

MEDICAL DECISION SUPPORT USING THE ANALYTIC HIERARCHY PROCESS

A B S T R A C T

The Analytic Hierarchy Process for medical and hospital decision support allows the user to design a hierarchical structure and weigh the trade-offs between decision criteria and alternatives to facilitate improved clinical and management decisions.

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Using case studies, this paper describes how CIOs, CTOs, IT/IS specialists, and clinical engineers can use the Analytic Hierarchy Process (AHP) to improve the quality of diverse and important decisions that hospitals face today. AHP is a versatile and proven decision support tool that allows the user to design a hierarchical structure for decision making and weighs the trade-offs between decision criteria and alternatives.^{1,2}

The recommended steps for examining and weighting the relative importance of the multiple criteria affecting many decisions have been summarized as:

- Identifying the alternatives available and the personal criteria on which they will be evaluated
- Determining how well the alternatives achieve personally meaningful criteria, based on an assessment of available data and personal preferences
- Assessing the importance of each criterion in the decision-making process
- Making a choice among the alternatives after synthesizing the results from the previous steps³

The process also weights the alternatives for each criterion. These recommended steps help resolve the conflicts that often exist when choosing between multiple competing criteria and alternatives.^{4,5,6}

Many books and articles exist that delve into the details and applications of AHP,^{5,7,8} but the following brief introduction is provided as background.

- First, AHP is a PROCESS: the process requires elucidating personal criteria and evaluating the relative importance of each criterion and then determining how the alternatives achieve each of the criteria.
- Second, AHP organizes the decision into a HIERARCHY of criteria and alternatives: the criteria are organized according to perceived logical and natural groups to improve the clarity and usability of the model and to create properly proportioned subcategories that ensure all important criteria are accounted for and receive the proper weight in the decision.
- Third, AHP is ANALYTIC: it uses pairwise comparisons to help the user express the perceived relative importance of every criterion against every other criterion within

K E Y W O R D S

*Analytic Hierarchy Process (AHP) Decision support Pairwise comparison
Expert Choice Collaboration Health technology assessment*

each hierarchical group to establish the proportional weight each criterion should receive in the decision, and it uses the relative importance of each group to establish that group's weighted importance.

Every criterion must have an evaluation system established as well, and several alternative modes may be used for this. One mode uses pairwise comparisons of the alternatives' relative performance for each criterion. Another mode allows creation of scoring or rating categories that are assigned the appropriate relative proportion for meeting a criterion's goal. A third mode allows use of an equation to convert numeric performance of an alternative into a relative performance value.

Pairwise comparisons can be time consuming, especially if there are many pairs. Sometimes, too, as will be illustrated in the following example, the user cannot be completely consistent in every case. Therefore, the pairwise comparisons are statistically evaluated for consistency as well, to help identify and resolve gross inconsistencies. This prevents inappropriate application of a model that may have serious hidden internal defects.

A Simple AHP Example

A simple clinical example can serve to illustrate the pairwise comparison process, and how it is used by AHP. Take, for example, a patient's choice between (AC)acetaminophen, (AS)aspirin, and (IB)ibuprophen for a sinus headache. One important criterion might be the reliability of pain relief for his/her sinus headaches.

In evaluating the performance of the alternative medications, AHP requires that the judgments be expressed as pairwise comparisons. For example, if the patient has found that IB is twice as reliable as AS and AS is three times as reliable as AC, a simple mathematical inference may be made that IB is six times as reliable as AC. If the patient did, in fact, evaluate IB as six times as reliable as AC, his assessment would be perfectly consistent. This ratio of 6:3:1 would result in proportional weights for each alternative of 0.6, 0.3, and 0.1 for IB, AS, and IB, respectively, assuming that the weights sum to 1.

However, suppose the patient's experience is that IB is 10 times more reliable than AC? Using matrix mathematics, AHP computes an inconsistency level of .03, which is well

below the common inconsistency rejection level of .10 (reference). AHP would convert this new patient assessment into the ratings weights of 0.649, 0.274, and 0.077, for IB, AS, and AC, reflecting the stronger bias towards IB for this patient's sinus headache relief. (See Saaty 1977 for an explanation of the approach used to compute these weights.)

This simple model can be expanded easily by adding additional criteria or groups of criteria. For example, suppose the patient is selecting an allergy relief pill, and that AC, AS, and IB formulations were offered with the same allergy medication and at identical prices. For this patient the IB formulation would obviously be best.

The power of AHP comes into play, however, when there are trade-offs between criteria and one alternative is not best for all criteria.

For example, consider three different brands of combined headache and allergy compounds: Brand X allergy medication that is formulated with IB (X-IB), Brand X formulated with AS (X-AS), and Brand Y formulated with AC (Y-AC). Now suppose that both X-IB and X-AS are only half as reliable as Y-AC. In this case, X-IB and X-AS would have weights of 0.25 and Y-AC would have a weight of 0.50 for reliability of allergy relief.

The final decision becomes more complex, however, because to this patient, there may be a major difference between the importance of reliability of headache and allergy relief. AHP manages this by simply asking the patient to indicate the relative importance of headache and allergy relief. If this patient believes that allergy relief is 5 times more important than headache relief, then AHP will compute the relative weight as 5/6, or .833 for allergy relief and 1/6, or .167 for headache relief.

The final stage of the AHP calculation is called synthesis. The synthesis stage multiplies the allergy and headache criteria weights (0.833 and 0.167) by the relative performance of each formulation for each of the criteria, and expresses that as relative scores.

This is nothing more than a weighted average. For example, the final weight for X-IB is $0.167(0.649)+0.833(0.250)=0.317$. The weights for the X-AS and Y-AC are 0.254 and 0.429, respectively. In this decision, it can be seen that not only is Y-AC preferred to X-IB, but also it is 1.35 (0.429/0.317) times or 35 percent more preferred than X-IB. Similarly, Y-AC is preferred 69 percent more than X-AS. This example illustrates the value of AHP

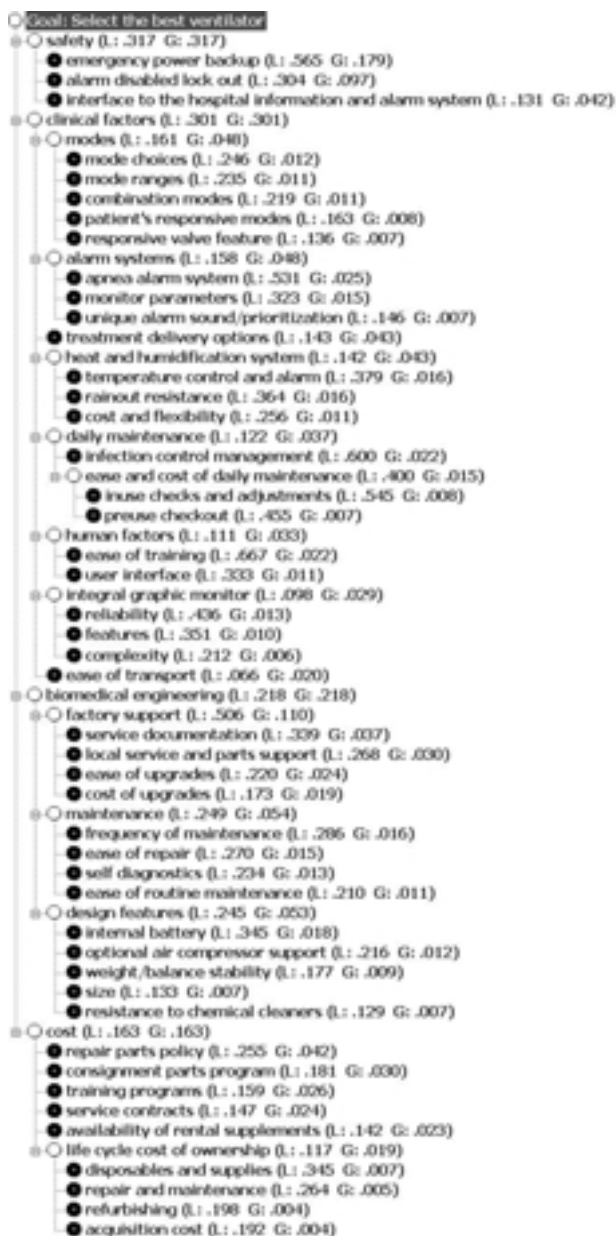
“The study found that the combination of educational materials and personalized AHP-based decision analysis resulted in almost all of the patients electing to proceed with prostate cancer screening.”

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Figure 1. Screen shot of Expert Choice showing graphical interface capability.



Figure 3. Expert Choice screen shot of Neonatal Ventilator AHP model.



in using judgments that are ratio or proportionally based. The decision might change if another patient has different weights for headache and allergy relief.

A graphically enabled AHP software package, such as Expert Choice 2000, can make this process a bit easier for the user. For example, Expert Choice will simultaneously display the pairwise comparison relationships in bar chart and pie chart formats, to help the patient visualize the resulting weights, as shown in figure 1. Further, if the bar or pie charts do not look quite right, they can be interactively adjusted until they look correct.

An AHP modeling tool, like Expert Choice, allows rapid interactive development of models and eases the pairwise comparison process. As the number of criteria and alternatives grows, however, the number of pairs grows quickly. If there were 6 criteria, then as many as 15 pairwise comparisons are needed to determine the criteria weights. Now, if three alternatives were evaluated for each criterion, there would be 3 x 6, or 18 additional pairwise comparisons needed for a total of 33 judgments. Although each of the pairwise comparisons might be simple, each one would still take time to create, explain, and enumerate. For this reason, AHP is often reserved for decisions that have significant cost or impact that makes the time investment worthwhile. A number of such medical case studies will be described shortly.

A recent simplification bears comment, however. In Liberatore, et al,⁹ described below in more detail, a simplified paper-based method for patient preference analysis regarding prostate cancer screening was developed. In their methodology, they limited the patient's consideration to the three most important criteria. In addition, to simplify the data captured, the AHP scale was truncated and the patients were asked to rank order the criteria. A counselor helped the patient score his preferences and entered the scores into a programmable calculator for processing, which entirely eliminated the need for a PC. This approach allowed the investigator to give the patient an immediate score and strength of preference for deciding whether or not to undergo prostate cancer screening. Such innovative adaptations can make AHP even more accessible for patient and clinician decision making.

AHP Case Studies in Healthcare

In the following section, several medically related case studies are summarized to illustrate the diverse ways that AHP is being applied to: (a) help patients make critical choices, (b) help clinical engineers and clinicians evaluate alternative technologies to purchase, and (c) make medical staff selection decisions.

In the first study, a university hospital team evaluated the use of an AHP-based decision aid to help African American and mixed-population patients make critical choices about prostate cancer screening.¹⁰ In this study, mentioned above, the authors describe the trade-offs that a patient must make when confronting this decision. In short, the patient's willingness to undergo surgical or drug therapy may hinge on individual acceptance of potential side effects

like impotence or repetitious uncomfortable treatment and discomfort that reduce the patient's quality of life.

This study consisted of two phases: an educational process to inform the patient about the prostate gland, prostate cancer, and the benefits and risks of screening and treatment; and a decision process to identify, rank, and weigh the three most important factors for each patient facing this decision. The study found that the combination of educational materials and personalized AHP-based decision analysis resulted in almost all of the patients electing to proceed with prostate cancer screening.

Another recently completed AHP study addressed the selection of neonatal ventilators for a planned expansion of a neonatal intensive care unit (NICU).¹¹ This study used the expertise of a hospital's clinical engineering (CE) and respiratory therapy (RT) directors to construct an Expert Choice-based decision model, and documented the resulting evolutionary process of the interdisciplinary issues that had to be addressed. The model went through 6 iterations of evolution until it was completely acceptable to the CE and RT representatives, and each of these iterations took approximately 2 hours to complete. The resulting model, shown in figure 2, had four major hierarchical categories: Safety, Clinical Factors, Biomedical Factors, and Cost, each of which had final decision weights of 31.7%, 30.1%, 21.8%, and 16.3% respectively.

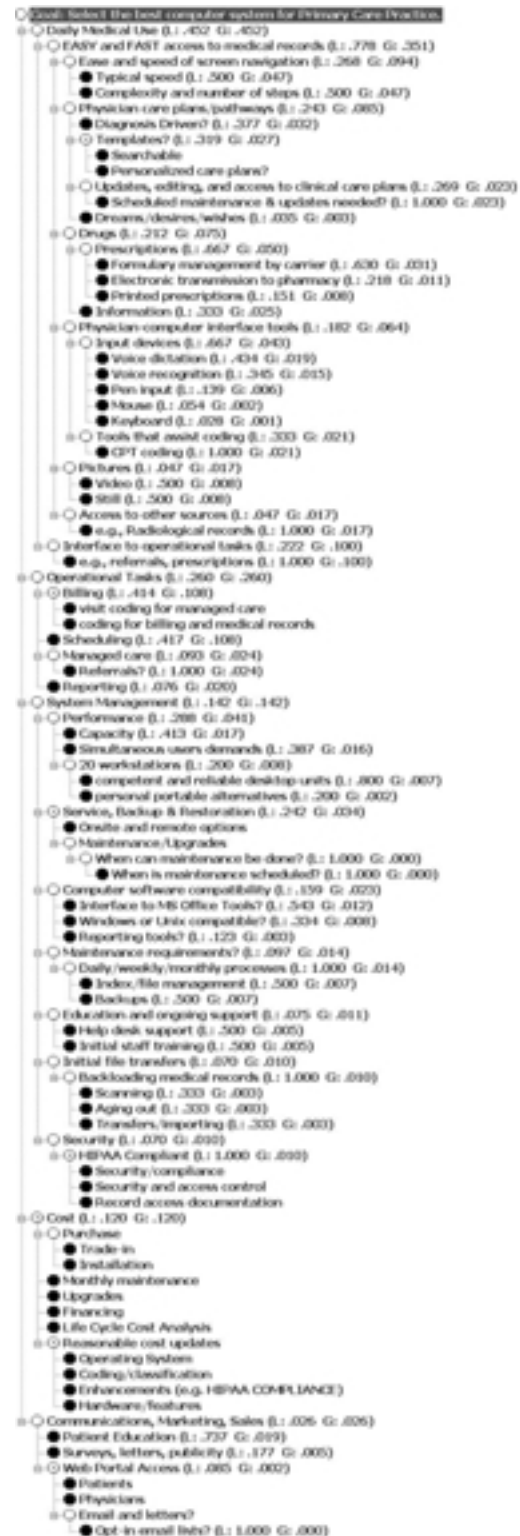
This AHP model helped the hospital staff identify and assign relative decision weights for 47 individual criteria within these four categories. Because the hospital staff was already comfortable using clinical rating systems, the AHP process used ratings categories for each of the 47 decision criteria. The CE and RT participants created weighted rating categories for each of these criteria (samples are shown in table 1).

In this application of AHP, ventilator options were not pairwise compared for each of the criteria. Instead, the alternatives were scored using the rating categories, which resulted in one alternative's overall score being 60 percent better than either of the other two. Samples of several rating categories, their relative weights, and scoring of the three alternative ventilators are also shown in table 1.

This study was important in showing the value of the interdisciplinary collaboration process used to build a mutually acceptable hierarchical decision model and the application of the model to the ultimate decision process. It also identified Cost as a much lower-ranked decision criterion than initially expected due to the significant safety and clinical factors associated with neonatal ventilation. The study illustrates the use of AHP as a new clinical engineering tool to support microeconomic health technology assessments (HTA), and suggests potential future research opportunity for macroeconomic HTA projects such as identifying the best medical technology for a national health system to implement.

A third completed study applied the AHP for the selection of residents for the five-year general surgery program at a major metropolitan hospital.¹² Three criteria were used: academic performance (e.g., college and medical grades,

Figure 3. Expert Choice screen shot of Primary Care Physician MIS system AHP selection model.



National Board of Medical Examiners examinations scores), personal fit (e.g., communication skills, appearance), and surgical appropriateness (e.g., surgery-rotation evaluation, letters from program directors).

Each applicant was interviewed by three committee members and was rated using the AHP and the traditional informal 0-10 scoring system used in previous years. The correlation of the results of the AHP and the traditional system were found to be statistically valid. The findings from this pilot study support the use of the AHP as a viable alternative for the selection of surgical residents. The AHP was found to be an alternative to the traditional, unwieldy, and subjective selection process.

Ongoing AHP Case Study Examples

An overview of three additional in-process case studies using AHP is now described to show the diversity of potential medical applications. One study involves selection of a new MIS system for a primary care physician practice, a second study is an AHP application to assist a surgeon's decision making for colorectal cancer treatment, and a third study focuses on improving patient discharge planning.

Figure 3 shows an AHP model that has been created for a large primary physician practice to help them select the best MIS system to acquire. The expertise of the two primary physician partners and their office manager was used to construct the model, which took four two-hour meetings to completely refine. The final model had five major decision categories: Daily Medical Use, Operational Tasks, System Management, Cost, and Communications, with final decision weights of 45.2%, 26.0%, 14.2%, 12%, and 2.6% respectively.

This model shows the clear and strong bias of this practice for a system that affords the physician fast and easy access to the medical records. This criterion alone makes up 35.1% of their decision. The physicians' time is so limited that they are not willing to wade through menu after menu on a display to obtain the needed information. They have made a clear decision that out-of-pocket cost is barely half as important to their decision as fast and easy access to their patient's information. That factor, by itself, is actually so more important to them that

they are willing to sacrifice considerable administrative staff time and effort if needed.

Other clinician factors, such as the ability to access video and other types of data, are much less important. Operationally, the practice wanted to ensure smooth day-to-day system use by their administrative staff to do routine processing, and competent billing and physician/patient scheduling. Because this practice has had prior MIS experience, the participants were careful to detail their maintenance, repair, and HIPAA compliance needs within the model.

Clearly, the last category of communication enhancements such as web access and e-mail for patients is not perceived as offering significant strategic value in the near future. For every rating criterion a set of rating categories and weights has been defined similar to those described in the neonatal ventilator case above. The 60 criteria and associated rating categories have been transformed into a survey document that the office manager is using to assess every computer system proposal. The surveys will be used as input documents to complete the evaluation and scoring of the alternatives to identify the best system for their needs.

Another AHP model that is being developed is a prototype to be used by colorectal surgeons to assess treatment alternatives. The main objective is to evaluate each patient for tumor severity and complexity.

The patient's score will help the surgeon decide if complex and lengthy microsurgical excision is likely to successfully and permanently eliminate the cancer. If not, more traditional colostomy surgery and lymphatic node excision would be undertaken, with the attendant surgical risks, recovery complications, and ongoing quality of life challenges for the patient living with an external colostomy bag.

A third AHP model is being developed to assist in patient discharge decision making. Each year more than 12 million hospital discharge referral decisions are made for Medicare recipients, yet there are no national, empirically derived, clinical guidelines to assist in making these important decisions.

Several recent studies have demonstrated the clinical and economic value of correctly identifying patients in need of discharge referral and ensuring appropriate follow-up care. A study is currently underway to identify a hierarchy of factors to support nurses and other clinicians' decision making

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regarding referrals for post-discharge follow-up for hospitalized older adults.¹³ AHP, along with other knowledge engineering tools, will be used to develop a decision support system for patient discharge decision making. The study will compare the sensitivity and specificity of the decision support system with hospital discharge referral decisions for older adults.

Conclusions

AHP, the Analytic Hierarchy Process, is a proven, valuable, and versatile decision support tool that hospital CIOs, CTOs, IT/IS specialists, and clinical engineers should consider using to improve the analysis, organization, and implementation of important decisions. When properly designed and applied, the AHP methodology can help to elicit the relevant criteria, assess each criterion's relative importance to the decision, quantify the inevitable inherently conflicting trade-offs, and structure and document the evaluation of the alternatives. The resulting scores allow relative comparison of the alternatives.

The AHP model can also be used to easily assess the relative impact that new information may have on the decision. As with any decision support tool, proper training and care must be used to build competent and reliable models that accurately reflect the unique experience and needs of the participants. As shown in the case studies, AHP can be used to directly improve medical decisions by clinicians and patients. Just as important, it can be successfully used to improve the complex information technology, healthcare technology, and general management decisions that have become such a large part of every hospital's budget.

Table 1. Sample of Neonatal Ventilator Rating Criteria, Weights, and Alternative Evaluations

Criteria Category	Ratings Names and Descriptions	Weight	Alternative 1	Alternative 2	Alternative 3
Daily maintenance requirements: Pre-use checkout	Simple	1.0	Simple	Very intensive	Simple
	Somewhat intensive	.76			
	Very intensive	.29			
Alarm system unique sounds & prioritization	Large number	1.0	Minimal/None	Large number	Minimal/None
	Select number	.76			
	Minimal/none	.35			
Responsive valve feature	Excellent	1.0	Limited	Excellent	Limited
	Adequate	.49			
	Limited	.10			
Factory support: service documentation	Excellent	1.0	Excellent	Limited availability	Limited availability
	Limited availability	.40			
	None	.09			
Training program	2 Staff training	1.0	No staff training	2 staff training	No staff training
	1 Staff training	.53			
	No staff training	.19			

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