6 $\sigma$  for QMHE in a KB system, KPIs are considered at each stage to create the suitable system as Figure 1 shows. The mentioned KPIs will be used later to generate the KB rules for different variables of L6 $\sigma$  in healthcare based on different levels of decision making at each organisational hierarchy.

#### *Knowledge representation*

Based on the knowledge acquired, it is very critical to know how to represent this knowledge in a practical way because it is the basis for learning how knowledge was obtained and interrupted. It could be represented into frames or rules. Rules represent the

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3 major elements of the scheme and easy to understand and write. The related KPIs will be  
4 utilised to generate the KB rules for different variables of L6 $\sigma$  in QMHE based on  
5 organisational hierarchy levels of decision making. Rules are produced in IF....THEN way  
6 where IF is the premise and THEN is the action (Awad and Huntington 1996). In this paper,  
7 the proposed system will be built by rules' production as it is simplified in following  
8 example;  
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14 **IF** *home state is London*

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16 **THEN** *home country is the UK*  
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19 The KB rules will be stored in the KB database and integrated with the GAP analysis  
20 methodology to achieve optimal analysis and assessment outcomes of the decision making  
21 process as the next step will show.  
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### 25 **GAP analysis methodology**

26 The main purpose of this step is to benchmark each rule with the desired level. To  
27 achieve that, all rules will be converted to questions in the KBS as the following example  
28 shows;  
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32 **IF** *the organisation has a benchmark of Lean Six Sigma with other organisation (Yes:*  
33 *GP; No: BP-PC-1)*  
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37 **Q.** *the organisation has a benchmark of Lean Six Sigma with other organisation? (Yes or*  
38 *No)*  
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41 If the user selected Yes, it means a Good Point (GP) and if he/she selected No, it  
42 means Bad Point (BP). This BP is ranged from Problem category (PC) 1 which indicate a  
43 very serious problem to Problem category (PC) 5 which indicates a minor problem as  
44 Appendix A shows.  
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### 48 **Verifying the structure and contents of the KBS**

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50 The design of the system is set to assess the organisational capabilities from different  
51 perspectives, starting from a broad strategic level and narrowing down to the most  
52 operational level. As the study is targeting the implementation of L6 $\sigma$  in a QMHE, it is  
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necessary to study the critical success factors and critical failure factors involved in implementing L6 $\sigma$  in a similar environment.

In fact, the initial KBL6 $\sigma$ -QMHE KBS structure was presented in two conferences' papers (Al Khamisi et al., 2017a) and (Al Khamisi et al., 2017b). The feedback obtained was used to refine the KB system and consequently the related development steps as part of the verification process.

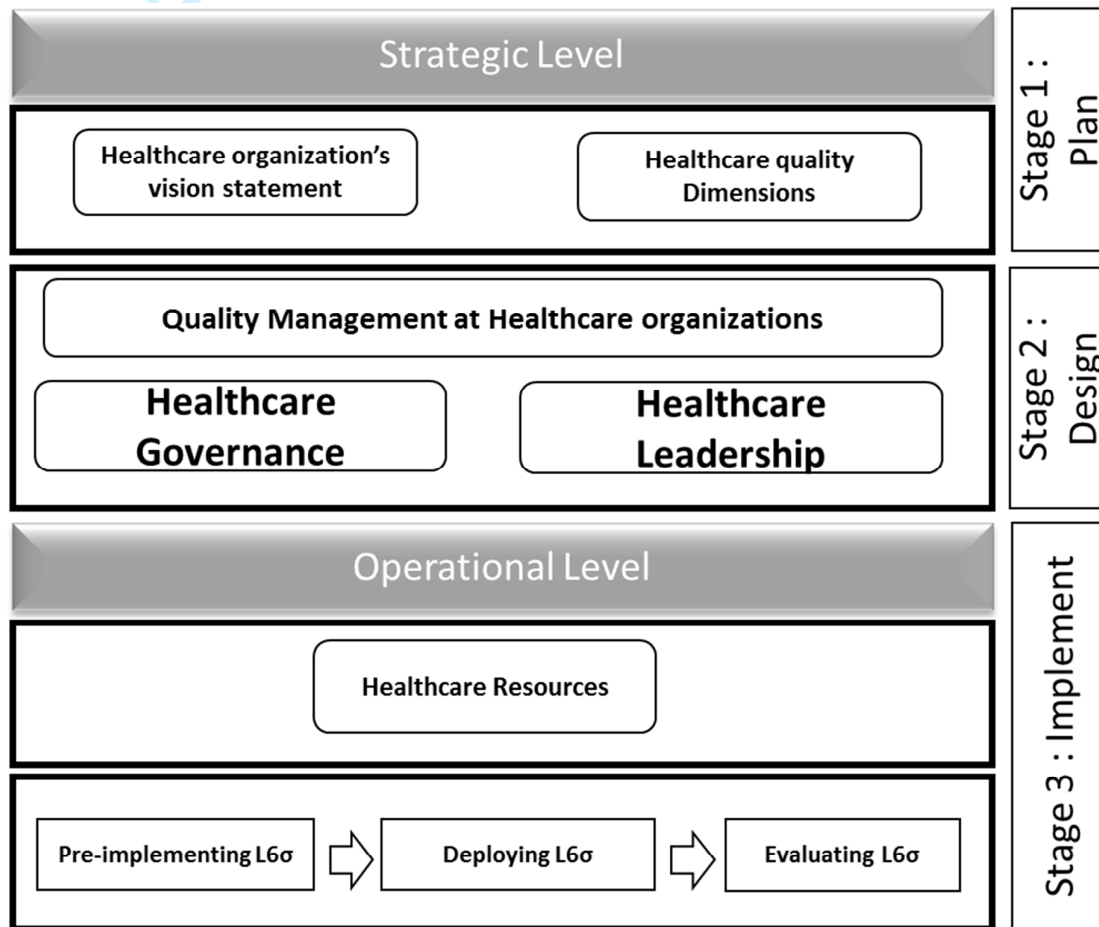


Figure. 1 The initial structure of KBL6 $\sigma$ -QMHE System

### Stage 1: Planning

The first step for the L6 $\sigma$  KBS is to formulate the planning stage at the strategic level. This planning stage consists of healthcare Organisation's statement and healthcare quality dimensions. Healthcare quality dimensions have been discussed and illustrated in WHO,

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3 ACI, JCI and NHS as part of several healthcare dimensions. ACI (2016) introduced eight  
4 quality dimensions in healthcare, as follows: *population focus, accessibility, safety, work*  
5 *life, client-centered services, continuity of services, effectiveness and efficiency*. Comparing  
6 with ACI, the WHO report (2006) added *equitability* and excluded *population focus and*  
7 *work life*. The selection of L6 $\sigma$ -QMHE system dimensions (*patient-centered, accessibility*  
8 *and effectiveness*) has been included after a process of comparison between literature and  
9 discussion with healthcare quality experts.  
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15 The clarity of goals, objectives and readiness assessment are very essential in  
16 development of the planning stage to look for the different aspects that affect the main  
17 target. Poister and Streib (2005) found that the most frequently reported elements were the  
18 development of goals and objectives and the development of a vision for a future followed  
19 by review of the organisational mission. George (2003) summarized approaches to conduct  
20 a readiness assessment as: select the L6 $\sigma$  Champion, establish a baseline of the  
21 organisation, interview top management, engage key influencers and assess the impact of  
22 what is found. As mentioned above, two main factors will be considered in the planning  
23 stage: an organisation's vision statement and assessment of quality dimensions.  
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### 30 **Stage 2: Designing**

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34 Moving to designing stage, the first factor that needs to be considered and captured in  
35 the L6 $\sigma$  KB system is healthcare QM standards, through a systematic review of different  
36 healthcare standards such as: Joint Commission International (JCI) (JCI, 2010),  
37 Accreditation Canada International (ACI) (ACI, 2016), National Health Services (NHS,  
38 2011), and Saudi Arabia Healthcare standards (Council, 2006). JCI has divided its standards  
39 into two sections: patient-centred standards and healthcare Organisation management  
40 standards. The first section focuses on clinical quality and the second section focuses on  
41 administrative part that includes QM, leadership and governance. Although, ACI has listed  
42 70 standards in different areas' clinical and non-clinical, the key ones are: governance,  
43 leadership, primary care, ambulatory services, critical care, diagnostic imaging, disaster  
44 preparedness, emergency, medicine, obstetric, operating rooms, surgical care, reprocessing  
45 and sterilization, and laboratories standards.  
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3 The proposed L6 $\sigma$  KB system will focus on governance and leadership standards to  
4 cover all possible QM perspective issues. As such, the system will use the ACI standards  
5 and apply both perspectives.  
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8 Governance standards address the growing international request for an enhanced  
9 governance function for increased accountability over decision-making in healthcare  
10 Organisations. According to ACI (2016), the standards are grouped into four themes:  
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- 13 • Functioning as an effective governing body.
- 14 • Developing a clear direction for the Organisation.
- 15 • Supporting the Organisation to achieve its mandate.
- 16 • Being accountable and achieving sustainable results.

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21 Leadership standards address the growing international request for clarity regarding  
22 the roles and responsibilities of health care Organisations and their leaders to deliver the  
23 supports and infrastructure needed to drive excellence and quality improvement in health  
24 service delivery. According to ACI (2016), the leadership standards are grouped into five  
25 sections that each address a key leadership responsibility that Organisations must have in  
26 place as part of their pursuit of quality and safety. The five sections are:  
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- 31 • Creating and sustaining a caring culture.
- 32 • Planning and designing services.
- 33 • Allocating resources and building infrastructure.
- 34 • Planning for disasters and emergencies.
- 35 • Monitoring and improving quality and safety.

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40 These governance and leadership standards must be integrated with L6 $\sigma$  performance  
41 measures. Accordingly, the conceptual design will consider the most suitable L6 $\sigma$  elements  
42 with respect to governance and leadership standards in order to generate L6 $\sigma$  of QMHE.  
43 This requires having a controlling methodology that can activate two deliverables in  
44 KBL6 $\sigma$ : governance standard and leadership standard and the benchmarks between the  
45 current practise and the desired (benchmark) ones.  
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### 51 **Stage 3: Implementation**

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54 The third stage is the implementation which arises under the operational level. In this  
55 stage, both allocating resources and implementation of L6 $\sigma$  are used to accomplish the  
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3 selected projects after passing the initial assessments. In this stage, KBS will assess how the  
4 financial resources are allocated to cover human resources, capital and consumable  
5 expenditures. WHO considers human resources as one of three principle health system  
6 inputs, with the other two main inputs being physical capital and consumables (WHO,  
7 2000).

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12 Thereafter, the L6 $\sigma$  KB system will measure the L6 $\sigma$  Pre-implementing stage in the  
13 healthcare organisation by three factors: its ability to select and identify the services needed  
14 based on the patient and employees requirements and needs; its ability to draw value  
15 streams; and the matching of its prioritization to patient and employee's needs. George  
16 (2003) summarized the phases of deployment as occurring into four phases; readiness  
17 assessment, engagement, mobilization and performance.

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23 In the Evaluating phase, the process called DMAIC will be used as a key L6 $\sigma$   
24 methodology to improve processes in the healthcare organisation. This methodology is  
25 repeated if it is not successful from the first time. The implementation strategy in this  
26 research is built on extensive investigation of DMAIC key success and failure factors,  
27 which implies a DMAIC cycle as a screen type approach in which the project or issue must  
28 be tested against some main conditions to decide whether it can be structured to meet the  
29 DMAIC criteria.

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35 It can be seen from the system diagram in Figure 1 that all of the stages are  
36 integrated with verification, validation, and feedback process. The feedback acquired from  
37 discussion of healthcare quality managers, presenting conferences' papers (and receiving  
38 feedback) and using the knowledge of L6 $\sigma$  Black Belt and Master Black Belt holders is  
39 input to refine the KBS and accordingly the related development steps, as part of the  
40 verification and validation process. Thus, the initial structure of Five levels in KBS in  
41 Figure 1 is translated into a KBS as Figure 2 shows.

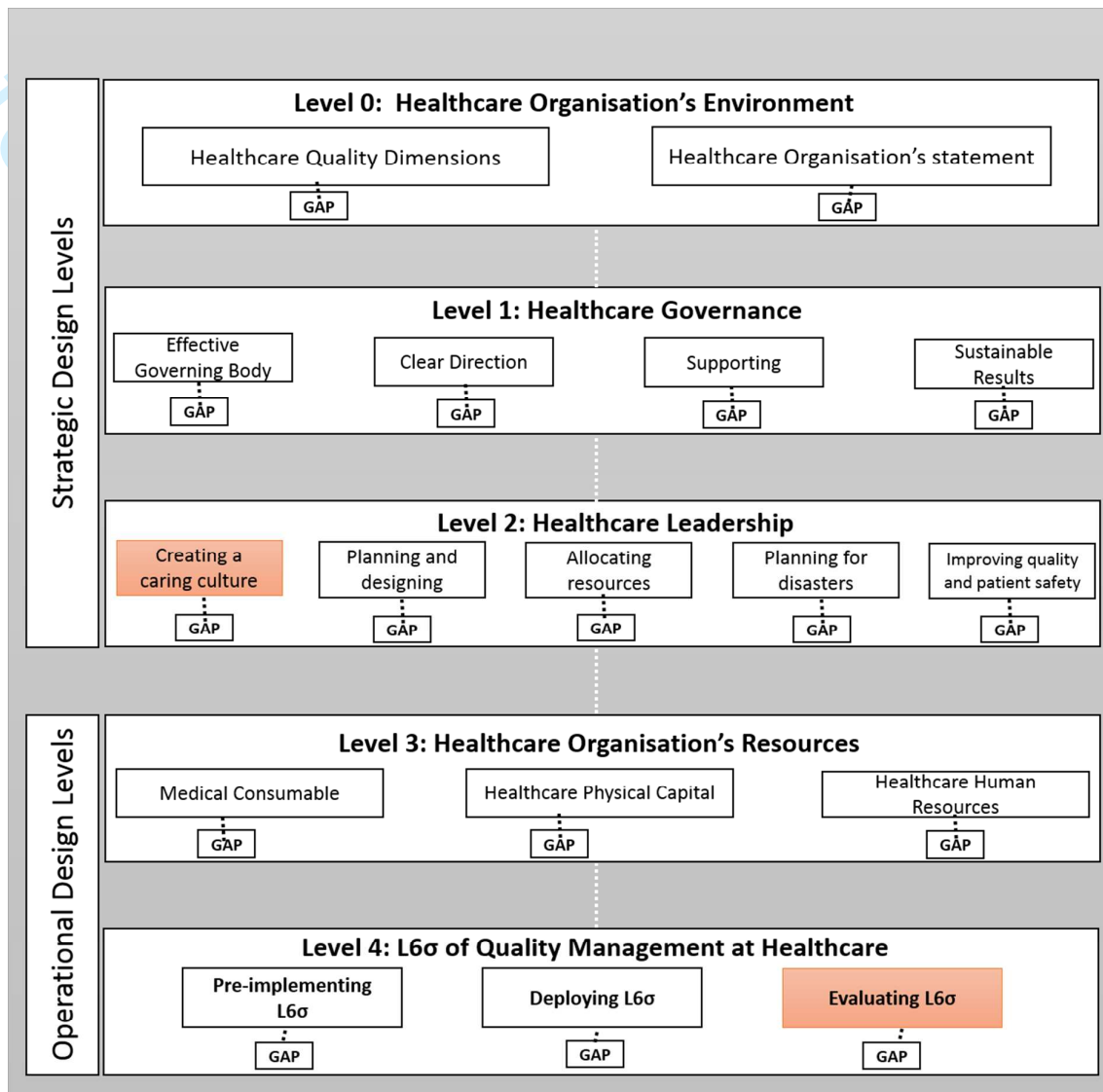


Figure.2 KBL6σ-QMHE System structure

As seen in Figure 2, the strategic issues fall under structure Levels 0 to 2, whereas the tactical and operational issues are under Levels 3 and 4. Generally, the structural system represents the interrelation among all Levels (Level 0 to Level 4) and the areas in which to perform GAP analysis as a benchmarking technique.

#### 4. Generating KB Rules

The following two examples of the KBS will be presented to highlight in detail the process of creating KB rules followed by the typical outputs in the next section. They belong to *Healthcare Leadership Module* and *Implementation of L6σ perspectives Module*. These sub-modules are *Creating a Caring Culture in Level 2* and *L6σ Evaluation in Level 4*.

#### 4.1 Level 2 Sub-Module: Creating a Caring Culture

The main purpose of developing the project selection sub-module is to assess if the organisation has a caring culture based on its values and whether it promotes health and safety environment and quality improvement.

For the KBS, Figure 3 elucidates the road map of the flowchart of *Healthcare Leadership Perspective Module* with the requisite KPIs. Using this road map, literature review, meeting experts and reading case studies, KB rules were developed using knowledge acquisition methodologies mentioned before. These KB rules were, then, logically structured and programmed into the software's ES shell.

The user will be in the beginning queried some questions that will decide whether the Organisation has create a caring culture based on its values and whether it promotes healthy and safety environment and quality improvement. Then, the system will examine the planning and designing process to make sure if it is satisfying the community needs and response to its changes and implementing operational plan to do that. After that, the system will inspect the resources allocation. This should be done by controlling the financial resources to maximize efficiency, manage the physical environment and use equipment and technology safely.

Consequently, the user will be asked questions regarding the preparedness of organisation for emergencies and disasters. The improvement of quality is the next examining part under this perspective. In this part the user will be asked about the risk managing process in the organisation, improving patient safety and developing a QM system.

The KB rule sets were generated and structured using the flowchart in Figure 3.

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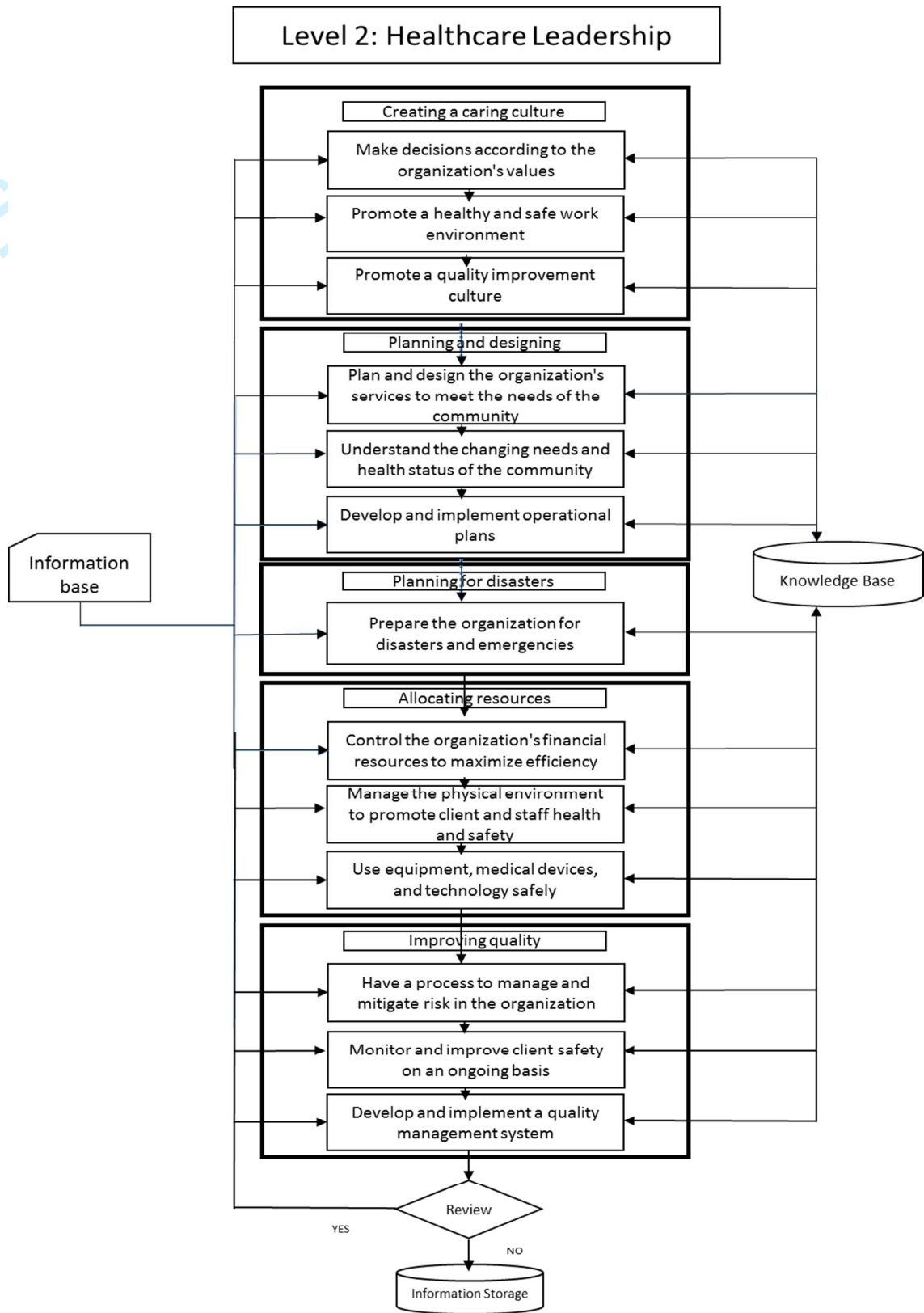


Figure. 3 Flowchart of Level 2 Healthcare Leadership Perspective Module



Actually, each KPI in this module is also connected to the information base as the data acquisition platform and benchmarked with the existing knowledge of best practices. Finally, the user feedback must be reviewed and verified at the end of the process. The following example shows the KB rules of *Creating a Caring Culture Sub-Module*:

- IF** *The Organisation's leaders participate in defining or updating the Organisation's values statement (Yes: GP; No: BP-PC-1)*
- AND** *the Organisation's leaders communicate and system the values throughout the Organisation (Yes: GP; No: BP-PC-1)*
- AND** *the Organisation's leaders develop and implement policies addressing the rights and responsibilities of clients (Yes: GP; No: BP-PC-3)*
- AND** *the Organisation's leaders develop and implement an ethics framework to support ethical practice (Yes: GP; No: BP-PC-2)*
- AND** *the ethics framework defines processes and tools for managing ethics issues, dilemmas, and concerns (Yes: GP; No: BP-PC-4)*
- AND** *the Organisation's leaders assign and monitor accountability for the ethics framework and the processes to address ethics issues (Yes: GP; No: BP-PC-1)*
- AND** *the Organisation's leaders build the Organisation's capacity to use the ethics framework (Yes: GP; No: BP-PC-2)*
- AND** *the Organisation's leaders have a process for gathering and reviewing information about trends in ethics issues, challenges, and situations (Yes: GP; No: BP-PC-2)*
- AND** *the Organisation's leaders use information about trends in ethics issues, challenges, and situations to improve the quality of services (Yes: GP; No: BP-PC-2)*
- AND** *the ethics framework includes a process for reviewing the ethical implications of research activities (Yes: GP; No: BP-PC-2)*
- AND** *the Organisation has a policy and process for the review of formal research projects by an objective reviewer or body (Yes: GP; No: BP-PC-3)*
- THEN** *the Organisation's leaders deliver services and make decisions according to the Organisation's values and ethics*
- OR** *The Organisation's leaders do not deliver services and make decisions according to the Organisation's values and ethics*

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3 Knowledge acquisition is a demanding process in which a knowledge engineer cooperates  
4 with the expert to capture and transform expertise into coded program by eliciting  
5 information from the expert, interpreting the information and building rules that represent the  
6 expert's knowledge. As a pre-requisites for acquisition, knowledge engineer must take in  
7 consideration the problem domain, selecting the right expert and preparing well for the  
8 knowledge acquisition.  
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14 The answer options for any question are given during the interactive mode will be  
15 considered based on the content and context. It might be a nearby answer, in which the  
16 options of the correct answer are given in a range of intensity or relevant practise, or an open  
17 answer in which the user must give his/her personnel experience or comments in that specific  
18 practise. However, the nearby answer is considered to be the best in which to deliver the  
19 correct input to the KBL6 $\sigma$  of QMHE system.  
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24 The significance of the answering statement will be measured by Problem Category  
25 (PC) in case the question is intended for GAP analysis. As it can be seen each KB rule is  
26 consist of IF-THEN's statement. Each question is assessed by Good Point (GP) and Bad  
27 Point (BP). If the user answers Yes, it will be GP and if the answer is No, it will be BP. This  
28 BP is weighted according to its Problem Category (PC) as shown in Appendix A. The scales  
29 will be in the range from PC1 to PC5 where PC1 has the higher weightage scale.  
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34 Some questions could be puzzling or difficult to understand. Therefore, the  
35 Explanation Facility is used to prevent any misunderstanding by the user of the question  
36 given. It contains additional information and knowledge about key areas such as standardised  
37 definitions or statements that will help the user understand the question. Such facility will be  
38 used for the KBL6 $\sigma$ -QMHE system instead of using Fuzzy Logic to discover and eliminate  
39 any uncertainty in understanding the KB rules.  
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#### 44 **4.2 Level 4 Sub-Module: Evaluation of L6 $\sigma$**

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46 The main purpose of developing this sub-module is to evaluate the implementation of  
47 L6 $\sigma$  in the healthcare organisation using a process called DMAIC as structured in Figure 4.  
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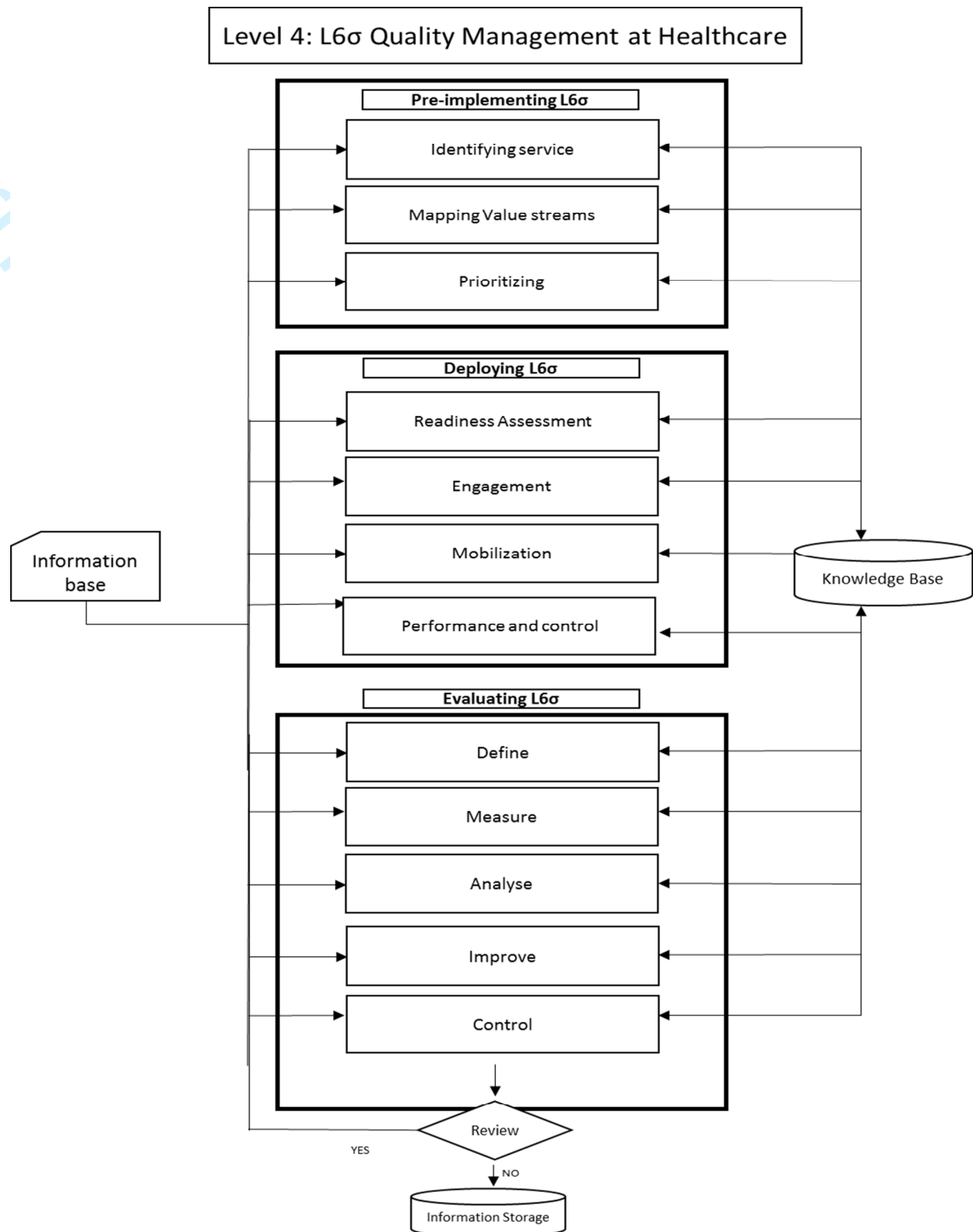


Figure. 4 Flowchart of Level 4 L6 $\sigma$  Quality Management at Healthcare Perspective Module

The user will be in the beginning queried some questions that will decide whether the organisation has choose a valued project with the respect of clear value stream and correct prioritization. Then, the system will examine the deployment process in combining with the L6 $\sigma$  Perspective Module. This should discover the detecting all the influences that should be

reflected when structuring how L6 $\sigma$  will be used, getting people enthusiastic about L6 $\sigma$ , founding the organisational set-up, applying deployment plans, creating control measures and processes to guarantee that L6 $\sigma$  improvements sustain.

Consequently, the user will be asked questions regarding improvement as a part of L6 $\sigma$ . The improvement stage is consisting of DMAIC process as discussed earlier. The improvement stage consists of DMAIC process as discussed earlier. Each KPI in this module is also connected to the information base as the data acquisition platform and benchmarked with the existing knowledge of best practices. Finally, the user feedback must be reviewed and verified at the end of the process. The following brief example of the KB rules of *L6 $\sigma$  Evaluation Sub-Module* is shown below:

- IF** *the organisation has a benchmark of L6 $\sigma$  with other organisation (Yes: GP; No: BP-PC-1)*
- AND** *the organisation recognise the importance of L6 $\sigma$  (Yes: GP; No: BP-PC-3)*
- AND** *the organisation have a clear culture towards L6 $\sigma$  (Yes: GP; No: BP-PC-1)*
- AND** *the organisation have a structured communication route (Yes: GP; No: BP-PC-3)*
- AND** *the organisation have adopted qualified L6 $\sigma$  trainers (Yes: GP; No: BP-PC-3)*
- AND** *the organisation has identified the areas of the 7 waste streams in any chosen L6 $\sigma$  project (Yes: GP; No: BP-PC-3)*
- AND** *the organisation has created a data collection plan for the whole variables need to assessed (Yes: GP; No: BP-PC-4)*
- AND** *the process capability related to any L6 $\sigma$  project has been measured to meet customer expectations (Yes: GP; No: BP-PC-5)*
- AND** *the measurement system of collecting data is accurate and does not cause inherent variation (Yes: GP; No: BP-PC-2)*
- AND** *the L6 $\sigma$  healthcare practitioners can measure data that help set priorities and criteria (Yes: GP; No: BP-PC-1)*
- AND** *the L6 $\sigma$  healthcare practitioners can analyze carefully required measurements (Yes: GP; No: BP-PC-2)*
- AND** *the L6 $\sigma$  healthcare practitioners can define which processes which need improvement (Yes: GP; No: BP-PC-1)*

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3 **AND** *the L6 $\sigma$  healthcare practitioners can improve result of analysis accordingly*  
4 **(Yes: GP; No: BP-PC-3)**

5  
6 **AND** *the L6 $\sigma$  healthcare practitioners can control if the implementation was*  
7 *successful to make sure that improvement is continuous over time* **(Yes: GP; No:**  
8 **BP-PC-2)**

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10 **THEN** *the healthcare Organisation has a good system of evaluating L6 $\sigma$*

11  
12 **OR** *the Organisation statues is poor in respect to L6 $\sigma$  evaluation.*

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15 The process flowchart shown in Figure 4 shows the *L6 $\sigma$  Perspective Module*. It is  
16 observable that some KPIs intercut with the other KPIs in other modules; this issue will be  
17 solved by generating action rules in which the system must check and transfer data between  
18 modules in a cross-functional manner. Each KPI is connected with an information base as a  
19 data acquisition platform and benchmarked with the existing knowledge of best practises.  
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## 23 24 **5. Testing the KBS**

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26 The KBL6 $\sigma$ -QMHE system has developed through a process starting from knowledge  
27 acquisition, followed by knowledge representations, followed by GAP methodology  
28 integration and ending by verifying its structure and contents. The next step is to test this  
29 KBS ability to react with the users and give a logic answers. Consequently, two sub-modules  
30 has been selected to conduct this test; *Creating a Caring Culture and L6 $\sigma$  Evaluation*. A total  
31 number of 459 questions (KB rules) were asked. From these, 301 answers as GPs and 158  
32 number were recorded as BPs. The BPs were categorised as 39 PC-1, 26 PC-2, 49 PC-3, 26  
33 PC-4 and 18 PC-5 which need to be eliminated to achieve benchmark standards for these two  
34 sub-modules.  
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41 The results for *Creating a Caring Culture Sub-Module* are shown in Table 1. A total  
42 number of 244 questions (KB rules) were asked. From these, 163 answers were recorded as  
43 GPs and 81 number were detected as BPs. The BPs have been categorised as 13 PC-1, 13 PC-  
44 2, 29 PC-3, 14 PC-4 and 12 PC-5 which need to be eliminated. The target is always to  
45 eliminate PC1 and PC2 respectively.  
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Table 1 Results and Analysis of creating a caring culture sub-module

Sub-Module	Dimension	Number of Questions	Good Points (GP)	Bad Points (BP)	Bad Point Problem Category (PC)				
					1	2	3	4	5
<b>Creating a caring culture</b>	Organisation's values and ethics	75	54	27	5	6	8	2	6
	Quality of work life	83	52	25	2	3	11	8	1
	Quality improvement culture	86	57	29	6	4	10	4	5
	<b>Sub Total</b>	<b>244</b>	<b>163</b>	<b>81</b>	<b>13</b>	<b>13</b>	<b>29</b>	<b>14</b>	<b>12</b>

A key aspect from this analysis is that in the quality improvement culture dimension 29 BPs (6 PC-1, 4 PC-2, 10 PC-3, 4 PC-4 and 5 PC-4) which, for quality management, is a significant factor that will reflect negatively on improving a quality culture in the healthcare environment. It is remarkable that hospital's leaders are not developing a confidential process for staff to bring forward concerns and complaints. Consequently, the hospital has to focus on correcting the problems from category 6 PC-1 before fixing the other 4 PC-2, 10 PC-3, 10 PC-4 and 5 PC-5.

Therefore, the most critical dimension that needs to be focused on is *Quality Improvement Culture* since it has 6 PC-1 and 4 PC-2. This indicates the urgent need of building quality and patient safety culture among healthcare practitioners. The second critical area is *Organisation's Values and Ethics* which has 5 PC-1 and 6 PC-2.

The results of *L6 $\sigma$  Evaluation Sub-Module* and its five DMAIC Dimensions are shown in Table 2. A total number of 215 questions (KB rules) have been asked. From these, 138 answers were recorded as GPs and 78 number were detected as BPs. The BPs have been categorised as 26 PC-1, 13 PC-2, 20 PC-3, 12 PC-4 and 6 PC-5 which need to be eliminated.

A key aspect from this analysis is that in the Control dimension 22 BPs (5 PC-1, 5 PC-2, 9 PC-3 and 3 PC-4) which, for quality management, is a significant factor that will reflect negatively on controlling the L6 $\sigma$  projects in the healthcare environments. It is remarkable that L6 $\sigma$  team is not doing well in the control phase of the DMAIC process which will be as a result will minimise the success of L6 $\sigma$  projects. Consequently, the hospital has

to focus on correcting the problems from category 5 PC-2 before fixing the other 5 PC-2, 9 PC-3 and 3 PC-4.

Table 2 Results and Analysis of L6 $\sigma$  evaluation sub-module

Sub-Module	Dimension	Number of Questions	Good Points (GP)	Bad Points (BP)	Bad Point Problem Category (PC)				
					1	2	3	4	5
L6 $\sigma$ evaluation	Define	51	27	15	6	2	7	0	0
	Measure	47	23	12	4	3	1	3	1
	Analyse	52	20	11	6	1	3	0	1
	Improve	42	24	17	5	2	0	6	4
	Control	23	44	22	5	5	9	3	0
	<b>Sub Total</b>		<b>215</b>	<b>138</b>	<b>77</b>	<b>26</b>	<b>13</b>	<b>20</b>	<b>12</b>

It is very obvious that the main problem is at all DMAIC Dimensions have 26 PC-1. Thus, more attention has to be given to all DMAIC Dimensions during the implementation of L6 $\sigma$  in the healthcare environments.

## 6. Conclusion

This paper has presented the detailed development of L6 $\sigma$ -QMHE system using a hybrid integration of KB rules and GAP technique for best practice benchmark. The KB L6 $\sigma$ -QMHE system is designed to assess the healthcare organisation's capabilities through Five Levels of different strategic and operational perspectives with a view to enhancing the QM in healthcare environment. The strategic level focuses on assessing the readiness of the organisation through the Governance and Leadership standards of ACI while the operational level evaluates the healthcare resources and L6 $\sigma$  implementation requirements. The initial structure of this KBS has been verified via two published papers. Furthermore, the KBS has been tested by users to assess its working and responding. To do this test, 459 KB rules were developed from two sub-modules. The process of generating KB rule sets and their implementation is given with examples for both *Creating a Caring Culture* and *L6 $\sigma$  Evaluation* sub-modules.

The *L6 $\sigma$  Evaluation Sub-Module* was found that all DMAIC Dimensions had PC-1 greater than 5. In *Creating a Caring Culture Sub-Module*, it was found that the Dimensions of Quality improvement culture have the most critical part with 6PC-1. Consequently, these

results identify the key problems (GAPs) which need to be eliminated to achieve the Benchmarks. As corrective actions, the healthcare quality managers need to focus more on building quality and patient safety improvement culture. Moreover, great attention has to be given to all DMAIC Dimensions.

As Table 3 shows, Out of 459 KB rules answered, the system has categorised 301 as GPs and the remaining 158 as BPs. The 158 bad points are categorised into different problem categories (39 PC-1, 26 PC-2, 49 PC-3, 26 PC-4, and 18 PC-5) where they represent the actions that need to be enhanced to reach the desired level of QM.

*Table 3 Results and Analysis of both tested sub-modules*

Sub-Module	Number of Questions	Good Points (GP)	Bad Points (BP)	Bad Point Problem Category (PC)				
				1	2	3	4	5
<b>Creating a caring culture</b>	<b>244</b>	<b>163</b>	<b>81 (33%)</b>	<b>13</b>	<b>13</b>	<b>29</b>	<b>14</b>	<b>12</b>
<b>L6<math>\sigma</math> evaluation</b>	<b>215</b>	<b>138</b>	<b>77 (35%)</b>	<b>26</b>	<b>13</b>	<b>20</b>	<b>12</b>	<b>6</b>
<b>Total</b>	<b>459</b>	<b>301</b>	<b>158 (34%)</b>	<b>39</b>	<b>26</b>	<b>49</b>	<b>26</b>	<b>18</b>

A key aspect from this analysis shows that BPs number is almost the same in both sub-modules. Almost 34% (158) of the total questions are BPs of which 39 PC-1, 26 PC-2, 49 PC-3, 26 PC-4 and 18 PC-5. It is really a significant factor that hospital's governing body should give attention to the 39 BPs of PC-1 that need urgent solutions.

In summary, this paper has illustrated that the KBL6 $\sigma$ -QMHE system development and testing in two different sub-modules. The available results need to be validated in a real healthcare area. This system approach will be helpful in assisting the decision making process in order to achieve benchmarks in QM of Healthcare Environment.

## 7. Appendix A: Problem Categories and Description of GAP Technique (Kochhar et. al, 1991)

Category	Description
PC1	This indicates a very serious problem, which should and can be resolved in the short term and the result of the problem is quite likely to provide a real short-term benefits.
PC2	This indicates a major problem, which is likely to have pre-requisites to the system and is better dealt with as part of an appropriate and logical improvement and implementation plan.
PC3	This indicates a problem and can be dealt with now. If resolved, it is likely to produce short-term benefits.
PC4	This is not a serious problem. Although it could be dealt with now, it is unlikely to produce short-term benefits. Therefore, it should only be dealt with if it is a prerequisite for other things.
PC5	This is not really a good or bad point itself. The questions associated with this category are primarily asked to identify certain situations in the environment, which upon subsequent probing by succeeding questions may well reveal problems.

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