An Analytic Hierarchy Process approach to assess health service quality

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AN ANALYTIC HIERARCHY PROCESS APPROACH TO ASSESS HEALTH SERVICE QUALITY

A Thesis

by

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ABSTRACT

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While improving quality in health care is currently at the forefront of professional, political, and managerial attention, the key dimensions constituting health-care quality have not been fully understood. Also, few valid approaches have been proposed to the measurement of health-care quality. In this research, the Analytic Hierarchy Process (AHP) approach is applied to study the structure of health-care quality and deducted relative importance weights for each of the quality elements. A statistical quality model is derived to assess medical equipment quality which is an important part constituting the general health-care quality. Finally, the application of the AHP model to assess health-care quality is demonstrated based on a scenario.

DEDICATION

This Master's Thesis is dedicated to my mother Hua Yan, my father Fulin Li, and my girlfriend Huiqiang Zheng. Without their encouragement and love, I cannot be who I am now.

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CHAPTER I

INTRODUCTION

The U.S. health care system has been undergoing great challenges in recent years. Some research pointed out that these challenges are due in part to an aging population, mounting competitive pressures, increasing consumerism, and emerging treatments and technologies (Ludwig-Beymer *et al*. 1993; O'Connor *et al*. 2000). Among all these challenges, improving quality in health care is currently at the forefront of professional, political, and managerial fields. Although numerous research has been conducted concerning the determination and improvement of health-care quality, the key dimensions constituting health-care quality have not been fully understood. Also, few valid approaches have been proposed to the measurement of health-care quality.

The size, complexity, and continuous dynamism of the health service present a barrier to understanding health service quality and developing valid models. Some researchers seek to provide insights to individual service providers and to limit findings to particular institutions. However, more generalized models are needed to cope with the impact of possible changes and to reduce the large amount of time and costs required in producing institution specific models.

Health service quality is multidimensional. Forman and Gass (1999) illustrated this property by taking a Malcolm Baldridge Award example which can be evaluated by seven different criteria. Multidimensional models for health service quality evaluation can be found in numerous published works. Headley and Miller (1993) identified 6 dimensions in a primary care clinic, Lytle and Mokwa (1992) developed seven-dimension model for a health care fertility clinic, and Licata *et al*. (1995) identified twelve dimensions in a health care setting. More quality models are presented in Section 2.1 of this thesis.

The multidimensional property of quality makes it an ideal field to apply the analytic hierarchy process (AHP) which is a powerful technique for analyzing complex problems. It can be used to structure a decision problem, represent and quantify its elements, link these elements to final objective, and evaluate different alternatives. Within AHP, a hierarchy structure is created to display different attributes and alternatives. The final objective is subdivided into elementary attributes which are all related to every alternative on the lowest level. Every element in a hierarchy can be associated with any aspect of the decision problem—qualitative or quantitative, carefully measured or roughly estimated, tangible or intangible. Preferences can be obtained by pairwise comparisons of the alternatives for each attribute using a ratio-scale. In making the comparisons, people can use data, experience, insight, and even intuition in a logical way. It is a great advantage of AHP that allows decision makers to incorporate both objective and subjective considerations in the decision process. Furthermore, the same ratio-scale should be used when determining the attribute weights by pairwise comparisons of attributes which have the same upper attribute. Thus AHP could convert all the evaluations to numerical values and calculate the weight or priority of each element of the hierarchy. It has the capability of comparing diverse and often incommensurable elements to one another in a rational and consistent way.

AHP has been employed in broad areas such as choice decision, ranking, prioritization, resource allocation, benchmarking, and quality management. It is worth noting that AHP is always used along with or in support of other methodologies. Forman and Gass (1999) noted that AHP can be used in support of queueing theory in the situation of determining the number of servers in a queue. They also noted AHP could help decision tree analysis derive probabilities for the choice nodes. Similarly, this research would combine process capability analysis and goal programming techniques to study the quality of medical equipment and the quality of physicians, respectively.

This research addresses the quality issue of the health service system. The quality elements considered are not restricted to technical quality, but cover administrative quality, environmental quality, and interpersonal quality. The application of the AHP model to assess health-care quality is demonstrated based on a scenario. The thesis consists of six chapters including this introduction. The second chapter presents a literature review regarding the health service quality and the AHP methodology. Chapter 3 presents an analysis for the identification of quality elements constituting health-care quality with details. This procedure is carried out based on both physician's and patient's opinions, and knowledge from previous research. The chapter also describes the basic theory and mathematical foundations of AHP.

This is followed by an introduction of the process capability theory and equations to measure the medical equipment quality. Medical processes are categorized into testing processes and surgical processes. Models for assessing the failure rates of these two processes are developed. The chapter provides basis to assess medical equipment quality in a scenario described in the next chapter.

The fifth chapter provides a demonstration of the application of the proposed AHP model based on a scenario. The values of each quality element are either assessed based on the description of the scenario or assumed. The final weighted health service quality is calculated to show the application of the AHP model. The final chapter of the thesis presents conclusions and points out the future research direction. The chapter also discusses the pros and cons of AHP comparing with other techniques for assessing health service quality, such as goal programming.

CHAPTER II

LITERATURE REVIEW

This chapter reviews the literature related to health service quality and Analytic Hierarchy Process (AHP) in general. Health service quality has been studied for decades, and great efforts have been made to establish appropriate models for its measurement. AHP is a powerful tool to model complex systems, such as health service industry; therefore, it is believed that there is potential in applying AHP to analyze health service quality.

2.1 Health Service Quality

Health service quality is an abstract concept because of its “intangibility.” According to Donabedian (1980), quality for health systems was defined as “the ability to achieve desirable objectives using legitimate means.” Within the context of health care services, the quoted “desirable objective” implies an expected state of health. Some other definitions of quality also exist. Van Maanen (1984) noted that quality is an abstraction defining the margin between desirability and reality, and is a concept generally used in societies with a high standard of living. Moreover, similar opinions can be found in Gronroos (1984) which stated that performance can be judged against expectation, and in Parasuraman, Zeithaml, and Berry (1985) which considered service quality as the gap between expected and perceived service. Therefore, health care quality may be seen from the perspective of patients' expectations versus actual experiences. As such, the definition assumed in this thesis is based on the integration of quality factors related to patients expectations and the level to which those expectations are met.

As to the assessment of service quality, Chen and Yoon (1994) proposed a medical performance measurement system for Advanced Cardiac Life Support (ACLS) protocol operations based on linguistic variables and membership functions. Gonzalez and Lease (1994) applied similar approach to assess quality performance of a restaurant. Rosas (2003) applied goal programming and membership function to assess human error rates in the performance of ACLS. This approach could also be used with the AHP model established in this thesis to evaluate the quality of physicians in health service systems. A similar approach was used by De La Torre (2006) to establish a capability measuring system for the evaluation of the Mass Customization of a product. His research indicated the same approach could be useful in analyzing quality performance in many fields.

Some objective criteria such as mortality and morbidity have traditionally been used to assess health service quality. Among all the approaches for quality assessment, a very popular one is the structure-process-outcome model proposed by Donabedian (1980). In this model, "structure" generally refers to the organizations and conditions for health care delivery, "process" can be considered as activities associated with providing health care services, and "outcome", the most important aspect, is a change in a patient's current and future health status resulted from previous health care (Donabedian, 1966, 1980). To define outcomes of health care, Patrick (1986) improved “Five Ds” criterions (death, disease, discomfort, disability and dissatisfaction) to a more comprehensive six factors which are death, disease, physical well-being, psychological well-being, social well-being, and quality of life.

The structure-process-outcome model viewed quality as technical in nature, thus inevitably overlooking the subjective aspects in quality assessment. As the industry structure changes, patients play a more important role in defining what quality means in health care services. Hopkins (1990) pointed out that quality may be seen as essentially subjective because patients’ expectations are subjective. A considerable amount of research has been published to study the assessment of health care quality based on patient’s perspectives (e.g., Brady and Cronin 2001; Dagger *et al*. 2007). Specifically, Parasuraman, Zeithaml, and Berry (1985) identified 10 dimensions of service quality: access, communication, competence, courtesy, security, tangibles, reliability, responsiveness, credibility, and understanding or caring. Dagger *et al*. (2007) also developed a multidimensional, hierarchical scale for measuring health service quality, which includes interpersonal quality (interaction and relationship), technical quality (outcome and expertise), environment quality (atmosphere and tangible), and administrative quality (timeliness, operation and support). However, it is found that patients have difficulty in evaluating some dimensions like medical competence and security which are considered to be the primary determinant of service quality (Bopp 1990; Hensel and Baumgarten 1988). As a result, a question was raised “If patients in health care system cannot evaluate the important service dimensions, can they have a reasonable expectation about the services they received?” (Bopp 1990).

To answer this question, Lee *et al* (2000) noted that although patients’ perceptions are valuable, it is crucial to understand physicians' perceptions of service quality when designing and improving the health care system. In their research, physicians were asked to assess the quality of health care system based on an existing seven dimensions scale, which is defined as a modified SERVQUAL approach (the original SERVQUAL approach was proposed by Parasuraman, Zeithaml, and Berry, 1988). All the dimensional responses were collected using three different measurement methods: single-item global rating method, constant sum rating method, and multi-item rating method. The main findings in Lee *et al* (2000) suggested an ongoing effort is required to better understand health-care quality.

2.2 Analytic Hierarchy Process

The analytic hierarchy process (AHP) was developed by Thomas Saaty (1980). It is a powerful tool for decision makers to model complex problems in hierarchical structures showing the relationships of the goals, objectives, sub-objectives, and alternatives (Saaty 1980). AHP is composed of several existing concepts and techniques such as hierarchical structuring of complexity, pair wise comparisons, redundant judgments, an eigenvector method for deriving weights, and consistency considerations (Forman and Selly 1999). Forman and Selly (1999) also noted that the power of AHP has exceeded the sum of all the concepts and techniques listed above.

The foundation of AHP is the well-defined mathematical structure of consistent matrices and their right-eigenvector's ability to generate true or approximate weights (Mirkin 1979). In a later work by Saaty (1994), he summarized three basic principles behind AHP: decomposition, comparative judgments, and hierarchical composition or synthesis of priorities. The decomposition principle is applied to analyze and decompose a complex problem into a hierarchy of different structures. Then pairwise comparisons are carried out based on comparative judgments principle to evaluate all combinations of elements in a hierarchical structure. The principle of hierarchical composition is applied to compute the 'local' and 'global' priorities of each element (Satty 1994).

Forman and Gass (1999) described three relatively simple axioms which could also be considered as a basis of AHP. The first one, reciprocal axiom, requires that if the element A possesses a relative property that is $P_C(A,B)$ times higher than does element B, then the element B possesses the same property 1/ $P_C(A,B)$ times than does element A. The second "homogeneity" axiom states that to avoid unacceptable errors, the two elements being compared should not differ by too much. The third known as synthesis axiom requires that decision makers could not make judgments depend on lower level elements. Sometimes the third axiom may not apply when there is feed back.

According to a comprehensive survey by Zahedi (1986), AHP is suitable for any situation that requires structuring, measurement, and synthesis; therefore, the number and diversity of AHP applications has grown rapidly. Forman and Gass (1999) also provided an extensive summary of areas of AHP application:

- Choice – the selection of one alternative from a given set of alternatives, usually where there are multiple decision criteria involved.
- Prioritization/Evaluation – prioritization involves determining the relative weight of a set of

alternatives and evaluation means making an estimate or measurement for an alternative. Since it is more difficult to evaluate an alternative with multiple dimensions than just compare one thing to another, an evaluation is often performed as a prioritization.

- Resource allocation –determining the relative effectiveness of resources toward different objectives of an organization, helping the organization synthesize the often conflicting objectives and subjective information.
- Benchmarking – comparing the processes in one's own organization with those of the best organizations, and finding out how other organizations operate their processes, set the right goals and realize those goals.
- Quality management – dealing with the multidimensional aspects of quality, and providing a way to quantify the qualitative factors.
- Public policy – making competing constituencies regarding to a public policy decision better understand each other, and developing "win-win" solutions.
- Health care – better development of medical practice guidelines, evaluation of diagnostic procedures, and personnel allocation decisions.
- Strategic planning – assisting an organization to select the best strategies and allocating relevant resources to implement the chosen strategy.

The previous applications of AHP in quality management and health care provide insights for conducting this research. As health service quality is multidimensional, AHP is a suitable approach to structure the hierarchical quality elements and measure the relative importance weights for each of them. Also, as some quality elements constituting health service quality are subjective, AHP is a good way to quantify these elements. In the next chapter, the analysis for the hierarchical structure of the health service quality is presented with details. A pilot study is conducted to apply AHP for deriving relative importance weights for each quality elements.

CHAPTER III

ANALYSIS OF HEALTH SERVICE SYSTEM USING ANALYTIC HIERARCHY PROCESS (AHP)

3.1 Hierarchical Structures

Through the literature review, it was found that health service quality could be decomposed into four major parts: interpersonal quality, technical quality, environmental quality, administrative quality. The detailed hierarchical structures are shown in the Figure 3.1. There are four hierarchies shown in the figure, each of which is denoted as A, B, C, and D, respectively. The first hierarchy (A) stands for the health service quality. The second hierarchy (B) includes the four major quality categories, each of which is decomposed into two sub-quality categories as shown in the third hierarchy (C). The fourth hierarchy (D) contains the bottom quality elements which can be quantified with certain measurements. The hierarchical structure and the quality elements are discussed in the following subsections.

3.1.1 Interpersonal Quality

Interpersonal quality reflects the relationship developed between service providers and users. Within health care context, the term “service providers” refers specifically to physicians, nurses, and administrative staff. Physicians provide most critical health services to patients, such as

Figure 3.1 Index System of Health Service Quality Evaluation

First grade (A)	Second grade (B)	No.	Third grade (C)	No.	Fourth grade (D)	No.
Health service quality	Interpersonal quality	B1	Interaction	C1	Administrative staff vs. patients	D1
					Physicians vs. patients	D2
					Nurses vs. patients	D3
			Relationship	C2	Physicians vs. patients	D4
					Nurses vs. patients	D5
	Technical quality	B2	Physician	C3	Diagnostic error rate	D6
					Surgical accident rate	D7
					Drug error rate	D8
					Dosage error rate	D9
			Medical equipment	C4	Testing equipment error rate	D10
					Surgical equipment error rate	D11
	Environmental quality	B3	Atmosphere	C5	Cleanness	D12
					Temperature	D13
					Scent	D14
			Tangibles	C6	Layout	D15
					Signs and Symbols	D16
	Administrative quality	B4	Timeliness	C7	Waiting time	D17
					The ease of making or changing appointment	D18
					Hours of operation	D19
			Operation	C8	General administration	D20
					Coordination of different medical services	D21

diagnosing, surgery and prescription. Nurses assist physicians in treating patients, and they are also responsible for the safety and recovery of patients. Administrative staff keep records of both patient flow and material flow, thus managing information flow throughout the health care system. They are aware of the availability of physicians and nurses in order to deal with the appointment system.

Further studies show that specific relationship between service providers and users could be measured in two core themes: interaction and relationship (Brady and Cronin 2001). If patients made comments such as: “The physicians have good communication skills” or “The staff are supportive”, it can be indicated that the quality of interaction between service providers and users are generally good. Likewise, comments like “The doctors are like my family” indicate the positive relationship has been established. Thus, the interpersonal quality could be assessed through each sub-quality between each type of service providers and patients in both interaction perspective and relationship perspective respectively.

3.1.2 Technical Quality

Technical quality involves outcome of the treatment achieved (Mcdougall and Levesque 1994) and technical competence of a health service provider (Ware, Davies-Avery, and Stewart 1978). Two basic elements were identified which could have direct impacts on technical quality in health services. The first is physicians, whose experience, expertise and knowledge will greatly affect the outcome of medical treatment. In order to better quantify the relative quality of physicians, the concept of human reliability could be introduced. That is, this research ignores the gaps among different physicians due to experience and expertise, and only considers the probability that a physician will perform his/her medical task without error for a specified duration. In this sense, if a physician can perform a specific task without any error, the service quality is good.

This study identified four major areas in which physicians could make some errors, including diagnosis, surgery, medicine type and dosage. Diagnostic error is a very dangerous error a physician can make because it could result in many subsequent errors. It might be due to the expertise of physicians or simply the carelessness of physicians. The negative impact of diagnostic error is usually irreversible and could bring about very bad consequences. For example, it was reported that a blood cancer patient was diagnosed as having common flu, and the wrong therapy finally carried off his life. Also, surgical accidents are common mistakes made by physicians and could severely damage health service quality. For example, such accident could involve a doctor nicking a nerve which causes facial paralysis. Also, the surgical accident could cause some catastrophic results, such as a doctor performs a surgery that was not needed, or performs a surgery on a different part of the body than was dictated. Medication error is also a common error which could be further subdivided into drug type error and drug dosage error. It is possible that physicians might be unfamiliar with some type of drugs and prescribe wrong drugs, and the careless calculation of drug dosage could lead to undesirable results.

The second element contributing to the technical quality in health service is identified as medical equipment quality. Medical equipment is used to aid in the diagnosis, monitoring or treatment of medical conditions. While physicians are subject to human errors, some errors or malfunctions caused by medical equipment should also be responsible for a possible unsatisfied technical quality. First, some medical equipment could be poorly chosen. There are numerous types of medical equipment, and many of them would perform similar functions. Choosing the most appropriate equipment to diagnose or treat a specific disease is a very important issue in realizing the desirable outcomes. In addition, measurement errors could also happen in the functioning of medical equipment. For example, a malfunctioning sphygmomanometer could result in inaccurate measure of one's blood pressure and cause wrong diagnosis of the disease. Some operational errors are also reported to occur during a surgery process or other treatment processes requiring an operation. It was reported that the failure of stereotactic device might cause the operation performed at the wrong part of the body.

3.1.3 Environmental Quality

While previous research may put great emphasis on technical quality, this research introduces environmental quality as an indispensable element to assess health service quality comprehensively. In general, environment refers to surroundings of an object. The environment should be studied because the surroundings could always have great impact on the object of people's interests. Environmental quality involves with cleanliness, temperature, and all such factors which can have potential effects on human's mental and physical health (Bitner 1992). In health service context, five major elements were identified which can affect patients' perception on health service quality and even change their decisions on the service providers they prefer.

Atmosphere and tangibles are two themes underlying the five elements identified, which is discussed in the following paragraphs.

The atmosphere of a health service unit refers to the intangible, background characteristics of the environment. Through literature review and discussions with health practitioners, cleanliness, temperature and scent can be identified under the theme of atmosphere in the hierarchical model. It is not surprising that cleanliness is a critical element constituting the environmental quality, especially in a health service context. An unclean place would damage both physicians and patients' health and would promote the transmission of noxious bacteria and virus. Temperature is important in that appropriate temperature is a necessary condition for many kinds of medical tests and operations. Appropriate temperature can also make patients feel comfortable, which could help release the anxiety caused by long time waiting. Scent is a specific element in health care context. It is found that some patients made favorable comments to their clinic in part due to the fact "doesn't have that hospital smell" (Dagger *et al*. 2007). This also indicates that a severe hospital smell usually makes patients nervous and anxious.

According to Baker (1986), the tangibles of a health service unit refer to the physical elements of the service environment. As in health service context, the layout of the hospital and signs and symbols guiding patients to the designated areas are two important factors. An efficient hospital layout can promote staff efficiency by minimizing distance between frequently used spaces, allow easy supervision of patients by limited staff, and provide optimal functional adjacencies. For example, it is often desirable to locate the surgical intensive care unit adjacent to the operating suite because such layout could benefit patients, staff, and supplies. Similarly, well-designed hospital signs and symbols can facilitate patient flows and increase the efficiency of health service. A hospital has many functional units, and sometimes it is really a headache for patients to find their intended places. There is no doubt that some simple and clear signs and symbols are useful and cost-effective to solve this problem.

3.1.4 Administrative Quality

Gronroos (1990) noted that administrative services facilitate the production of a core service and add value to a customer's use of the service. Within the health service context, the functions of an administrative staff include checking in patients, handling electronic medical records, managing appointment system, gathering patients' information, checking out patients, billing and coding. Although administrative staffs do not directly treat patients, their quality work is required to maintain efficient patient flow and reduce errors in the operation of the whole hospital setting. This research identified two themes which can be considered to comprise the quality of administrative work: timeliness and operation.

Timeliness means patients are able to receive their medical services in a timely manner, and reduce the negative results due to unnecessary delay. It involves the arrangement to receive medical services, under which three quality elements were specified. The first quality element constituting timeliness is check-in waiting time. A patient must check in before he/she receives any medical treatment, so excessive check-in waiting time could be frustrating for patients and would greatly damage the health service quality. The second element is the ease of making or changing appointment. Some comment by patients like "you can get an appointment when you need an appointment" indicates an efficient appointment system operated by administrative staff. During check-out process, a follow-up appointment should also be scheduled based on doctor's notations, thus eliminating the need for patients to reschedule appointments. The third element is hours of operation of a health service setting. While short hours of operation could result in diversion of many patients and might be merciless for emergent patients; long hours of operation could cause complaints from physicians and staffs and increase the probability of medical errors due to distraction caused by excessive working hours.

The second theme of operation facilitated core medical service through the general administration of the hospital and the coordination of the different medical services. General administration can be viewed as the quality of administrative work in an operational perspective. Administrative staff should not only provide patients with timely service, but also with accurate and effective service. A good quality administrative work can be described as "the administration of things is well organized." Likewise, good coordination of the different medical services can make the whole hospital system as a whole functional unit rather than several independent units, thus facilitating treatment process of a patient and improving the health service quality.

3.2 Weight of Quality Elements

In order to synthesize the influence of every quality element and assess the health service quality in a single measure, there is a need to know the weight of each element. It is no doubt that not all the quality elements play the equal role in determining the whole health service quality. For example, some patients may prefer a hospital with good technical quality but weak environmental quality, rather than the one with good environmental quality but weak technical quality. Specifically, within the administrative quality perspective, patients may care more about average waiting time in a hospital than the hours of operation. This research employed AHP method to analyze and quantify this difference.

3.2.1 Basic Theory of AHP

According to Saaty (1980), AHP is composed of several techniques such as hierarchical structuring, pairwise comparisons, redundant judgment, eigenvector method for deriving weights, and consistency evaluation. The first step of AHP requires the structuring of a complex problem as a hierarchy, which is done in the identification of quality elements work in section 3.1. Then the pairwise comparison process is conducted to derive ratio scale measures. The incorporation of redundancy to the pairwise comparison process ensures a reduction of measurement error because redundant responses are capable of minimizing inconsistency. It is worth noting that the pairwise comparison process can be performed using words, numbers, and graphical bars. While words may be the most convenient for personal use, they are in nature subject to inaccuracy compared with numbers and graphical bars. The power of AHP makes it possible to use words to compare qualitative factors and derive quantitative weights.

Pairwise comparison means all quality elements in a level of the hierarchy should be compared related to the single element which is directly above them. The comparison can be made in terms of either importance, preference, or likelihood. As to health service context, this research only considers the relative importance of each pair being compared and use a ratio to represent it. There is no standard scale for this ratio value, but the numerical scale from 1 to 9 is most commonly used in practice. In that scale, a value of 1 means the two elements being compared are equally important, and a value of 9 means one element is extremely more important than the other one. A more precise interpretation of the different numerical ratio is shown in the Table 3.1.

Table 3.1 AHP Pairwise Comparison Numerical Scale and Its Explanation

Numerical Value	Verbal Scale	Explanation
1.0	Equal importance of both element	Two elements contribute equally
3.0	Moderate importance of one element over another	Experience and judgment favor one element over another
5.0	Strong importance of one element over another	An element is strongly favored
7.0	Very strong importance of one element over another	An element is very strongly dominant
9.0	Extreme importance of one element over another	An element is favored by at least an order of magnitude
2.0, 4.0, 6.0, 8.0	Intermediate values	Used to compromise between two judgments

(Forman and Selly, 1999)

Some people may question the accuracy of this type of subjective comparison, but Forman and Selly (1999) verified that a number of these pairwise comparisons taken together can bring about very accurate results based on a sort of average values. Note that the subjective scale, such like “much more important”, is more attractive in real life situation than only a quantitative scale. Also, the common sense is that it is easier to compare two elements at a time than to compare many all at once, which further testified the appropriateness of pairwise comparison.

3.2.2 From Comparison Matrix to Total Ranking

After the pairwise comparison processes within a level of hierarchy under a single element, all the ratios can be expressed in a matrix, which can be called comparison matrix A:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{3.1}$$

The comparison matrix can be also denoted as $(a_{ij})_{nxn}$, where a_{ij} is the ratio value of relative importance of element i to element j. Then a series of mathematical calculation could be performed to gain the weight of each element.

First, calculate the product of every row m_i

$$m_i = \prod_{j=1}^{n} a_{ij} \quad (i = 1, 2,\ldots,n) \tag{3.2}$$

then get the quartic root of m_i

$$\overline{w}_i = \sqrt[4]{m_i} \quad (i = 1, 2,\ldots,n) \tag{3.3}$$

Therefore, the weight of each quality element can be obtained

$$w_i = \frac{\overline{w}_i}{\sum_{i=1}^{n} \overline{w}_i} \tag{3.4}$$

and the vector of weights can be written as

$$\overline{w} = (\overline{w}_1, \overline{w}_2, \ldots, \overline{w}_n)^T \tag{3.5}$$

Saaty (1980) noted the relationship between comparison matrix and element weights can be expressed as

$$A\overline{w} = \lambda\overline{w} \tag{3.6}$$

The problem of solving for a nonzero solution to this set of equations is known as eigenvalue problem. Also he pointed out that since the sum of the eigenvalues of a positive matrix is equal to the sum of the diagonal elements, the nonzero eigenvalue has a value of n, the size of the matrix. That eigenvalue can be denoted as λ_{max} and can be obtained by

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(AW)i}{w_i} \tag{3.7}$$

$$AW = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_j \end{bmatrix} \tag{3.8}$$

where W is the corresponding eigenvector of λ_{max} and w_i is the weight of each element. Recall that allows inconsistency, and it is relevantly easy to measure this consistency issue by using the eigenvalue λ_{max}. A consistency index (CI) is introduced and the expression is as follows

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{3.9}$$

Note that a CI=0 means all the judgments are perfectly consistent, and the bigger CI is, the worse consistency the judgments are. A CI value of 1 indicates judgments are not made intelligently, but rather at random. Therefore, as it can be indicated from the equation, the closer λ_{max} is to n, the more consistent the judgments are. While it is reasonable to use (λ_{max}-n) as a measure of consistency, the equation (3.9) Saaty (1980) defined represents the average of the remaining eigenvalues.

To measure the inconsistency in a more meaningful perspective, another index called consistency ratio (CR) was introduced by Saaty (1980). CR was defined as the ratio of the consistency index for a group of judgments to the average consistency index for random comparisons for a matrix of the same size. The mathematical expression for CR is

$$CR = \frac{CI}{RI} \tag{3.10}$$

where RI is the average of the consistency index of matrices of the same size as CI. A table containing RI values for n less than 16 is shown in the Appendix. If more than one pairwise comparison processes are performed to yield the weights, then the overall consistency ratio should be calculated using

$$CR_o = \frac{\sum_{i=1}^{m} w_i CI_i}{\sum_{i=1}^{m} w_i RI_i} \tag{3.11}$$

where w_i is weight of the quality element with respect to the corresponding pairwise comparison process, and it is assumed that a number of m sets of comparisons are performed before the overall consistency ratio is calculated. CR is a very useful value in AHP analysis and is widely used. When CR is less than 0.1, it can be concluded that the set of judgments are acceptably consistent; otherwise, the judgments are unacceptable, and the pairwise comparison process should be performed again until a satisfactory value for CR is achieved.

3.2.3 Application of AHP in Assessment of Health Service Quality

In order to calculate the weights of each quality element in the health service model, this research obtains sufficient data from pairwise comparison processes. A pilot study is conducted to apply AHP method for deriving relative importance weights. Physicians, patients and students were involved in the pilot study. The researchers chose these three types of participants in order to gain judgments from different perspectives to reflect a more general result. Specifically, physicians and patients are directly involved with health service activities and could possibly provide judgments based on their own experiences and interests. Students may either have received health service before or have no experience, so their opinion can be neutral and reflect no bias. In the pilot study, if there was disagreement regarding to a particular importance of a quality element, the issue was discussed until agreement was reached.

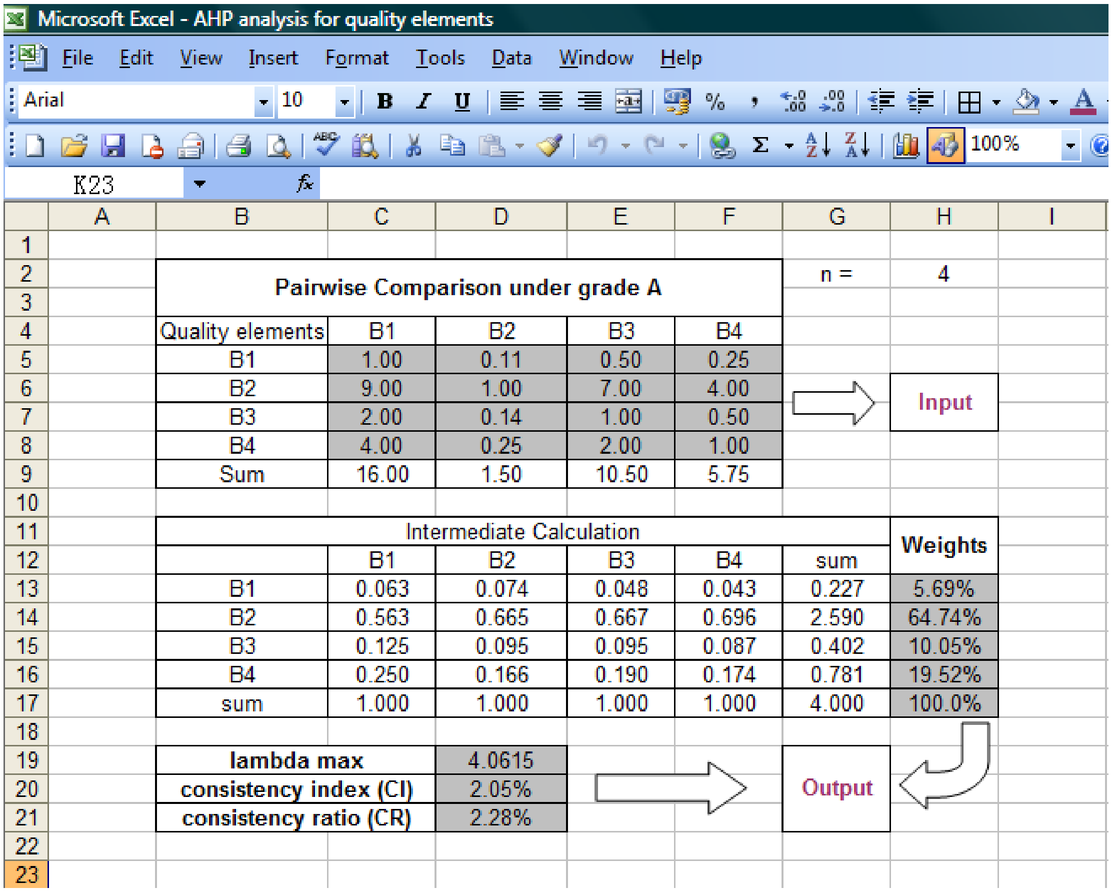
The questions asked in the pilot study based on AHP procedures is relatively simple and does not contain much information regarding to the specific meanings of each quality elements as discussed in Section 3.1. The researchers are required to answer all questions regarding to the understanding of concepts and make a detailed introduction about the AHP model. Therefore, it is believed that few misunderstandings would occur due to the detailed description of each quality element. This research would take the elements under first hierarchy as an example to illustrate the process of obtaining weights through pairwise comparison.

Based on the pairwise comparison numerical scale and its explanation in Table 3.1, the respondents of the pilot study made the following judgments (Table 3.2) regarding to the relative importance of interpersonal quality, technical quality, environmental quality and administrative quality in health service. All other pairwise comparison results are attached in the appendix.

Table 3.2 Pairwise Comparison among Four Quality Elements in the Second Hierarchy

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Interpersonal : Technical	2	9
Interpersonal : Environmental	2	2
Interpersonal : Administrative	2	4
Technical : Environmental	1	7
Technical : Administrative	1	4
Environmental : Administrative	2	2

A spreadsheet application was created to facilitate the calculation of weights from pairwise comparisons. The interface of the application is simple and user friendly. It only requires the researchers to input the data obtained from the pilot study and the spreadsheet can automatically yield the results needed, including the weights of each quality element, the eigenvalue of the comparison matrix, the consistency index , and the consistency ratio. All the calculations are based upon the discussion of derivation of weights in Section 3.2.2. A screen snap of the spreadsheet calculation of weights of the four quality element in the second hierarchy is shown in the Figure 3.2.



Microsoft Excel - AHP analysis for quality elements

Pairwise Comparison under grade A				
Quality elements	B1	B2	B3	B4
B1	1.00	0.11	0.50	0.25
B2	9.00	1.00	7.00	4.00
B3	2.00	0.14	1.00	0.50
B4	4.00	0.25	2.00	1.00
Sum	16.00	1.50	10.50	5.75

n = 4

Input

Intermediate Calculation						Weights
	B1	B2	B3	B4	sum	
B1	0.063	0.074	0.048	0.043	0.227	5.69%
B2	0.563	0.665	0.667	0.696	2.590	64.74%
B3	0.125	0.095	0.095	0.087	0.402	10.05%
B4	0.250	0.166	0.190	0.174	0.781	19.52%
sum	1.000	1.000	1.000	1.000	4.000	100.0%

lambda max	4.0615
consistency index (CI)	2.05%
consistency ratio (CR)	2.28%

Output

Figure 3.2 Calculation of weights using Excel spreadsheet

As Figure 3.2 shows, the weights of interpersonal quality, technical quality, environmental quality and administrative quality are 0.0569, 0.6474, 0.1005 and 0.1952 respectively. Thus, technical quality is considered to be a dominating element in determining the whole health service quality and requires further investigation, following are administrative quality and environmental quality. On the contrary, interpersonal quality is considered to be the least important. It is not difficult to interpret this result since patients and students usually have more concerns about the outcome of the medical treatment which is most tightly linked with technical quality of health service. At the same time, physicians tend to pay more attention to administrative quality since it is related to their working hours and their schedules of appointment, and other issues they have interests in.

As to the issue of consistency, it has been determined that the set of judgments are acceptably consistent when both CI and CR are less than 0.1 (Saaty 1980). Figure 3.2 shows a CI value of 0.0205 and a CR value of 0.0228, which indicate a very good consistency level of the judgments made by the respondents. This satisfactory result is attributed to the efficacy of the pilot study during which judgments are not made by a particular individual but from the discussion of a group of persons.

After several pairwise comparison rounds, a completed pilot study result sheet is obtained. With the help of the spreadsheet application, it is easy to calculate weights for each quality element. Note that the weights yielded from the spreadsheet can only be viewed as "local weight". That is, this weight only reflects the relative weight with respect to the upper quality element. If each hierarchy in the AHP model was considered as a whole, the sum of all the weights in that hierarchy should be 1. This kind of weight is called "global weight" and it can be simply calculated as the product of all the upper "local weights". Figure 3.3 contains the "global weights" for every quality element in the hierarchical model. The completed pilot study sheet and calculations of "local weights" are included in the appendix at the end of this thesis.

Figure 3.3 Global Weights of Quality Elements in Health Service System

First grade (A)	Second grade (B)	Weights	Third grade (C)	Weights	Fourth grade (D)	Weights
Health service quality	B1	0.0569	C1	0.0379	D1	0.0045
					D2	0.0232
					D3	0.0102
			C2	0.0189	D4	0.0126
					D5	0.0063
	B2	0.6474	C3	0.4316	D6	0.2341
					D7	0.1007
					D8	0.0603
					D9	0.0366
			C4	0.2157	D10	0.1078
					D11	0.1078
	B3	0.1005	C5	0.0502	D12	0.0392
					D13	0.0069
					D14	0.0042
			C6	0.0502	D15	0.0335
					D16	0.0167
	B4	0.1952	C7	0.1627	D17	0.1141
					D18	0.0347
					D19	0.0139
			C8	0.0325	D20	0.0217
					D21	0.0108

The overall consistency ratio (CR_o) for all the pairwise comparisons can be calculated using equation (3.11). In this research, $CR_o = 0.032 \leq 0.10$, indicating the results are consistent and acceptable.

3.2.4 Interpretation of the Results of AHP

The global weights shown in Figure 3.3 provide many insights to understand the health service quality. Within interpersonal quality context (B1), interaction quality (C1) is more important than relationship quality (C2), and the interpersonal qualities between physicians and patients (D2 and D4) are considered to be more important than other pairs. This result is not surprising in that patients tend to establish a good relationship with physicians to receive better treatment and good interactions between service providers and patients are the basis for receiving better treatment.

Within technical quality (B2), it can be indicated that good physicians (C3) contribute more to a desirable health outcome than good medical equipments (C4). Diagnostic errors (D6) damage the quality of physicians most among the four quality elements within C3, and both the testing equipment errors (D10) and surgery equipment errors (D11) have the same importance in affecting the medical equipment quality. The physicians' opinions play a major role in achieving agreement in assessing the technical quality in that they are more knowledgeable in this part.

As to environmental quality (B3), atmosphere (C5) and tangibles (C6) are considered to have equal importance. Specifically, the cleanness (D12) and the layout (D15) are the most important factors within C5 and C6, respectively. It is indicated that patients have more concern for cleanness than other atmosphere factors. Also, the layout is important in that a good hospital layout can facilitate patient flow and make the health system more efficient.

Timeliness (C7) is considered to be more important than operation (C8) within administrative quality (B4) because waiting time (D17) is included in C7. Excessive waiting time can severely damage the outcome of medical treatment because many diseases can only be cured within a specific time period. Also, the ease of making or changing appointment (D18) and hours of operation (D19) within C7 present more importance than the two quality elements within C8 based on the result of the pilot study.

3.2.5 Evaluation of Health Service Quality

After the weights of each quality element in a health service system have been collected, it is possible to evaluate the quality of the health service system. The most difficult part in such an evaluation is to find appropriate method to quantify each quality element in the bottom hierarchy. The abstract concept of health service quality has been represented with many detailed quality elements, but some of them still require further investigations in order to make the problem solvable. This research will focus on the technical quality part in part due to the dominating importance of this part explored from the AHP analysis, and also due to the limited time for completing this research. In the future, if each quality element of a particular health service system is appropriately quantified, the weighted health service quality could be expressed as

$$HSQ = \sum_{i=1}^{n} w_i v_i \tag{3.12}$$

where HSQ is the numerical measure of the health service quality, v_i is the quantified value of quality element i, w_i is the weight of quality element i, and n is the total number of quality elements in the bottom hierarchy.

CHAPTER IV

STATISTICAL QUALITY MODEL TO ASSESS MEDICAL EQUIPMENT QUALITY

As presented in the previous chapters, the health technical quality in the AHP model can be further divided into physician quality and health equipment quality. The physician quality involves with several possible errors caused by human factors. Obviously, the lower rates of the errors are, the better quality indicated. Although human errors are essentially subjective, numerous research have been conducted in this area, yielding reasonable approaches to quantify these elements. Also, such data can be also found in various health databases if a health service unit in a particular location is investigated. The attention would be given on the quality of medical equipment, which is more objective but lack of extensive research. Section 4.1 introduced the process capability analysis which is a tool to yield medical equipment error rates from real medical processes.

4.1 Quantification of Process Error Rate

In the production system, process capability is applied to describe the uniformity of the process. As to health care system, some processes could also be modeled through process capability, such as surgery. So it is possible to apply process capability analysis to quantify the variability of a medical operation, analyze this variability relative to the specific requirement, and help to improve the medical equipment or procedures used in an operation.

In order to use simple and quantitative ways to express process capacity, this research used process capability ratio (PCR) C_p and C_{pk}. The sole purpose of these indices is to determine whether the medical process is capable of producing final results which are within the predefined medical specifications. The result of a medical operation can be influenced by both physicians and equipments, so it is nature to make comparison to the situation as in production system in which the result is always based on the workers and machines. For example, in a normal tumor cutting operation, the length of surgical incision is based on the volume and location of the tumor. While the optimal size of the incision can be predefined, the actual size is always varied due to the variability of surgeons and equipment. Since it is difficult to analyze the variability of surgeons, the attention is given on the variability of equipment and the possible errors resulted from this variability. In the following subsections, the quantification of process capability under a hypothetical surgical situation is described.

4.1.1 Potential Capability Index C_p

First of all, note that the theory of process capability analysis and the following equations are based on the following two assumptions:

- The process is in statistical control.
- The measuring element has a normal distribution.

The upper and lower specification limits of a specific medical process could be denoted as USL and LSL. Their difference, USL-LSL is referred to as the allowable spread of the process (Kocherlakota 1992). The potential capability index only takes care of the process spread and further assumes the process mean is centered between the lower and upper specification limits. Note that in most quality control situations, the natural tolerance of the process is set at 6σ. Then, using the estimate of the variability of the process σ, the process capability ratio can be calculated as

$$C_p = \frac{USL - LSL}{6\sigma} \tag{4.1}$$

The values of USL and LSL can be different in different medical conditions, and σ must be estimated from sample data usually in the forms of $\bar{x}$, R (mean and range) control charts. This estimated standard deviation is denoted as $\hat{\sigma}$. According to Pearson and Hartley (1966), when R control chart is used, the estimate of standard deviation is

$$\hat{\sigma} = \bar{R} / d_n \tag{4.2}$$

where d_n is the expected value of the range in samples of size n from a standard normal distribution. They also provided the values of d_n, but note that d_2 is always used in place of d_n.

When an $\bar{x}$, s chart is used instead of $\bar{x}$, R chart, the estimate of the standard deviation can be expressed as

$$\hat{\sigma} = \bar{s} / c_n \tag{4.3}$$

where c_n is the expected value of s in samples of size n from a standard normal distribution and

$$c_n = \sqrt{2}\,\frac{\Gamma(0.5n)}{\Gamma(0.5n - 0.5)} \tag{4.4}$$

Note that in both $\bar{x}$, s chart and $\bar{x}$, R chart, the process average can be estimated over k subgroups as

$$\mu = \frac{1}{k}\sum_{j=1}^{k} \bar{x}_j, \tag{4.5}$$

The index C_p is a useful tool to measure how much "natural variation" a process experience relative to its specification limits. The larger the value of C_p is, the more proportion of the process outputs is within these limits, thus desirable. It can be concluded that the process has good capability in the sense that the product is conforming to required specification to a significant extent. The percentages of process fallout with different values of C_p are shown in the following table:

Table 4.1 Relationship between C_p and Percentage of Process Fallout

USL - LSL	C_p	**Process Fallout**
6σ	1.00	0.0027
8σ	1.33	0.633×10^{-4}
10σ	1.67	0.573×10^{-6}
12σ	2.00	0.197×10^{-8}

Chan et al. (1988) proposed a modified version of the C_p index, C_{pm}, because C_p fails to take into account the target value T of the process. They replaced the previous estimated standard deviation $\hat{\sigma}$ with the squared root of the mean squared error around T, yielding

$$C_{mp} = \frac{C_p}{\sqrt{1+(\frac{\mu - T}{\sigma})^2}} \tag{4.6}$$

which reduces to C_p if the target value equals to the process mean.

4.1.2 Actual Capability Index C_{pk}

The potential capability index C_p does not take into consideration about the location of the process mean relative to the specifications. It is common that many processes cannot be correctly centered on the nominal value. Therefore, the capability index C_{pk} is introduced to measure the actual capability performance considering both location and dispersion. The expression of C_{pk} is

$$C_{pk} = Min\left(\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right) \tag{4.7}$$

Note that if $C_p = C_{pk}$, the process is centered at the midpoint of the specifications, and the process is off-center if $C_{pk} < C_p$. Also note that a less than zero value of C_{pk} means the process falls outside of the specification limits. The assumption of normal distribution is also held in these situations.

The difference between C_{pk} and C_p can be used to measure how off-center the process is operating. Similar to C_p, in order to estimate the process capability around a target T, the index C_{pkm} can be defined as

$$C_{mpk} = \frac{C_{pk}}{\sqrt{1+(\frac{\mu - T}{\sigma})^2}} \tag{4.8}$$

4.1.3 Process Capability Index for Non-normal Process

An important assumption underlying the above notations is that the distribution of the quality characteristics data is normal. However, the production processes and medical processes are very often nonnormal. Bernardo and Irony (1996) noted that skewed distributions are frequent, but quality practitioners are often not qualified to achieve reasonable transformations to normality. To tackle this problem, two general approaches have been proposed for different families of distributions. One approach is to transform the data using mathematical functions into a normal distribution appearance, the other approach is to extend the definitions of the process capability indices to the case of non-normal distribution. Kotz and Johnson (1993) presented these approaches with details.

This research uses the quantile based approach proposed by Clements (1989) to handle non-normal data due to its relative ease of implementation. His approach is capable of calculating C_p and C_{pk} for a distribution of any shape using the non-normal percentiles. After denoting U_p as 99.865 percentile of observations and L_p as 0.135 percentile of observations, the new C_p and C_{pk} (denoted as $C_{p(q)}$ and $C_{pk(q)}$) is as follows:

$$C_{p(q)} = \frac{USL - LSL}{U_p - L_p} \tag{4.9}$$

$$C_{pk(q)} = Min\left(\frac{USL - X_{0.5}}{U_p - X_{0.5}}, \frac{X_{0.5} - LSL}{X_{0.5} - L_p}\right) \tag{4.10}$$

where $X_{0.5}$ is the median value referring to the center of the skewed distribution.

4.1.4 Process Capability Index for Multivariate Process

All the previous calculations have been restricted to the study of one variable. However, Porter and Oakland (1990) noted that in the majority of process control situations, several output variables are often measured. Since it is well known that a non-conforming product is often faulty in several related attributes, those output variables tend to show strong correlation. As a result, it is insufficient to provide good control of the process with consideration of a single important variable.

According to Porter and Oakland (1990), the sample means and standard deviation of a p-variate normal distribution process with l samples of size n are

$$\bar{x}_{jk} = \sum_{i=1}^{n} \frac{x_{ijk}}{n} \tag{4.11}$$

$$s_{jk} = \sqrt{\sum_{i=1}^{n} \frac{(x_{ijk} - \bar{x}_{jk})^2}{(n-1)}} \; ; \quad j = 1,2,\ldots,p; \quad k = 1,2,\ldots,l \tag{4.12}$$

where x_{ijk} is the ith measurement of the jth process output in the kth sample. And the covariance between process outputs j and h in the kth sample is

$$s_{jhk} = \sum_{i=1}^{n} \frac{(x_{ijk} - \bar{x}_{jk})(x_{ihk} - \bar{x}_{hk})}{(n-1)} \; ; \quad k = 1,2,\ldots,l; \quad j \neq h \tag{4.13}$$

This research only focuses on the process capability analysis of each medical equipment within a medical surgery context. Each medical equipment will be assumed to have only one output variable representing its major functions, so further exploration of the capability analysis for multivariate process is beyond the scope of this study. However, for comprehensive analysis of the health service technical quality and medical surgery procedures, all possible output variables should be considered and would be a concern in future research.

4.1.5 Relationship between Process Capability Index and Probability of Process Fallout

In order to quantify the influence of each element in a medical process, only capability indices are not enough. A mapping from process capability indices, such as C_{pk}, to the measures of probabilities of process fallout should be established. Then if C_{pk} can be calculated through process observations, the chance that the process is operating successfully is easy to obtain. Remember that Chapter 3 presented several error rate elements in the hierarchical structure of health service technical quality, and those elements are naturally tractable in this sense.

In univariate and normally distributed medical surgery process, Montgomery (2004) provided a mathematical function to measure the probability of process fallout. The univariate normal probability density function is

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \qquad -\infty < x < \infty \tag{4.14}$$

where μ is the mean of the distribution and σ is the standard deviation. He noted that the process fallout is the complement of process yield which is approximately equal to the area under the above probability density function.

From equation (4.7), if the capability index C_{pk} and the standard deviation σ of the process are obtained, the corresponding standard deviation σ_c can be calculated as

$$\sigma_c = 3C_{pk}\sigma \tag{4.15}$$

Then the probability of process fallout is

$$P_f = \frac{1}{\sqrt{2\pi}} \int_{-\sigma_c}^{\sigma_c} e^{-t^2/2} dt \tag{4.16}$$

Several possible P_f values with different C_{pk} are represented in the Table 4.2:

Table 4.2 Relationship between Process Capability Index and Probability of Process Defect

C_{pk}	σ_c	**Process Fallout**
0.33	σ	0.3173
0.67	2σ	0.0455
1.00	3σ	0.27×10^{-2}
1.33	4σ	0.1×10^{-3}
1.67	5σ	0.1×10^{-5}
2.00	6σ	0.2×10^{-8}

4.2 Framework of Assessing Medical Equipment Quality in A Medical Process

The quantification technique in the above section can be used to further assess health service technical quality. As previously mentioned, health service technical quality as one of the four second grade hierarchies in the AHP model, is more objective and can be evaluated through engineering techniques such as process capability analysis. The whole AHP health service quality model is huge and may require knowledge from different disciplines to establish comprehensive mapping from solid numerical measures to the bottom quality elements. Even within the technical quality grade, the modeling of human errors in the quality elements under

C4 grade still require enormous efforts and are beyond the scope of this study. However, it is believed that the efforts in using capability analysis to quantify the quality elements under grade C5 is still meaningful and would provide insights and incentive to carry on such research on this topic.

There are numerous different types of medical processes during a whole medical treatment. In general, this research categorized these processes into testing process and surgery process. The main difference between these two processes are the whole testing process always contains several parallel tests and the whole surgery process always involves with several sequential procedures. That is also to say, the final testing results are based on the results of several independent tests which have no influence to each other, while the outcome of a surgery could be attributed to the outcomes of all necessary procedures. Any failure in a procedure may cause the failure of the whole surgery, and even cause some irreversible result, such as death. The processes in both testing and surgery are illustrated in Figure 4.1:

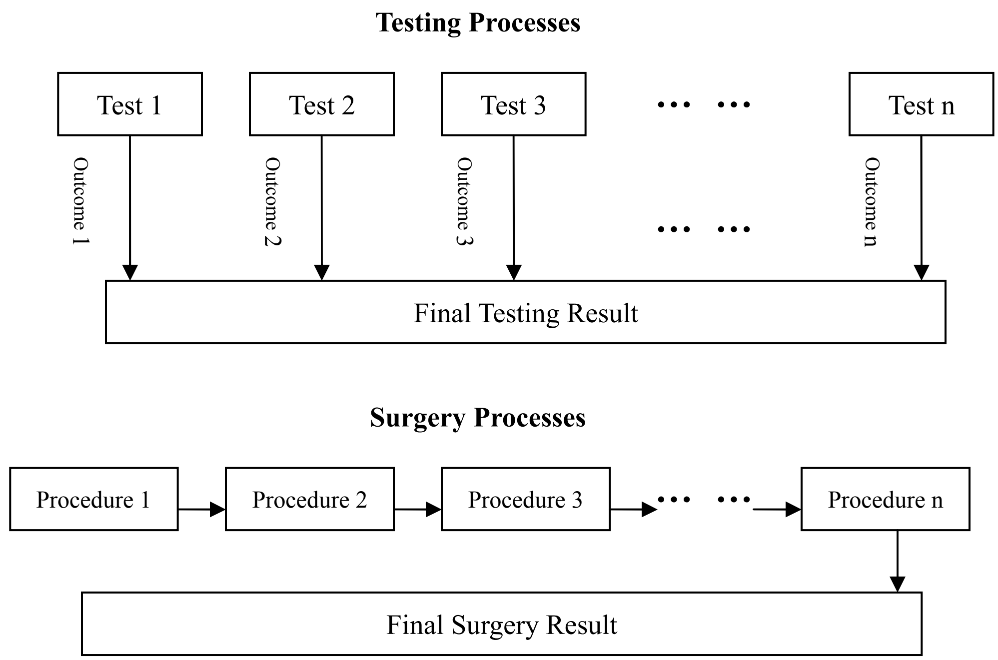


Figure 4.1 Comparison between Testing Processes and Surgery Processes

As mentioned before, it is assumed that the good quality health service means all processes and procedures are performed without errors and all medical equipment function well. It is likely that the patient's health situation is not improved due to the severity of his/her disease or injury, even if all the health services are provided properly and efficiently. In that case, it can be also considered that the quality of health care is good no matter what the outcome of the treatment is.

In this model, diagnostic errors, surgical accidents, drug errors and dosage errors caused by human errors are not considered. Human error is considered as contributing factor in accidents in both industries and health service systems. It generally includes four types or errors: (1) performance of an unnecessary action, (2) failure to perform a required action, (3) performance of an action but at an incorrect time, and (4) making a poor response (Salvendy 1982). It is nature to introduce the theory of human reliability (Park 1987) to predict the human error rates, which can be defined as the probability that a person will perform a task without error for a specific duration. Then it is another branch under which the AHP quality model can be further expanded. Focus is still given on the quality of medical equipment in this study.

The sequential processes in a surgery are relatively straightforward to be mathematically modeled using the process capability tools described in the previous section. Assume that only one major medical equipment will be used in a single procedure and the error rate of this equipment is independent from all other equipments. Recall equation (4.16) which defines the probability of process fallout, then the failure rate of the surgery can be expressed as (Ebeling 1997)

$$P_f(s) = 1 - \prod_{i=1}^{n} (1 - P_{fp}(i)) \tag{4.17}$$

where $P_{fp}(i)$ is the probability of failure of the ith procedure during a surgery process. The total number of procedures n required in a surgery is based on the type of the surgery and should be determined by surgeons. Note the equation is a simplified form of real situation and does not take into account other factors that might also cause the failure of a surgery.

The testing processes are a little complicated because of the uncertainty involved with the final testing result. It is known testing is a critical part in making accurate diagnosis. If physicians cannot make confident judges based on the patients' symptoms, many different tests prescribed by physicians should be necessary and important for further treatment. This research classified all the tests into four general types:

- Preliminary tests should be carried out in consulting room before the patient see the physician, such like weighing and height, measuring blood pressure, taking the patient's pulse, and auscultation. Usually, results of this type of tests are not the core contributors in diagnosing a patient, but they are still important in that they can provide assisting information in a diagnosis process.
- Some tests are required to be carried out in a laboratory, such as blood test, urine test, and stool test. These laboratory tests often require microscopic observations and medical equipment detection. It comprises large part of testing errors.
- Invasive tests often involve removal of cells or tissues for examination. These tests may take longer time and also pose highest risk upon patients. Such tests include biopsies and lumbar puncture, etc.
- Many tests require elaborate medical equipment, such as X-ray scanning, CT scanning, MRI (Magnetic Resonance Imaging), GCI (Gamma Camera Imaging), ECG (Electrocardiogram) and EEG (Electroencephalogram). These tests could incur high medical cost but at the same time bring about results with high accuracy.

Due to the possible diversity and complexity involved with medical tests, it is very difficult to propose a sophisticated model that accurately represents all the possible sequences among each test. It is possible that some test can only be performed after a certain test. In that case, the model would be inaccurate and even misleading. However, it is found that one of the characteristics of testing processes is their independence. It is seldom reported that an outcome of a specific test would have effect on the other test. In this sense, the parallel model of testing processes has its rationality.

Another issue worth mentioning in testing processes is whether the result of every parallel test will have the same impact on the final testing result. Up to now, the difference of impact among different tests is identified, but no clue is given in quantifying these differences. Therefore, an assumption is again made which eliminates the difference of impacts so that the theory for parallel system can be utilized. That is also to say, the final testing result is mainly based on one test result and the final testing result would be unreliable only if all tests are failed due to medical equipment errors. Then the failure rate of the medical test before treatment is (Ebeling 1997):

$$P_f(t) = \prod_{i=1}^{n} P_{ft}(i) \tag{4.18}$$

where $P_{ft}(i)$ is the probability of failure of the ith test. In practice, the number of tests n should not necessarily be equal to number of all tests taken, but can be reduced through communications with the particular health practitioner. It is possible that a suspicious disease can be diagnosed only through several major important tests, so other tests that patient taken can be eliminated from the calculation of process failure rate. The next chapter demonstrates the use of this model to assess medical equipment quality, and other models recommended to assess other quality elements constituting health service quality.

CHAPTER V

DEMONSTRATION OF THE PROPOSED AHP MODEL BASED ON A SCENARIO

The scenario utilized in this chapter is concerned with the treatment of a male patient suffering from acute appendicitis. Before the patient went to the hospital, he consulted with a physician and made an appointment. It was very easy for him to make the appointment, and the doctor was nice and told him to begin fasting before surgery. After he arrived at the hospital, he was required to take preliminary tests and blood tests. He did not waste any time looking for right places to take the tests due to the well-designed layout of the hospital and the informative signs. The nurse who performed tests on him has 5 years of experience but had a very heavy workload at that time. After taking all the tests, he was asked to wait in the waiting room to take the surgery. The waiting time was acceptable (about half an hour), and he felt a little cold during waiting. His appendectomy was performed by a surgeon who had 10 years of surgical experience and also had a very heavy workload. The surgery lasted forty minutes. After the surgery, he was sent to the ward for recovery. He had good experience in the ward because the nurses and physicians were very nice and treated him like a family. Also, the ward is very clean and does not have the annoying hospital smell. After he left the hospital, he kept on taking antibiotics following the doctor’s prescription until full recovery.

In this scenario, if a 1 – 4 numerical scale is applied to assess each quality element, what the health service quality would be? (Assume 1 = poor quality, 2 = fair quality, 3 = good quality, and 4 = very good quality)

5.1 Medical Equipment Quality Analysis

The scenario described above involves all the four major quality elements, from B1 to B4. More attention is given to the medical equipment quality in this research as mentioned in Chapter IV. It is assumed that all medical equipment affecting health service quality was used during only testing and surgery processes (appendectomy). An investigation concerning the procedures and major equipment used in these processes is conducted.

5.1.1 Procedures in Appendectomy

In an appendectomy, a surgeon needs to remove the inflammatory vermiform appendix from the patient's abdomen in order to cure the ailment. Note that in some cases the appendicitis would resolve automatically without any surgery, while in more often cases the disease will cause an inflammatory mass to form around the appendix.

A characteristic of appendicitis is that it is relatively hard to be definitely diagnosed. Sometimes exploratory surgery is performed when a patient has unexplained abdominal pain. In this case, even the pain is not caused by infection of the appendix, the surgeon would probably remove the appendix due to its uselessness and prevention of future appendicitis. However, this is not usually the case because few patients would like to take the risk accompanied with the operation only on the purpose of detecting possible disease. Therefore, this study does not consider this exploratory surgery situation and would assume that all appendectomies are performed targeting on the inflammatory appendix only.

Various online sources were referred regarding the testing and surgery procedures required for treating a patient with appendicitis. All the testing processes can be categorized into four major parts:

1. Preliminary tests: include measuring the patient's temperature, blood pressure, pulse, and respirations.
2. Blood tests: are usually done on plasma or serum and are used to determine physiological and biochemical states of the patient. They require a laboratory analysis performed on a blood sample that can be drawn from a vein in your hand or from the bend in your elbow.
3. Chest X-ray: is mainly carried out to make sure the patient's heart and lungs are healthy enough for the surgery.
4. Heart monitor: shows a tracing of each heartbeat. It should be used through out the process of the surgery and to monitor the real-time heart condition of the patient.

While all the tests can be generally considered independent with each other, procedures during a surgery are commonly sequential. The success of a particular procedure relies on the outcomes of all the previous procedures. The common surgery procedures are listed as follows:

1. Anesthetic is given prior to the surgery.
2. The abdomen is disinfected and draped.

3. The incision is made over McBurney's point which is one third of the way from the anterior superior iliac spine and the umbilicus.
4. The various layers of the abdominal wall are opened.
5. The appendix is identified, ligated and divided at its base
6. Each layer of the abdominal wall is closed in turn.
7. The skin is closed with stitches or staples.

5.1.2 Medical Equipment in Appendectomy

As the main procedures have been explored for testing and surgery in appendectomy, the next step should be investigating the equipments used in these procedures. The workload for investigating medical equipment is enormous due to the huge quantity and variety of available medical equipment. This work was carried out through searching from the Internet, and consulting with surgeons, medical staff and equipment providers. The intention is to find the most typical and widely used equipment for this study. The more equipment the model include, the more reliable results can be obtained. Several most commonly used medical equipment were listed in Table 5.1 with their most possible errors and quality indices. Note that the quality indices listed in the table are far from sufficiency and for illustration only.

Table 5.1. Diagnostic Tests Equipment

Type of Test	Function	Equipment Name	Possible Error	Quality Index
Consulting room tests	Auscultation	Stethoscope	Less sensitive	Frequency range
	Weighing and height	Weighing machine	Inaccurate	Capacity; Accuracy
	Measuring blood pressure	Sphygmomanometer	Inaccurate	Accuracy
	Taking the patient's pulse	Watch	Inaccurate	Accuracy
	Breath test	Air analyzer	N/A	Measurement range
	Reflex test	Tendon hammer	N/A	N/A
	Eye examination	Ophthalmoscope	Inaccurate diopter	Diopter range
	Hearing test	Audiometer	Out of range	Frequency range; Intensity level
	Rectal examination	Glove	Polluted	N/A
Invasive test	Biopsies	Scalpel, Pledget, Microscope	Polluted	Magnification factor
	Lumbar pucture	Spinal needle, Manometer	Polluted	N/A
Laboratory test	Urine test	Urine dipsticks, Microscope	Insufficient precision	Magnification factor
	Stool test	Vials, Microscope	Insufficient precision	Magnification factor
	Blood test	Needle, Fingerprick, Microscope	N/A	Magnification factor
Elaborate medical equipment test	X-ray scanning CT scanning Ultrasound testing MRI (Magnetic Resonance Imaging) Gamma camera imaging		Timmer error: Radiation output error; Kilovoltage error; Beam quality	Timmer deviation (s), radiation deviation (mAs); Kilovoltage accuracy (kV); Beam quality (mm)
	Electrocardiogram (ECG) Electroencephalogram (EEG)		Signal error	Voltage deviation (mV); Frequency deviation (Hz)
	Endoscopy	Endoscope	Poor image quality	N/A

* N/A means the data is not available

As to the four testing procedures in appendectomy, only one major equipment was chosen for each procedure in order to depict the general framework to apply the model. Specifically, stethoscope is used most frequently in preliminary test, microscope is used in blood test, X-ray scanner is applied to examine chest, and Electrocardiogram (ECG) machine is used to monitor heart conditions. The patient flow through these tests was illustrated in Figure 5.1

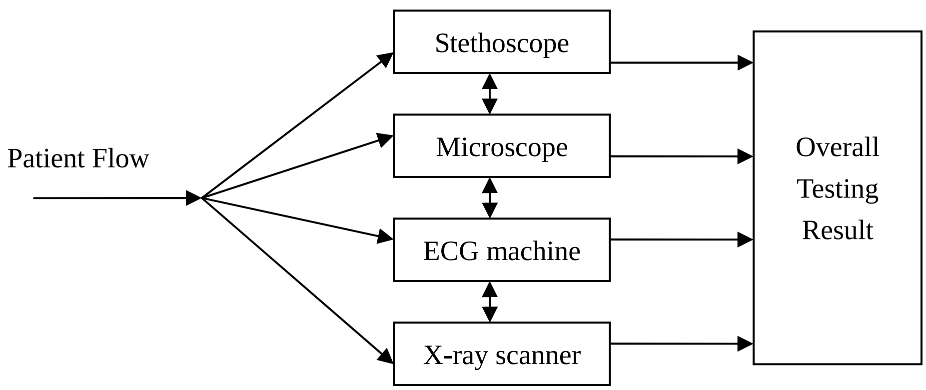


Figure 5.1 Patients Flow through four Major Equipment in Medical Testing

Likewise, major equipment used in appendectomy surgery could be identified. In the first procedure, intravenous tube is placed for giving anesthetics. Then adhesive drapes are used to prevent surgical site infection. The third procedure involves various cutters, including scalpels, lancets and etc. Retractor should be used in procedure four to actively separate the edges of the surgical incision. They also should be used in procedure five to identify the appendix in combined use of cutters. Then both retractor and towel clamp are used to close abdominal walls in turn. The last procedure involved with the simple use of medical staples or stitches. The authors once again illustrated the major medical equipments that a patient would go through during appendectomy in Figure 5.2.

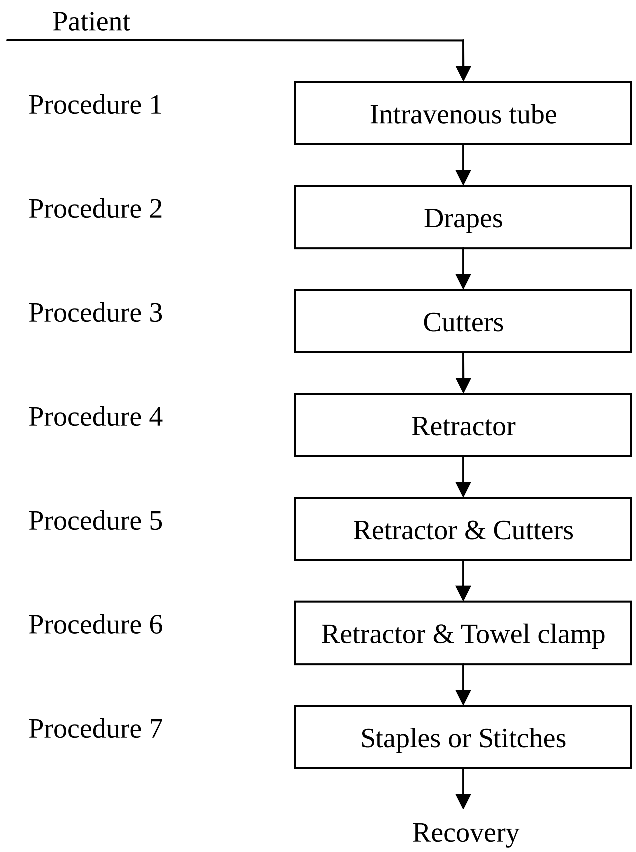


Figure 5.2 Major Surgical Equipments A Patient Goes through during Appendectomy

With the knowledge of major procedures and equipment required for an appendectomy, it is possible to evaluate the testing equipment error rate and surgical equipment error rate as denoted in the AHP quality model as D10 and D11. Each medical equipment could be assigned a quality index based on Table 5.1 or other sources. If the process is normally distributed, the process capability indices could be calculated using equation (4.1) and (4.7). If the process follows a non-normal distribution, equation (4.9) and (4.10) could be used to measure the process capability. Then the failure rate for each process can be obtained using equation (4.15) and (4.16). Equations (4.17) and (4.18) can be used to yield the testing equipment error rate and surgical equipment error rate.

To establish a mapping from the equipment error rates to the 1 – 4 numerical scale quality value, an interview with some experts should be conducted based on the approach used by Gonzalez and Chen (1996) and Rosas (2003). The error rate range from 0 to 1.00 was divided into 21 equally distributed error rate values (the interview sheet is attached in the Appendix IV). The interview collected the following data: the truthfulness from 0 to 1 that an equipment error rate can be represented as very good quality, the truthfulness from 0 to 1 that an equipment error rate can be represented as good quality, the truthfulness from 0 to 1 that an equipment error rate can be represented as fair quality, the truthfulness from 0 to 1 that an equipment error rate can be represented as poor quality. After the data was collected, the fuzzy membership functions for each quality level could be developed (Figure 5.3). Then the different error rates could be distributed into the four quality levels based on the intersection values of these four curves (Table 5.2).

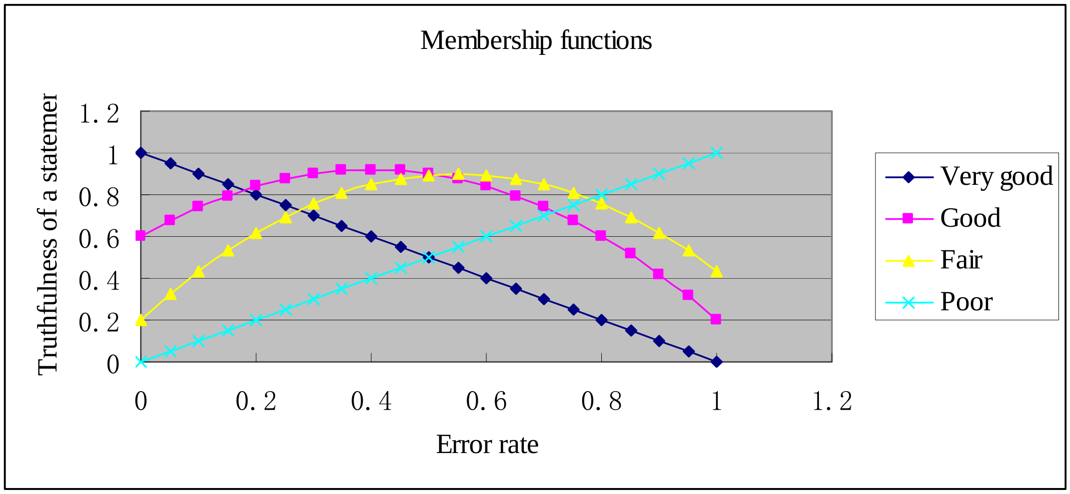


Figure 5.3 Membership functions for each of the four quality levels

Table 5.2 Four quality levels and corresponding ranges of error rates

Quality Level	Numerical Quality Value	Range of Error Rates
Very Good	4	0 – 0.18
Good	3	0.18 – 0.49
Fair	2	0.49 – 0.78
Poor	1	0.78 – 1.00

In this scenario, no data was collected about the medical equipment used in testing and surgery processes. For demonstration only, this study assumed enough data regarding medical equipment had been collected, and the testing equipment error rate and the surgical equipment error rate had been calculated as 0.21 and 0.07, respectively. According to Table 5.2, the quality values for testing equipment and surgical equipment are 3 and 4, respectively.

5.2 Other Quality Elements Analysis

Another highly weighted quality element is the quality of physicians as denoted as C3 in the AHP quality model. This quality element can be assessed through several sub-quality elements involving with human errors including diagnostic error (D6), surgical error (D7), and medication error (D8, D9). Rosas (2003) provided an approach to analyze human errors based on the performance of Advanced Cardiac Life Support (ACLS). Her approach can be expanded to fit in this research context.

It is assumed that the patient would only be treated by three physicians, each of which is responsible for diagnosis, surgery, and prescription, respectively. The approach applied to assess quality of physicians is composed of the following steps, as also found in Gonzalez (1995) and Rosas (2003):

1. Consult with the experts to identify the factors that affect the diagnosis of appendicitis and appropriate descriptors and levels these factors could take.
2. Create a table containing all personal profiles based on the factors and descriptors previously identified.
3. Conduct an interview with experts for evaluation of each personal profile based on a numerical scale from 45 to 150.
4. Use regression linear programming model to fit the data and yield relative weights for the factors of a certain level.
5. Develop four fuzzy linguistic descriptor sets to represent the possibility of making error. The four sets are described as: (1) make a mistake; (2) is likely to make a mistake; (3) is not

likely to make a mistake; (4) will not make a mistake.

6. Conduct another interview to obtain the membership function for the four sets based on the work by Gonzalez and Chen (1996).

7. Enter the obtained data into excel and apply regression analysis of the data, yielding four best-fit curves for each membership function.

8. The intersections of each of the curves define the bounds of each descriptor set. Therefore, given a certain personal profile index, the likelihood of the human error during diagnosis can be determined. The quality value would be 1 if this likelihood falls into descriptor set 1 (make a mistake), 2 if this likelihood falls into descriptor set 2 (likely to make a mistake), and so forth.

Note that the steps described above are used to determine the physician's diagnostic quality (D6). As to the physician's surgical quality (D7) and prescription quality (D8, D9), the same steps should be followed except for the corresponding change in the first step regarding the identification of factors and descriptors. Also note that this is only a brief description of the approach to assess physician quality, and the detailed steps for applying this approach can be found in Rosas (2003).

The purpose of this scenario study is only to demonstrate the use of the AHP model to assess health service quality, so the detailed analysis of human errors was not conducted. It is assumed that all the analysis had been conducted based on the approach described above, and the quality values for D6, D7, D8, and D9 were determined to be 2, 3, 4, and 4, respectively.

For other quality elements except the ones within technical quality context, judgments were made based on the description of the scenario at the beginning of this chapter. For example, the scenario stated that the patient did not waste any time looking for right places to take the tests due to the well-designed layout of the hospital and the informative signs, so the qualities for hospital layout (D15) and signs and symbols (D16) were assigned values of 4 (very good quality) and 4. However, the waiting time before the surgery was acceptable (about half an hour) and the patient felt a little cold during waiting, so the qualities for waiting time (D17) and temperature (D13) were assigned values of 3 (good quality) and 2 (fair quality). Some quality elements were not mentioned in the description, such as hours of operation (D19) and coordination of different medical services (D21), the middle value of the numerical quality scale—2.5—was assigned to these elements. The final quality element indices with their quality values and relative weights were shown in Table 5.3. The weight of each quality element is obtained from pairwise comparison processes (Chapter 3), so it can be considered as a general result and applicable to the scenario.

Table 5.3 Quality Weights and Values based on a Scenario

Index	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
Weight	0.005	0.023	0.010	0.013	0.006	0.234	0.101	0.060	0.037	0.108	0.108
Value	4	4	4	4	4	2	3	4	4	3	4
Index	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	
Weight	0.039	0.007	0.004	0.034	0.017	0.114	0.035	0.014	0.022	0.011	
Value	4	2	4	4	4	3	4	2.5	3	2.5	

Based on the description of the scenario and the assumptions regarding the data, the weighted health service quality value can be assessed using equation (3.12), which in this scenario, is 3.14 out of 4. The quality value can be interpreted that the patient described in the scenario experienced a good quality health service generally. As different scenarios could happen, different values for health service quality could be yielded based on the AHP model and the approaches used in this study.

CHAPTER VI

CONCLUSION

In this thesis, an Analytic Hierarchy Process (AHP) approach is proposed to assess health service quality. Most previous research regarding the assessment of health service quality were developed from marketing perspective and only relied on human judgments. The approach used in this research not only takes into account human judgments, but also investigates the detailed reasons behind those judgments. In this research, the application of AHP makes it possible for researchers to have a deeper insight of every hidden element under the general context of health service quality. After discovering those elements, techniques such as process capability analysis and goal programming could be used to assess the quality values of these elements, and the weighted health service quality value could be yielded as a main output of the AHP model.

Specifically, a literature review regarding to the topics of health service quality and analytic hierarchy process (AHP) is conducted. Several previous works in each topic are sorted and presented. The previous research provides great insights in doing this research. Then the main investigation of health service quality using AHP is discussed, including detailed identification of quality elements within the general health service quality, data collection process, and quantification of each element using AHP's algorithm. Finally, a scenario is created to demonstrate the use of the AHP model to yield health service quality index value. As a result, the main contribution of this research should be providing an approach to evaluate the essentially abstract "health service quality" using accessible numerical values.

The effectiveness of AHP in assessing health service quality can be compared to goal programming (Gonzalez 1995). Goal programming can be thought of as an extension of linear programming to handle multiple objective measures. The objective function of a goal programming model may consist in non-homogeneous units of measure. Other advantage of goal programming is its ease of use, since the goal programming problems can be solved using linear programming software, such as LINDO. Comparing with AHP, it is believed that both approaches could be useful within health service quality context.

The limitation of this research is that it does not include practical data to assess the medical equipment quality and physician quality, but only demonstrates the procedures to conduct this work. Also, conducting the process capability analysis and human reliability analysis (Rosas 2003) require extensive efforts that are beyond the scope of this thesis. Future research direction lies in looking for more accessible approaches for quantifying each quality element within the AHP model, comparing the outputs of the model based on various scenarios, and collecting real data to test the model.

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APPENDIX A

APPENDIX A

ANALYTIC HIERARCHY PROCESS QUESTIONAIRE

In the following tables, please provide numerical value from 1-9 regarding the relative importance of each pair of quality elements. The verbal representations of the numerical values are shown below:

Table 1 AHP Pairwise Comparison Numerical Scale and Its Explanation

Numerical Value	Verbal Scale	Explanation
1.0	Equal importance of both element	Two elements contribute equally
3.0	Moderate importance of one element over another	Experience and judgment favor one element over another
5.0	Strong importance of one element over another	An element is strongly favored
7.0	Very strong importance of one element over another	An element is very strongly dominant
9.0	Extreme importance of one element over another	An element is favored by at least an order of magnitude
2.0, 4.0, 6.0, 8.0	Intermediate values	Used to compromise between two judgments

(A) First Hierarchy

Which element in each pair is more important in contributing the improvement of the whole health service quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Interpersonal : Technical		
Interpersonal : Environmental		
Interpersonal : Administrative		
Technical : Environmental		
Technical : Administrative		
Environmental : Administrative		

(B) Second Hierarchy

b1. Which element in each pair is more important in contributing the improvement of the interpersonal quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Interaction : Relationship		

b2. Which element in each pair is more important in contributing the improvement of the technical quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Physician : Medical equipment		

b3. Which element in each pair is more important in contributing the improvement of the environmental quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Atmosphere : Tangibles		

b4. Which element in each pair is more important in contributing the improvement of the administrative quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Timeliness : Operation		

(C). Third Hierarchy

c1. Which element in each pair is more important in contributing the improvement of the interaction quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Administrative staff vs. patients : Physicians vs. patients		
Administrative staff vs. patients : Nurses vs. patients		
Physicians vs. patients : Nurses vs. patients		

c2. Which element in each pair is more important in contributing the improvement of the relationship quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Physicians vs. patients : Nurses vs. patients		

c3. Which element in each pair is more important in contributing the improvement of the physician quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Diagnostic error rate : Surgical accident rate		
Diagnostic error rate : Drug error rate		
Diagnostic error rate : Dosage error rate		
Surgical accident rate : Drug error rate		
Surgical accident rate : Dosage error rate		
Drug error rate : Dosage error rate		

c4. Which element in each pair is more important in contributing the improvement of the medical equipment quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Inappropriate equipment rate : Measurement error rate		
Inappropriate equipment rate : Operational error rate		
Measurement error rate : Operational error rate		

c5. Which element in each pair is more important in contributing the improvement of the atmosphere quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Cleanness : Temperature		
Cleanness : Scent		
Temperature : Scent		

c6. Which element in each pair is more important in contributing the improvement of the tangible quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Layout : Signs and Symbols		

c7. Which element in each pair is more important in contributing the improvement of the timeliness quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Waiting time : The ease of making or changing appointment		
Waiting time : Hours of operation		
The ease of making or changing appointment : Hours of operation		

c8. Which element in each pair is more important in contributing the improvement of the operation quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
General administration : Coordination of different medical services		

COMPLETED QUESTIONNAIRE

(A) First Hierarchy

Which element in each pair is more important in contributing the improvement of the whole health service quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Interpersonal : Technical	2	9
Interpersonal : Environmental	2	2
Interpersonal : Administrative	2	4
Technical : Environmental	1	7
Technical : Administrative	1	4
Environmental : Administrative	2	2

(B) Second Hierarchy

b1. Which element in each pair is more important in contributing the improvement of the interpersonal quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Interaction : Relationship	1	2

b2. Which element in each pair is more important in contributing the improvement of the technical quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Physician : Medical equipment	1	2

b3. Which element in each pair is more important in contributing the improvement of the environmental quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Atmosphere : Tangibles	1	1

b4. Which element in each pair is more important in contributing the improvement of the administrative quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Timeliness : Operation	1	5

(C). Third Hierarchy

c1. Which element in each pair is more important in contributing the improvement of the interaction quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Administrative staff vs. patients : Physicians vs. patients	2	6
Administrative staff vs. patients : Nurses vs. patients	2	2
Physicians vs. patients : Nurses vs. patients	1	2

c2. Which element in each pair is more important in contributing the improvement of the relationship quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Physicians vs. patients : Nurses vs. patients	1	2

c3. Which element in each pair is more important in contributing the improvement of the physician quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Diagnostic error rate : Surgical accident rate	1	3
Diagnostic error rate : Drug error rate	1	4
Diagnostic error rate : Dosage error rate	1	5
Surgical accident rate : Drug error rate	1	2
Surgical accident rate : Dosage error rate	1	4
Drug error rate : Dosage error rate	1	2

c4. Which element in each pair is more important in contributing the improvement of the medical equipment quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Testing Equipment error rate : Surgical Equipment error rate	1	1

c5. Which element in each pair is more important in contributing the improvement of the atmosphere quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Cleanness : Temperature	1	7
Cleanness : Scent	1	8
Temperature : Scent	1	2

c6. Which element in each pair is more important in contributing the improvement of the tangible quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Layout : Signs and Symbols	1	2

c7. Which element in each pair is more important in contributing the improvement of the timeliness quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
Waiting time : The ease of making or changing appointment	1	4
Waiting time : Hours of operation	1	7
The ease of making or changing appointment : Hours of operation	1	3

c8. Which element in each pair is more important in contributing the improvement of the operation quality? How important? (Please specify the numerical value based on Table 1)

Pair of quality element	The more important element (Input 1 or 2; 1 means the front element, 2 means the back element)	The magnitude of importance (Input integers 1 to 9; 1 means equal importance, 9 means extreme importance)
General administration : Coordination of different medical services	1	2

APPENDIX B

APPENDIX B

TABLE FOR RANDOM CONSISTENCY INDEX

Random Consistency Index (RI)	
n	RI
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

APPENDIX C

APPENDIX C

LOCAL WEIGHTS OF QUALITY ELEMENTS IN HEALTH SERVICE SYSTEM

Local Weights of Quality Elements in Health Service System

First grade (A)	Second grade (B)	Weights	Third grade (C)	Weights	Fourth grade (D)	Weights
Health service quality	B1	0.0569	C1	0.6667	D1	0.1180
					D2	0.6127
					D3	0.2693
			C2	0.3333	D4	0.6667
					D5	0.3333
	B2	0.6474	C3	0.6667	D6	0.5423
					D7	0.2333
					D8	0.1397
					D9	0.0847
			C4	0.3333	D10	0.6902
					D11	0.1492
					D12	0.1606
	B3	0.1005	C5	0.5	D13	0.7798
					D14	0.1374
					D15	0.0828
			C6	0.5	D16	0.6667
					D17	0.3333
	B4	0.1952	C7	0.8333	D18	0.7014
					D19	0.2132
					D20	0.0853
			C8	0.1667	D21	0.6667
					D22	0.3333

APPENDIX D

APPENDIX D

The testing and surgical processes have an medical equipment error rate of	From 0-1, how true is this statement: This error rate indicate the medical equipment quality is very good
0	
0.05	
0.10	
0.15	
0.20	
0.25	
0.30	
0.35	
0.40	
0.45	
0.50	
0.55	
0.60	
0.65	
0.70	
0.75	
0.80	
0.85	
0.90	
0.95	
1.00	

The testing and surgical processes have an medical equipment error rate of	From 0-1, how true is this statement: This error rate indicate the medical equipment quality is good
0	
0.05	
0.10	
0.15	
0.20	
0.25	
0.30	
0.35	
0.40	
0.45	
0.50	
0.55	
0.60	
0.65	
0.70	
0.75	
0.80	
0.85	
0.90	
0.95	
1.00	

The testing and surgical processes have an medical equipment error rate of	From 0-1, how true is this statement: This error rate indicate the medical equipment quality is fair
0	
0.05	
0.10	
0.15	
0.20	
0.25	
0.30	
0.35	
0.40	
0.45	
0.50	
0.55	
0.60	
0.65	
0.70	
0.75	
0.80	
0.85	
0.90	
0.95	
1.00	

The testing and surgical processes have an medical equipment error rate of	From 0-1, how true is this statement: This error rate indicate the medical equipment quality is poor
0	
0.05	
0.10	
0.15	
0.20	
0.25	
0.30	
0.35	
0.40	
0.45	
0.50	
0.55	
0.60	
0.65	
0.70	
0.75	
0.80	
0.85	
0.90	
0.95	
1.00	

BIOGRAPHICAL SKETCH

Mr. Yan Li received his Bachelor's degree in Mechanical Engineering at Tongji University, China. Then he went to the University of Texas-Pan American to pursue a Master's degree in Manufacturing Engineering. While in UTPA, he worked as both research assistant and teaching assistant in Manufacturing Engineering department. He assisted the instructor in teaching ENGR1101 (Introduction to Engineering) and MANE3351 (Manufacturing Engineering Analysis) to undergraduate students. He also conducted research in the topics including "analysis of health insurance coverage policies using queuing theory", "decision analysis for the implementation of Green Roof", and "modeling of compound Poisson arrival process in manufacturing system". He presented his paper "Analysis of uninsurance in healthcare systems using queuing models" in the Industrial Engineering Research Conference in Miami in 2009. He can be reached at tongjijacky@hotmail.com.