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O.R. Applications

The analytic hierarchy process in medical and health care decision making: A literature review

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Abstract

This paper presents a literature review of the application of the analytic hierarchy process (AHP) to important problems in medical and health care decision making. The literature is classified by year of publication, health care category, journal, method of analyzing alternatives, participants, and application type. Very few articles were published prior to 1988 and the level of activity has increased to about three articles per year since 1997. The 50 articles reviewed were classified in seven categories: diagnosis, patient participation, therapy/treatment, organ transplantation, project and technology evaluation and selection, human resource planning, and health care evaluation and policy. The largest number of articles was found in the project and technology evaluation and selection category (14) with substantial activity in patient participation (9), therapy/treatment (8), and health care evaluation and policy (8). The AHP appears to be a promising support tool for shared decision making between patient and doctor, evaluation and selection of therapies and treatments, and the evaluation of health care technologies and policies. We expect that AHP research will continue to be an important component of health care and medical research.
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1. Introduction

The United States continues to devote ever-increasing amounts of its resources to health care. The most recent statistics published by the US government indicate that health care spending was projected to reach $1.7 trillion or 15.3% of its gross domestic product (GDP) in 2003. In addition, this percentage is projected to increase to 18.7% in 10 years (Centers for Medicare and Medicaid Services and US Bureau of the Census, 2004). Total national health expenditures increased by 7.7% in 2003, four times the rate of inflation (Smith et al., 2005). Given the magnitude of these numbers and expenditures, improvement in health care and medical decision making can reap substantial benefits for both patients and health care providers alike. A variety of decision making methods and tools are available to support health care and medical decision making. The purpose of this paper is to review and assess the application of a well-known and widely used

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decision making methodology, called the analytic hierarchy process (AHP), to important problems in medical and health care decision making.

2. AHP background

The AHP, developed by Saaty (1977, 1996), is a decision making method for prioritizing alternatives when multiple criteria must be considered. This approach allows the decision maker to structure problems in the form of a hierarchy or a set of integrated levels, such as, the goal, the criteria, and the alternatives. The primary advantage of the AHP is its use of pairwise comparisons to obtain a ratio scale of measurement. Ratio scales are a natural means of comparison among alternatives and enable the measurement of both tangible and intangible factors.

An AHP analysis uses pairwise comparisons to measure the impact of items on one level of the hierarchy on the next higher level. For example, the criteria are pairwise compared in terms of their ability to achieve the goal, and the alternatives are pairwise compared in terms of their ability to achieve each of the criteria. At each level, the pairwise comparisons are organized into a matrix and the weights of the items being compared are determined by computing the maximum eigenvalue of the matrix. A weighted averaging approach is used to combine the results across levels of the hierarchy to compute a final weight for each alternative.

In cases where many alternatives need to be evaluated, the AHP ratings approach is often used. This approach requires that a series of ratings or intensities be developed for each criterion (for example, excellent, very good, good, fair, and poor). These intensities must be pairwise compared for each criterion, and then alternatives are evaluated by selecting the appropriate intensity for each criterion.

Another important advantage of the AHP is that it allows for inconsistency in judgment. However, the AHP also measures the degree to which the judgments are inconsistent and establishes an acceptable tolerance level for the degree of inconsistency. Other advantages and the disadvantages of the AHP have been extensively described and debated elsewhere. For example, a series of articles in Management Science (Dyer, 1990a,b; Harker and Vargas, 1990; Saaty, 1990; Winkler, 1990) address the comparisons of the AHP and multi-attribute utility theory.

Eckman (1989) offers a critique of the AHP and argues that the pairwise comparisons are arbitrary, differences in factors such as costs and infection rates are subjectively interpreted, and the modeling approach does not adequately represent the decision making problem and produces a unitless, and therefore meaningless, score. Dolan (1990) and Dolan and Bordley (1993) have argued convincingly against these claims. A tutorial on the use of the AHP in medical decision making has been offered by Dolan et al. (1989). These authors also describe the theory of the AHP and demonstrate how it can be applied to a typical medical decision. Feeg (1999) reports that the AHP compares favorably with magnitude estimation (ME) scaling for developing the weights for a set of elements such as subjects' intensity of perceptions in nursing studies.

Several authors have discussed the use of the AHP across a broad range of applications in health and medical decision making. Hatcher (1994) describes how the AHP can be included within a group decision support process (GDSS) and how the resulting system can be applied in a variety of health care decision making settings. Sloane et al. (2002) discusses the applicability of the AHP for medical and hospital decision support and briefly describes three completed studies (reviewed below) and three on-going studies.

3. Research methodology

To identify those journal articles that describe an application of the AHP in health care and medical decision making, an extensive search was conducted of the literature. The research process included various English language database searches using the AHP keywords "AHP," "Analytic Hierarchy Process," "eigenvector," "eigenvalue," and "pairwise comparisons." We searched Pub Med, CINAL (The Cumulative Index to Nursing and Allied Health Literature), and PsycINFO using the AHP keywords. In addition, we searched ABI/Inform (business) and Compendex (engineering) using AHP keywords in conjunction with the health care and medical keywords "health," "health care," "medical," and "medical decision making."

The topics of the articles, which were uncovered in the database searches were screened to determine: (1) if the AHP methodology had been applied, and (2) whether the AHP application fits within the medical and health care field. We used the MeSH (Medical Subject Headings) controlled vocabulary thesaurus, provided by the National Library of Medicine, to accomplish the latter task (www.nlm.nih.gov/pubs/

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factsheets/mesh.html). If the topic of an AHP article found in our database search appears on the MeSH list of descriptors, the article is included in this paper.

Our search excluded conference proceedings and doctorial dissertations since we assume that important research will eventually appear in academic or profession journals. We also exclude non-English language publications from our search.

4. Classification

A total of 50 articles that address specific AHP applications were included in this review. Each article was reviewed and classified by year of publication, health care category, journal, method of analyzing alternatives, participants, and application type. Very few articles were published prior to 1988 and the level of activity has increased to about three articles per year since 1997. The articles were classified in seven categories: diagnosis, patient participation, therapy/treatment, organ transplantation, project and technology evaluation and selection, human resource planning, and health care evaluation and policy. The largest number of articles was found in the project and technology evaluation and selection category (14) with substantial activity in patient participation (9), therapy/treatment (8), and health care evaluation and policy (8) (Table 1). Nearly 60% of the articles addressed health care management/administration issues with the remaining addressing patient care issues (Table 2).

Concerning AHP model characteristics, almost three-quarters of the articles used pairwise comparisons for evaluating the alternatives with the remainder using the ratings method (Table 3). Surprisingly, in over two-thirds of the articles the necessary pairwise comparisons were assessed using judgments from a group of individuals (Table 4). The 50 articles appeared in 39 different journals with the largest number of articles (6) appearing in *Medical Decision Making*, followed by *Socio-Economic Planning Sciences* (3) and with five journals, including *European Journal of Operational Research*, publishing two articles (Table 5).

5. Research review

5.1. Overview

In what follows, we briefly review the articles classified in the medical and health care categories listed in Table 1.

Table 1
AHP health care journal article counts by category by year

Health care category	Year																								Total
	1981	1982	1983	1984	1985	1986	1987	1988	1988	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	
Diagnosis													1		1	1		1									4
Patient participation												1	1		1		1		1	1			1		1	1	8
Therapy/treatment								2		1				1				1	1					1		1	8
Organ transplantation										1						1	1		1								4
Project and technology evaluation and selection								1			1	1		1			1		1	2	2	2	2				14
Human resource planning																	2				1						3
Health care evaluation and policy	1		1																			1		3	1	1	9
Total	1		1					1	2	2	1	2	2	2	2	2	5	2	4	3	3	3	3	4	2	3	50

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Table 2
Type of AHP application

Application type	Count
Management/administration	29
Patient care	21
Total	50

Table 3
Method for evaluating alternatives

Evaluation method	Count
Pairwise	36
Ratings	12
N/A	2
Total	50

Table 4
Participants involved in the application

Participants	Count
Individual	13
Group	34
Both	1
N/A	2
Total	50

Table 5
Journal list and article count

Journal Name	Article count
Academic Medicine	1
Archives of Pediatrics and Adolescent Medicine	1
BMC Medical Informatics and Decision Making	1
Computers and Industrial Engineering	1
Computers and Operations Research	2
Expert Systems with Applications	1
European Journal of Operational Research	2
Health Expectations	1
Health Progress	1
The Hong Kong Radiographers Journal	1
Hospital Topics	1
IEEE Transactions on Systems, Man, and Cybernetics	1
International Journal of Artificial Organs	1
International Journal of Health Care Quality Assurance	1
International Journal of Health Planning and Management	1
International Journal of Operations and Production Management	1
International Journal of Services Technology and Management	1
International Journal of Technology Assessment in Health Care	1
International Transactions in Operational Research	1
Journal of Clinical Epidemiology	1
Journal of Critical Care	1
Journal of General Internal Medicine	2
Journal of Health Care Marketing	1
Journal of Medical Systems	1
Journal of Pharmaceutical Marketing & Management	1
Journal of Rehabilitation Research and Development	1
Journal of the Operational Research Society	1
Mathematics and Computers in Simulation	1
Medical Decision Making	6
Methods of Information in Medicine	1
Operations Research	1
Pediatric Nursing	1
Quality Review Bulletin	1
Respiratory Care	1
Socio Economic Planning Sciences	3
The Journal of Urology	1
Theoretical Medicine	1
Theoretical Medicine and Bioethics	2
Total Quality Management	1
Total	50

5.2. Diagnosis

The AHP has been suggested and applied for use in medical diagnosis. Dolan et al. (1993) used the AHP to determine if endoscopy is overused for low risk patients with acute upper gastrointestinal bleeding. Twenty-five patients and 20 physicians participated in the study. The model consisted of five criteria: identify exact cause of bleeding, avoid test complications, minimize cost, avoid poor outcomes from bleeding, and minimize length of stay. The treatments considered include: immediate endoscopy, routine endoscopy, upper GI X-ray, and no routine test. Endoscopy was used 85% of the time at the authors' hospital, and was preferred by 92% of the patients, but only by 55% of the physicians. The difference between patient and physician preferences related to the ranking of the criterion: identify the cause of bleeding.

Castro et al. (1996) applied the AHP to the sequential selection of diagnostic tests for the analysis of upper abdominal pain. The criteria considered were cost, discomfort, risk, and diagnostic ability, while the alternatives were abdominal CT, upper GI series, abdominal ultrasound, and endoscopy. The overall diagnostic capability for each test was measured by weighing the diagnostic capability of each of the possible disorders (gastritis, ulcer, cholecystitis, and pancreatitis) by the probability of the disorder. Cost data for each test were obtained, while discomfort and risk were determined

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subjectively. Based on the judgments of five physicians that were combined using the geometric mean, the recommended initial test was the upper GI series. Assuming this test was negative, the probabilities of the various disorders were updated using Bayesian analysis, leading to revised diagnostic capabilities for each of the tests. The second AHP analysis yielded abdominal ultrasound as the best test. The process of alternating between AHP and Bayesian analysis can be reiterated as often as necessary to arrive at more informed choices.

Saaty and Vargas (1998) showed how the AHP framework with dependence across levels in the hierarchy can incorporate expert judgment for medical diagnosis with or without statistical data. The authors also showed that if expert judgment is unavailable, the approach produces results that agree with Bayes Theorem. The application of the model to a case study involves a woman in her second trimester who is admitted to the hospital with specific symptoms. Four diagnoses were considered by the doctor given the set of symptoms. The outcome is a compromise between the Bayesian approach which requires empirical evidence to make a diagnosis, and the more subjective clinical approach, in which physicians use experience, evidence, and environmental variables to diagnose patients.

Using the AHP, Bahill et al. (1995) elicited and organized the knowledge of domain experts that was incorporated into a decision support system to help speech clinicians diagnose children who have begun to stutter. The knowledge is arranged in a hierarchy and divided into rules that dealt with information obtained from an examination of a child and rules that dealt with information acquired from a case history interview. The knowledge was broken down to individual questions which were then decomposed into possible answers that were pairwise compared according to their importance. When the system was used, three clinicians with widely differing backgrounds produced diagnostic opinions that had little variability and were indistinguishable from the diagnoses of a panel of five experienced clinicians.

5.3. Patient participation

Patient participation in the medical decision making process has been addressed in several studies. Dolan and his colleagues have addressed shared decision making between patients and physicians, especially as related to colorectal cancer screening. Dolan and Bordley (1992) described how the AHP could be used to disseminate guidelines for colorectal cancer screening. The AHP model includes five criteria: decrease risk of colorectal cancer, avoid false-positive screening tests, avoid screening test side effects, minimize costs, and avoid inconvenience associated with screening. The alternatives include: no screening, fecal occult blood tests (FOBT) annually and sigmoidoscopy (SIG) every 3 years, SIG every 3 years, Barium enema (BE) every 5 years, colonoscopy (COL) every 5 years, FOBT annually and BE every 5 years, and FOBT annually and COL every 5 years. The doctor and patient would modify the model as needed, and then one or both would complete the analysis.

Following this study, Dolan and Bordley (1993) considered the hypothetical scenario of a 40-year-old man who has a risk factor that increases to 20% his chance of developing a common serious disease over the next 10 years. Alternatives include: do nothing, diet alone, and diet plus the addition of one of two possible drugs that differ in cost and effectiveness. Four criteria are considered: reduce the risk of developing the disease, avoid side effects, minimize out-of-pocket costs, and avoid hassles. A doctor–patient dialogue is presented to illustrate the process.

Dolan (1995) continued this research stream on colorectal cancer screening. In this study, 20 volunteers were recruited to perform an AHP analysis of five screening regimens for colon cancer. These volunteers were asked to imagine they were 50 years old, had a first-degree relative with colon cancer, and were making a decision about a colon cancer screening program for the next 25 years. The model consisted of criteria and alternatives similar to those used in Dolan and Bordley (1992). Ninety percent of the patients were able and willing to use the AHP. The difference between this result and the hypothesized 25% was significant. Dolan (2000) updated his AHP colorectal cancer screening approach using the guidelines of the American Gastroenterological Association.

Peralta-Carcelen et al. (1997) used the AHP to assess the preferences of pregnant women, pediatricians, and obstetricians for the policies of the American College of Obstetrics and Gynecology (ACOG) and American Academy of Pediatrics (AAP) for reducing the incidence of neonatal group B streptococcal (GBS) sepsis. The five criteria include: risk of infection in infant, mother's knowledge of GBS sta-

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tus, risk of anaphylaxis in mother, diagnostic tests received by infant, and cost. The results indicate that 81% of the pregnant women and 65% of the pediatricians preferred the AAP guidelines, while 83% of the obstetricians preferred the ACOG guidelines. Ninety percent of the women found the process to be useful and 88% said they would like this approach to be used by physicians in making patient care decisions. Seventy-three percent of pediatricians and only 43% of obstetricians reported that this technique would be useful in patient care.

Singpurwalla et al. (1999) apply the AHP to patient–physician shared decision making for two procedures: menopause treatment and cosmetic eyelid surgery. For eyelid surgery, the criteria were facilitate eye makeup application, mental attitude, life of procedure, minimize scarring, and minimize costs, with the alternatives being no surgery or surgery. For menopause treatment, the criteria are minimize costs, minimize breast cancer risk, protect against osteoporosis, protect against cardiovascular disease, minimize risk of endometrial cancer, minimize breast cancer risk, and minimize medication side effects, with the alternatives of non-medical approach, estrogen replacement therapy, and hormone replacement therapy. For each procedure eight patient–physician pairs completed the necessary pairwise comparisons. AHP models were constructed to assess patient and physicians attitudes towards using the AHP in shared decision making. The majority of both patients and physicians agreed that this approach improved patient–physician communication, and thus assists shared decision making. The majority of the patients felt this approach was preferable to the conventional doctor–patient mode of decision making.

Liberatore et al. (2003) applied the AHP as part of a decision counseling protocol to assist African–American men to decide if they will undergo a prostate cancer screening examination (digital rectal exam and PSA test). The risk of dying from the disease is elevated by a factor of at least two among African–American men. Recommendations about annual screening exams are inconclusive since no randomized trials have demonstrated that screening can reduce mortality from prostate cancer. In addition, the diagnosis and treatment of early-stage prostate cancer can cause substantial adverse outcomes. The decision-counseling protocol included an educational component followed by a decision making session. A modified version of the AHP was used in the decision making session, where the patient was asked to identify and rate up to three criteria and consider screening and no screening as alternatives. The results demonstrated that a well-designed decision-counseling protocol administered by a trained facilitator can be successfully implemented in a primary care patient population.

Hummel et al. (2005) used the AHP to assist a rehabilitation team in evaluating the performance of two alternatives (functional electrical stimulation (FES) and conventional surgery) to improve the arm–hand function in people with sixth cervical vertebra level Motor Group 2 tetraplegia. The main criteria were ease of use, social acceptance, arm–hand function, minimal risks, and minimal load of treatment. The expert team consisted of two rehabilitation physicians, two occupational therapists, two physiotherapists, and one social worker, as well as a person with C6 complete tetraplegia. The team performed all criteria, subcriteria, and alternative pairwise comparisons. The rehabilitation team preferred conventional surgery (56%) to FES (44%). Potential recipients were then included in the study to see if they had different views on the level of importance of the evaluation factors and the final weightings of the alternatives. Eight rehabilitation centers specializing in SCI care in the Netherlands selected 34 persons with C6-level tetraplegia to participate in the study. Patients gave more weight to burden of treatment and less weight to functional improvement. Using the criteria weights of the 34 potential recipients and substituting the expert panel subcriteria and alternative weights did not change the overall preference to conventional surgery.

Richman et al. (2006) applied the AHP for prostate cancer treatment selection. The main criteria considered include: chance for cancer cure, risk of cancer progression, long-term survival, quality of life, limit acute complications of treatment, risk from blood transfusion, and cost to patient. Members from both patient and physician-expert groups evaluated all criteria and subcriteria using pairwise comparisons. The expert physician panel also provided weighted judgments linking the alternate treatment options with each of the lowest level subobjectives. The results of both analyses were combined to provide a prioritized list of the alternative treatments for both the patients and participants. The aggregated list of treatment options was similar for the patient and physician groups, as well the rank order of the main criteria. Concordance between initial treatment choice and the highest weighted model option was 59% for the patients

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but only 42% for the physicians. This study validates the usefulness of a computer based model to produce individualized, rational, clinically appropriate prostate cancer disease management decisions without physician bias.

5.4. Therapy/treatment

The AHP has seen application for the evaluation and selection of medical treatments and therapies. This work did not involve the patient in the decision making process. Dolan et al. (1989) provided a detailed review of the theoretical foundations and methodology of the AHP using the treatment of a dog bite wound as a motivating example. Dolan (1989) applied the AHP to select an antibiotic regimen to treat a young women hospitalized with acute pyelonephritis (kidney infection). The alternatives are seven intravenous antibiotic regimens. Criteria included maximize cure, minimize adverse effects (three categories), minimize cost, and minimize resistance. The criteria weights were based on pairwise comparisons made by 61 practicing clinicians. The weights for the regimens relative to maximize cure were based on the expected likelihoods of potential pathogens and their anticipated antibiotic susceptibilities. Five internists classified each type of adverse effect, and odds of occurrence were used to generate the weights. The cost weights were based on charges for the various regimens at the participating hospital. The resistance of the regimens was based on the judgments of three members of the hospital's infectious disease unit.

Dolan (1990) addressed the evaluation of treatment options for an adult with idiopathic nephritic syndrome. Previous analysis using single attribute utility analysis based on quality-adjusted life years found that two of the options, empiric steroids and biopsy first, had nearly identical expected utilities. However, some authors had indicated that several relevant factors were not included in the analysis. Dolan first recreated these results using the AHP, and then included a subjective criterion (maximize indirect benefits) to increase the representativeness of the model. Two different standpoints were analyzed using the expanded model. In one case empiric steroids was preferred, in the other, biopsy first was preferred. The results show that the AHP offers several advantages over single attribute models.

Dolan and Bordley (1994) applied the AHP to help decide whether to use isoniazid prophylaxis in uncomplicated cases of positive tuberculin tests. The alternatives considered were three representative patients 20, 35, and 50 years old, who had positive tuberculin tests of unknown duration and three the same ages whose positive tests had converted from negative to positive in the past 2 years. The two classes of criteria include: avoid tuberculosis (pulmonary and extra pulmonary) and avoid side effects (fatal and non-fatal). Published data were used to estimate how well each alternative fulfilled the evaluative criteria, and formed the basis for the required pairwise comparisons. Depending upon the relative importance of developing active tuberculosis as compared to avoiding isoniazid-related side effects, the preferred treatment strategy will differ. This result shows the importance of taking an individualized approach for the management of these patients' care.

Singh et al. (2006) applied the AHP to help decide on the preferred treatment for adults presenting with a sore throat. The criteria considered were reduce symptom duration, prevent infectious complication (local and systemic), minimize antibiotic side effects (minor and anaphylaxis), and prudent use of antibiotics (avoid under and over treatment). All criteria and subcriteria were assigned the same weight, with the exception of anaphylaxis which was judged to be strongly more important than minor side effects. The alternatives were no test, no treatment; rapid strep test and treat if positive; throat culture and treat if positive; rapid strep test and treat if positive, and if negative, throat culture and treat if positive; and treat without further tests. Four scenarios are evaluated for each of the possible values of the Centor score, a well validated clinical index. Published data were used to estimate how well each alternative fulfilled the evaluative criteria, and formed the basis for the required pairwise comparisons. Depending upon the Centor score, the preferred treatment strategy will differ, and these results are sensitive to the weights assigned to the criteria. Optimal clinical management depends on both the clinical probability of a group A streptococcal infection and clinical judgments that incorporate individual patent and practice circumstances.

Carter et al. (1999) applied the AHP and the analytic network process (ANP – allows feedback in the hierarchy) and compared them with a Markov process (transitions related to the progression or non-progression with the disease) for evaluation of treatment for a patient who has breast cancer. The AHP model considered cancer concerns, patient

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concerns, and complications arising from the therapy. Observation, radiation, tamoxifen, a combination of radiation and tamoxifen, and simple mastectomy were the alternatives considered. All three models agreed on the ranking of the preferred treatment-radiation and tamoxifen, but there were variations in the rankings of the other alternatives. AHP and ANP required less development time than the Markov process. The Markov process did provide more detailed results, whereas AHP and ANP gave only rank orders of the alternatives, but included more patient input.

Koch and Ridgley (1998) discussed how the AHP could be used to measure the humaneness of individuals. Such measurement might potentially impact decisions about life-sustaining care for individuals such as anencephalic infants. There were three criteria used: past performance, present capability, and future potential. Several subcriteria were identified and three alternatives were considered: Baby K, an anencephalic infant; Normal Infant; and Arthur Ashe, Jr., who was HIV infected after receiving tainted blood in the 1980s. The process was tested at the Hospital for Sick Children, Toronto.

Chang et al. (2004) discussed the application of the AHP as part of a case-based reasoning (CBR) approach for patient discharge planning in Taiwan. Categories of long-term resources available include senior welfare institutions, community care resources, and home care resources, with 24 options in total. Using information obtained from experts, the seven evaluation dimensions selected include: functional conditions, physical conditions, main caregiver(s), support systems, nursing care, basic information, and medical care awareness. Each evaluation dimension is composed of several indices. The AHP is used to establish the weights of each of the seven evaluation dimensions and the indices that comprise them. The suggested approach requires computing a weighted average similarity index for a new case as compared with evaluated cases within the database. To verify the feasibility of the suggested approach, it was applied to discharge cases in neurology and pulmonary from a medical center in Taiwan. High levels of similarity and accuracy of discharge planning were achieved for five sample cases.

5.5. Organ transplantation

The AHP has seen application for organ transplant eligibility and allocation decisions. Cook et al. (1990) applied the AHP to develop a rating system allocation of cadaver livers for orthotopic transplantation. The five major criteria considered were: logistical considerations, tissue compatibility, waiting time, financial considerations, and medical status. A variety of medical and health care professionals at the University Health Center of Pittsburgh were interviewed to develop the hierarchy. All patients for a possible liver transplant would be screened by a selection committee, and after acceptance as a transplant candidate, would be stratified by size and by blood type into appropriate lists. Patients that met appropriate inclusion screening criteria would then be ranked for selection. Using sample cases, the AHP model results were favorably compared with the existing multifactorial point system.

Koch and his colleagues have conducted several studies related to organ transplantation issues for sick children. Koch (1996) discussed the issues related to the selection of individuals for inclusion on organ transplantation lists, and the process of assigning organs to specific individuals. The author argued that prescriptive factors affect the selection of individuals as transplant candidates, and that rank waiting time for the transplant is not the sole factor in determining organ recipients. The model considered includes four normative criteria: compatibility, medical status, financial, and waiting time, as well as logistics. In addition, a preliminary set of prescriptive criteria and subcriteria was proposed by the author to help determine placement on a transplant list, and was under discussion at a hospital for sick children in Canada.

Koch and Rowell (1997) developed a set of criteria and subcriteria for organ transplant eligibility that was analyzed by two focus groups at a hospital for sick children in Canada. The criteria include: intelligence, survival, physical independence, activity following a successful transplant, social recognition, and compliance. Each focus group discussed the required pairwise comparisons, and the judgments of the participants were combined using the geometric mean. The results relating to the importance of the criteria are discussed in detail, and differences with US and international surveys on this topic are noted. Survival and activity were the most highly weighted criteria, while intelligence and compliance were viewed as much less important. Koch and Rowell (1999) continued with this stream of research and discussed the results obtained from four small focus groups, including two hospital groups, members of a local chapter of the Down

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Syndrome Family Association, and a control group of citizens drawn from Toronto Beaches community. Survival was strongly valued over all other criteria. Some differences on the importance of compliance were found among the groups.

5.6. Project and technology evaluation and selection

There have been numerous applications of the AHP for selection and evaluation of projects and technology in health care settings. Turri (1988) described the application of the AHP to assist a hospital select a magnetic resonance imaging vendor. A committee was appointed to narrow the decision alternatives down to three vendors, using price, technology, siting, service, service contract, cryogen contract, and patient comfort as criteria. The evaluation process took significantly less time than the approach previously used. As part of this process, researchers interviewed the vendors, studied and compared their price quotations, contacted references, and visited operating sites using each vendor's equipment.

Hummel et al. (2000a) proposed the application of the AHP to the medical technology assessment that occurs during the development process and prior to clinical diffusion. Hummel et al. (2000b) then applied the AHP to perform a constructive medical technology assessment (CMTA) of a new blood pump called a PUCA (pulsatile catheter pump) pump. The panel members included a multidisciplinary group of developers, manufacturers, and end-users, including a cardiologist, a surgeon, a veterinarian, and six engineers. The assessment was based on medical, economic, and social factors developed by the team. The evaluation of the PUCA pump as compared to two competitors led to focusing the pump's diffusion for use by specific groups of patients and to modifications relating to safety and ease of use.

Two studies considered the evaluation of ventilators for hospital purchase. Chatburn and Priamano (2001) used a formal decision-making tool known as an additive, compensatory, multi-attribute utility model to help decide how to buy a ventilator at a hospital. Input from various stakeholders is incorporated into the decision process. The authors discussed how AHP could be used to develop the various weights used in the model. The situation described is based on an actual capital budget proposal developed at University Hospitals of Cleveland.

Sloane et al. (2003) evaluated neonatal ventilators for a new women's health hospital using the AHP. The model was developed iteratively, based on pairwise comparisons supplied by the hospital's directors of respiratory therapy and clinical engineering. The four categories of criteria in order of their importance were: safety, clinical factors, biomedical engineering factors, and cost. Intensities (rating categories) and their weights were developed for the 46 evaluative criteria. The alternatives considered were the existing ventilator, an updated version, and a state-of-the-art unit, with the latter having the highest overall score. The participants found the AHP to be easy to use and apply, and supported the decision to purchase the ventilator recommended by the model.

Cho and Kim (2003) applied the AHP to the selection of medical devices and materials for grants by the Korean Ministry of Health and Welfare. The three categories of criteria include marketability, technology applicability, and public benefits, with subcriteria under the first two categories. Within the hierarchy, the 88 alternatives were organized into "middle groups" of alternatives which in turn were organized into "large groups" of alternatives. The funding priorities of the 88 alternatives were identified, and the top 15 products were funded. A team of eight medical personnel and four medical engineers performed the evaluation.

Tak (2002) discussed the application of the AHP to evaluate image quality of both conventional and computed radiology as part of a benchmarking study in Hong Kong. The categories of criteria include: correct image identification, correct marker(s), good exposure, good positioning, region of interest included (mandatory), radiation protection exercised, correct cassette size and orientation, no preventable artifacts, and correct protocol chosen (computed radiology only). An evaluated image would be rated as 0 or 1 for each subcriterion to determine the score. A pilot study was underway at two hospitals using the evaluation process developed.

Rossetti and Selandari (2001) applied the AHP to help decide whether a fleet of mobile robots can replace a traditional human-based delivery system in clinical laboratories and hospital pharmacies. Their AHP model incorporated economic and technical performance factors, as well as social, human, and environmental criteria. The technical performance measures were assessed through computer simulation. The methodology was applied to the University of Virginia Health Science Center. The analysis showed that a fleet of mobile robots can be preferred to a human-based transportation system.

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Besides the evaluation of health care equipment, the AHP has been applied to prioritize various types of projects and information systems. Tarimcilar and Khaksari (1991) developed an AHP model to prioritize capital projects for a mid-sized hospital. The problem hierarchy includes three major criteria: economic, social, and political. The attributes and stakeholders form the next levels, and the alternatives are evaluated with respect to these. In their example, the alternatives include: establishing a home health agency, purchasing two urgent care centers, develop a series of wellness programs, and establish several specialty outpatient clinics. The analysis led to the wellness and urgent care options having the highest and nearly identical final scores, and both of these options were selected for investment and are operating successfully.

Ross and Nydick (1992, 1994) presented a case study that describes Sterling Pharmaceutical's AHP-based approach for allocating their R&D budget to cancer research projects. More than 100 oncology opportunities are examined by Sterling each year, with the vast majority of these rejected. Four evaluation criteria were identified: scientific data, fit with available resources, compatibility with oncology strategy and portfolio, and financial and business strategic fit. Judgments were provided by a group of experts and the alternatives were rated using the intensity levels identified by the experts. The model was developed so that the alternative projects can be evaluated sequentially. An evaluation of a previous set of proposals identified the minimum AHP score that resulted in a funding recommendation.

Kahen and Sayers (1997) discussed the possible application of the AHP to the selection of medical expert systems for transfer to developing countries. The appropriateness of these technologies for developing countries, the criteria to be used in selection of the technology to be transferred, and the need for a systematic approach to the evaluation are discussed. The hierarchy could include efficiency and effectiveness criteria, along with criteria addressing progress, adequacy, relevance, and impact.

Lee and Kwak (1999) developed an integer goal programming (GP) model that aids in allocating a health care system's information resources for strategic planning. The AHP was used to establish the priorities of the health care system's goals. The four major goals are: budget allocation, project implementation, network construction, and human resource allocation. The health care system used in this study is one of the top comprehensive health care organizations in St. Louis. The results indicate which projects should be funded and what network design should be selected, and the extent to which each of the goals is achieved. Kwak and Lee (2002) used a similar approach for the same health care organization in St. Louis to allocate a health care system's information resources. The four goals, in priority order are: financial budget, operational projects, information management, and personnel. The criteria used to evaluate these goals are: effectiveness, delivery, partnership, competitiveness; and costs. The results indicate which projects should be funded by year and the extent to which each of the goals is achieved.

5.7. Human resource planning

The AHP has seen application in hospital human resource planning and in the selection of resident physicians. Kwak et al. (1997) developed an AHP-based human resource planning model for hospital laboratory personnel. Ten stakeholders participated in a Delphi process that determined the set of factors and the required pairwise comparisons for separate demand and supply models. The alternatives were the different levels of the degree of change of demand and supply of laboratory personnel. The resulting AHP priorities were treated as probabilities, and subjective probability distributions and expected values were generated for the changes in demand and supply. After combining the results of the participants, the importance priority, impact on demand or supply, and net effect (impact × priority) of each supply and demand factor was determined. The paper concludes by discussing those factors found to have the largest net effects, so that supply and demand can be brought into balance.

Weingarten et al. (1997) discussed an AHP approach for the selection of 5-year general surgery residents. The AHP ratings model consists of three criteria: academic performance, personal fit, and surgical appropriateness. The weights of the criteria and the scores of the candidates were obtained from the resident selection committee. The AHP approach was run in parallel with the existing system that uses the average of a 0–10 candidate scoring (traditional ranking), followed by a final meeting where the candidates are discussed and ranked (advocacy ranking). The AHP and traditional rankings were significantly correlated in both years. The AHP ranking was correlated with the

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advocacy ranking in the first year only. The results support the use of the AHP as a viable alternative to the traditional process.

In a similar study, Hemaida and Kalb (2001) applied the AHP for selecting first-year family practice residents at a Midwest medical center. The criteria were developed based on responses from a group of 17 residents, faculty, and hospital administrators. The ten members of the Residency Recruitment Committee developed the pairwise comparisons of the six selected criteria. Pairwise comparisons of a random sample of four of the ten candidates selected for personal interview were made by the two co-chairs of the Recruitment Committee and the vice president of human resources. The ranking of these four candidates was consistent with the informal ranking system currently in use. Benefits included focusing on the key decision factors, reducing decision making time, and making the process more efficient and less subjective.

5.8. Health care evaluation and policy

Several studies have applied the AHP for the evaluation of health care facilities and in health care policy analysis. Early studies include the work of Hannan et al. (1981) who applied the AHP to develop ranks and priority weights for the conditions and standards for New York State's long-term care facilities. A set of tentative decision rules were developed that define actions to be taken if specific standards or conditions are not met. Odynocki (1983) applied the AHP to study the legislative conflict over National Health Insurance Policy during the Carter administration using a forward–backward planning process.

Recently there has been increased interest in applying the AHP to the evaluation of health care facilities. Hariharan et al. (2004) and Dey et al. (2004) described how the AHP can be used to evaluate the performance of hospitals. Hariharan et al. (2004) evaluated two tertiary care hospitals in Barbados and India, identified areas where each hospital did not perform well, and suggested recommendations for improvement. A questionnaire was used to help clinicians and managers to identify the most important evaluation factors. Brainstorming was conducted to finalize the list of critical success factors through consensus building and to obtain all needed pairwise comparisons. The key criteria are: patient care, establishment, and administration. A ratings approach was also used to compute a final weight for each hospital. Dey et al. (2004) used a similar approach to evaluate the performance of an intensive care unit in a Barbados hospital. Hariharan et al. (2005) reports on continuing research on the evaluation of tertiary care hospitals and applies the methodology described above to ICUs in Barbados, Trinidad, and India.

Using the AHP, Longo and Masella (2002) evaluated the performance of alternative organizational processes within different operating blocks, such as patient care, in eight Italian hospitals. The evaluations are based on cost, quality, income, and an overall perspective that equally weights the three criteria. Judgments are provided by the authors in conjunction with nurses and clinicians.

Ahsan and Bartema (2004) applied the AHP to evaluate the performance of the thana health complexes (THCs) that provide primary health care facilities to 85% for the population in Bangladesh. The five key criteria include: THC activities, maternal care, child health, family planning, and management. Experts participated in a Delphi process and scored all the criteria and subcriteria. Seven thanas were evaluated based on quantitative data collected from the public health department of the agency sponsoring the study. Differences in the performance of the thanas for each of the five key criteria and overall were analyzed. The results can be used to determine those thanas that require improvements in specific areas and in decision making related to expanding new facilities.

Chang (2006) applies the AHP as part of a study of service quality for a nursing home. The subject nursing home is located in Taiwan and provides 24 hour care and medical or rehabilitation service. Quality function deployment was used to translate customer needs into appropriate technical requirements and services. The five main criteria (taking care of patient livelihood, nursing personnel attitude, food and drink hygiene, the hardware of the organization, and medical treatment services) were organized into 35 client demand subcriteria. The criteria and subcriteria were pairwise compared by a sample of 30 nursing home residents. The degree to which each of the subcriteria contributes to the technical design elements for the nursing home was then determined. Taking into consideration the correlation among the quality factors, a fuzzy utility value was computed to determine the technical importance of the quality characteristics. The most important areas requiring improvement were identified as emergency processing speed, profes-

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sional medical personnel, and complete and accurate resident information.

6. Discussion and conclusions

Health care and medical decision making has been an early and on-going application area for the AHP, a proven decision-making methodology that has seen widespread applications across numerous fields. This review identifies a substantial body of literature that applies the AHP to health care and medical decision making problems. Since 1997, its application has remained steady, suggesting continued interest in the use of this method.

The AHP appears to be well suited to group decision making environments in health care. Although interest in diagnosis seems to have faded, patient participation and therapy/treatment are two application areas of continuing interest. For example, the AHP appears to be a promising support tool for shared decision making between patient and doctor. One major obstacle to implementation is physician acceptance. Physicians are not accustomed to using formalized methods to assist in decision making. We would hope that this barrier becomes less relevant as more and more successful applications are documented.

The AHP has seen extensive and on-going use in the evaluation and selection of medical technology, and capital and information systems projects. Recently, there has been increased interest in its application for evaluating health care facilities. The AHP has seen many similar applications in non-health care businesses so it is quite natural that researchers have applied AHP in the health care field. These application areas show the power of the AHP as an evaluation tool.

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