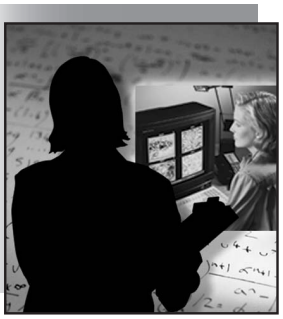

Using a Decision Support System Tool for Healthcare Technology Assessments

Applying the Analytic Hierarchy Process to Improve the Quality of Capital Equipment Procurement Decisions

BY ELLIOT B. SLOANE

The field of fiscally competent healthcare technology assessment (HTA) for clinical engineers was formally launched in the mid-1980s with the Emergency Care Research Institute's (ECRI) seminal "Devices and Dollars" report. Since then, those methods have been taught in dozens of countries but they have not kept pace with contemporary decision support system (DSS) tools. This article will discuss an HTA application using a well-developed business tool from the operations research/operations management (OR/OM) field, the analytic hierarchy process (AHP). The AHP methodology provides a proven, structured, and well-documented tool for conducting HTAs for hospitals, integrated delivery networks, or other healthcare providers. A case study based on the selection of a neonatal ventilator is used to illustrate a successful use of the AHP for HTA. Clinical engineers can use this design as a prototype for performing HTAs in their own institutions.

HTA History and Background

Medical technology is constantly improving—or at least, changing—which often causes complex interactions between outcome, efficacy, training, support, risk, and cost. Because of the costs and consequences of selecting and implementing medical technologies, HTA has become a strong and growing worldwide discipline [1]–[4]. HTA is not solely an issue for the wealthy countries, as even the smallest of countries is affected by changing clinical and epidemiologic trends; world loan reforms and global economics; donations of drugs, devices, and supplies; and technological advances. HTA has emerged as an international research and regulatory issue for both industrialized and developing countries as documented in recent publications by the Pan American Health Organization (PAHO) [5]–[7] about Latin American and Caribbean experiences.

Even in U.S. hospitals, the process of selecting an approved, legally available health technology is often quite complex. At the very least, it requires thorough consideration of multiple stakeholders' views about the vast number of features, benefits, and risks that are associated with most health technologies. Hospitals sometimes establish technology selection committees—which include clinical, administrative, and clinical engineering members—in order to ensure that all relevant factors are examined. These committees must wrestle with the fact that in most cases, various features and benefits are offset with risks and limitations. In some cases, the benefits favor one department or application, such as the Emergency-Room trauma patients, but are less suitable for other departments or applications, such as the Cardiac Catheterization Lab. Every brand and model of product that the hospital might consider has a different blend of features, costs, applications, limitations, risks, and ownership costs. The hospital's administration and committee typically have to decide on the key criteria it will use for the selection and determine a way to fairly and accurately weigh, contrast, and choose the best alternative.

The AHP is a well-proven DSS widely used in many industries that is herein being adapted to an HTA task. This article presents the fundamentals of HTA and of the AHP, uses a case study to show how clinical engineers used the AHP for a neonatal ventilator selection project, and describes several potential future HTA applications for the AHP.

Although humanity has a long-standing tradition of scientific evaluation of medicinal herbs that dates back to antiquity, the rapid rate of invention, commercialization, and clinical use of electromechanical and pharmacological technologies since the mid-1950s has had many unintended negative consequences [4]–[6]. The particularly acute negative economic and health impacts have sparked new regulatory initiatives in developing countries and the United States [4], [8].

Among the earliest acknowledged detailed technical studies of health technologies were those performed by ECRI, as published in their *Health Devices* journal. In 1971, their very first published report [9] documented that 13 of the 22 manual pulmonary resuscitators then on the U.S. market were defective, ineffective, and potentially very dangerous. For example, one design combined an adult-sized breathing mask with an infant-sized squeeze bag. Another model lacked any valve to prevent the patients' exhaled breath from being repeatedly recycled into their lungs. Other models' defective mechanical design all but ensured that the patient's airway would collapse, preventing any effective movement of air at all. In most if not all cases, use of one of these defective designs would most likely lead to brain damage and death, instead of successful resuscitation.

In 1969, there were no U.S. laws to control medical device manufacture, sale, or distribution, and no U.S. agency had the

authority to remove the products from the market. Significantly, existing medical journals refused to publish ECRI's findings; such negative reports conflicted with their editorial policies, not to mention their advertiser's interests. U.S. laws to regulate medical technologies came into existence in 1975, and they have been evolving to keep pace with the explosion of interlinked drug, device, and biologics fields ever since. Mr. David Link, the original director of the Federal Drug Administration's (FDA's) Bureau of Medical Device and Diagnostics, pointed out in his June, 2001 "Harken Address" to the Association for the Advancement of Medical Instrumentation in Baltimore that formal, explicit medical device standards had been avoided in the United States for years. Instead, a process of premarket registration and/or approval, manufacturing quality oversight, and post-market approval was put in place. While this regulatory approach was credited with minimizing undesirable delays in innovation, it created complications of its own because every device can have quite unique advantages, disadvantages, risks, and limitations. Furthermore, each device can have a different human interface design, which has been shown to cause operator errors and inefficiency in other industries [10], [11].

More than three decades after the successful launch of *Health Devices*, today ECRI publishes dozens of related journals, newsletters, and books and conducts worldwide research, education, and consulting on the subject. ECRI has been a World Health Organization (WHO) Collaborating Center for Health Technology Assessment since 1988 as well [12]. ECRI is also one of the major contributors to the U.S. Center for Medicare and Medicaid Services technology assessment program, is an active participant in the Agency for Healthcare Research and Quality (formerly the Agency for Health Care Policy and Research), and is a federally designated Evidence-Based Practice Center [13].

However, ECRI's thorough testing, research, and reports are often only a starting point in an individual healthcare provider's technology selection decision-making process. Even though each of the available health technologies may be relatively safe and effective, each often offers very different features and trade-offs. ECRI's own SELECT™ program and its variants are designed to provide "personalized" recommendations for individual care health providers. Those services typically require the expertise of trained ECRI analysts to organize and interpret the results for the hospital.

In order to allow hospitals to do more of their own work, ECRI incorporated a basic analysis software tool, known as *Easy*, in their SELECT program in the early 1990s [14]. Based on Decision Pad MS-DOS software, the *Easy* DSS software system allowed entering criteria, allocating weights for each criterion, and assigning scores to the performance of each alternative under consideration [15]. It could not handle the natural inconsistencies of different stakeholders' assessments, and, more importantly, it did not use ratio-based measurements. This tool represented a useful early personal computer (PC)-based HTA application, but because it only had limited flexibility, was not Windows-based, and could easily be misused or misinterpreted, it failed to become accepted. Since that time, however, no specific decision support tool has yet emerged to effectively assist in the technology-evaluation and decision-making process.

When selecting a DSS tool for HTA, it is important to identify a situationally correct ratio-based DSS model so that each variable is properly proportioned with respect to its contribution to the whole model. Scoring tools, like grade-point averages (GPAs) in college, are not generally suitable. (Consider, for example, a surgeon with a 3.5 GPA who barely passed the anatomy and physiology courses. That doctor might not really be the person you would want to hire for your operating room—nor perform your brain surgery—despite a decent GPA!) In a DSS tool that does not use a ratio measurement basis, the quantity of outright scoring and computational errors can quickly destroy the model's validity. As in the GPA example, the sheer multitude of less-important criteria can accumulate so many scoring points that they inaccurately distort the model, leading to an inaccurate interpretation.

Models that appear to be reasonable can be devised using spreadsheets but their use is completely limited by the user's skills and training. In one such hospital spreadsheet model that this author examined, several crippling flaws were identified. First and most seriously, many important scores had been omitted because "the alternatives all performed equally well." The problem with this defective logic was that none of those important features received any scores at all, leaving the whole decision to a plethora of less-relevant items! That illogical simplification was like omitting the grades for an engineering student's major courses because they were all excellent; the remaining grades for the electives, core, and minor courses would then be the only ones included in the GPA. Second, the various categories of criteria were not themselves ratio-proportioned to an idealized 100% "best alternative." The result was that the alternative scores were incorrectly weighted with respect to each other. (e.g., a "10" for battery life does not mean that another alternative with a "5" is half as good; simply adding up arbitrary scores will yield an inappropriate impression of relative benefit or deficit between the alternatives.) This led to a decision based on inaccurate data.

As will be discussed later, the AHP is a ratio-based DSS, and each feature and alternative is properly proportioned to the whole decision process. It not only allows collection of quantitative data (e.g., this defibrillator weighs 6 oz more than two other defibrillators), but it also allows weighting the importance of that difference (e.g., the user may decide that a 6-oz weight difference is irrelevant, and, therefore, can assign an equal weight to all three products for that criterion.) Further, because the AHP was originally developed for use in the social sciences, its weighting scales have been carefully developed and calibrated to help collect qualitative information as a valid, ratio-based quantitative value (i.e., the AHP is designed to reliably convert statements like "this model is two times easier to learn than that model" or "this product is a lot more awkward to hold and operate than that one" into ratio-scaled numeric values). This is a very important benefit of the AHP because qualitative data such as human factors can be a very important part of the decision process. Unfortunately, without a validated tool like the AHP, it can be very difficult to evaluate and integrate qualitative data.

Micro- Versus Macro-Economic HTA

The HTA field has developed its own "language" and definitions [4], [16]–[18]. In particular, WHO and other experts make it clear that the term "health technology" must encompass all potential technical facets, including things, people, and processes. Thus, devices, drugs, homeopathic and/or food supplements, biologics, genomic products, nanotechnologies, medical and surgical procedures, clinical decision support

Few business school researchers understand the medical field, but it has been encouraging to see how often they can quickly identify and apply their portfolio of well-documented tools and techniques once they understand a healthcare problem.

software, and many other emerging inventions and medical alternatives are within the scope of HTA. This broad perspective is important because it reinforces the need to examine many competing devices, drugs, human resources, and infrastructure implications when seeking the optimal solution for clinical problems that fit finite fiscal limits.

Without a general-purpose decision support methodology, it is often very difficult to compare one or more health technologies. There is often a complex interplay of advantages and disadvantages between various drugs, devices, and medical techniques. For example, for any specific group of patients it is not always clear whether chronic lower back pain is best treated with a device such as a transcutaneous electrical nerve stimulator unit, a nonsteroidal anti-inflammatory drug, exercise, osteopathic manipulation, narcotics, or microsurgery (among the many options). Each alternative has a different cost, risk, application, and the desirability of each can vary widely when viewed from the patient, general population, insurance payer, legal, or governmental perspective. Experts like Goodman [16], [18] have identified two broad HTA classes: microeconomic and macroeconomic health technology assessments ("microassessment" and "macroassessment" hereafter) to help categorize these differing viewpoints.

Macroassessments

The macroassessment process is often used for national, international, and global analyses. In a macroassessment, scientific studies may have to be carefully evaluated for validity, accuracy, and generalizability before being included in the analysis [3], [17], [19]. This process is also sometimes referred to as "evidence-based assessment of technology," and large databases of vetted studies have been created. By their nature such statistically robust, generalizable studies are often long, complex, and expensive. They require rigorous clinical, methodological, and statistical examination and comparison. Complicating the process is the fact that some published scientific research has unacceptable mistakes and biases. Other studies may have uncertainties caused by corporate sponsorship, raising suspicions of conflicts of interest at many levels. In addition, the conclusions of studies may differ, or they may even contradict each other completely. This may reflect a local or national economic or health situation where the studies were done. It may point to a statistical variability in the patient populations that were studied, or may even reflect a slight but significant difference in the study methodologies. The differences cannot merely be overlooked without careful review and analysis.

For example, the success of a specific HIV drug treatment regimen may depend on several factors, including the diagnostic techniques available, refrigerated storage and distribution capacity, reliability of patient dose compliance, community education, cultural beliefs, and cost. What may be feasible, recommended, and successful at a specific moment in time in "developed" countries, for example, may not be a possible consideration in a poverty-stricken country for several more years, if ever [19], [20]. Macroassessments of health technologies can be used to address health policy and health-system decisions. New PC decision support tools, like the WHO Essential Health Technology Program [21], are emerging to aid selection and deployment of proven and accepted health technologies, though they may not attempt to infer or imply the "best alternative" for any individual situation.

Microassessments

The microassessment for health technology is usually applied to much more local situations, such as a hospital or physician practice selecting a specific drug, device, or procedure for adoption. Such assessments are, by necessity, constrained to predetermined patient populations; clinical care practices; legal, ethical, and social standards of care; economic circumstances; availability of other necessary resources; and other similar circumstance-specific details [19], [20]. Because of local circumstances or history, no two situations are ever exactly alike. For example, a regional hospital in Alaska may have to be quite independent, and all specialized care might need to be available within the facility itself. By contrast, in a major metropolitan city in the United States, one hospital may be able to focus on children, another on cancer, a third on cardiology, and so on. While there may be overlap in certain diagnostic or emergency services, specialized technology and resources can be focused in separate institutions to offer the best results in the most cost-effective way. Many published microassessments are limited to the net present value (NPV) financial analysis [22] or various cost-benefit analyses [23], [24]. When properly performed, NPV analysis does accurately analyze the expensive life cycle ownership costs associated with many health technologies but financial impacts only reflect one of the many critical issues that need consideration. The NPV is only part of the decision, however. It should be included in the decision, but, as will be seen, it is not necessarily the most appropriate deciding factor. On the other hand,

most of cost-benefit analysis studies focus on patient care costs and revenues or on outcome studies. These studies are useful at both the macro and micro level for deciding if a technology should be adopted at all. However, such studies rarely examine specific product trade-offs, so they are not easily or reliably used for selecting a particular brand or model for purchase unless virtually all other factors are equal or irrelevant. Also, as the initial indications for use are expanded, a technology that first appears far too costly may in fact become very valuable over time. If the initial evaluation prevents its introduction then significant benefits may never be realized. (Witness the valuable services now provided by computerized axial tomography or magnetic resonance imaging).

Related Literature

Prior to the current study, there were very few examples of medical applications of the AHP. The topics covered included medical product design optimization [25], [26]; clinical decisions [27]; patient decision making [28], [29]; physician practice management computer system selection [30]; and surgical resident selection [31]. The focus of this current AHP research, however, is on paving the way to new and novel HTA applications for hospitals, integrated delivery networks, nursing homes, home healthcare, and other similar healthcare providers. These healthcare providers are confronted with diminishing revenues in an era of increasing demands, expectations, and liability risks [8]. The case study presented here illustrates how clinical engineers can use the AHP to improve the quality of diverse and important capital equipment procurement decisions that hospitals and other providers face.

As an overview, the literature describes these recommended steps for examining and weighting the relative importance of the multiple criteria affecting decisions: 1) identifying the alternatives available and the individual criteria on which they will be evaluated; 2) determining how well the alternatives achieve meaningful criteria, based on an assessment of available data and personal preferences; 3) determining the importance of each criterion in the decision-making process; and 4) making a choice among the alternatives after synthesizing the results from the previous steps [32]. The decision process must also weight the alternatives for each criterion. These recommended steps can be used to help resolve the numerous conflicts that often exist when choosing between multiple competing criteria and alternatives [35]–[40].

Very detailed literature on AHP and its application to a broad range of decision tasks is available [41]–[48]. For the newcomer, there are three basic fundamental concepts about the AHP that should be understood because they are the root of the name itself. First, the AHP should be viewed and understood as a *process*. This process requires elucidating criteria from the users, evaluating the relative importance of each criterion, and then determining how well the alternatives meet each of the criteria. The process is usually one of human deliberation, consideration, discussion, and negotiation, and not merely an assignment or determination of some physical quantity or fact. Second, the AHP requires organization of a decision into a *hierarchy* of criteria. These criteria are organized according to perceived reasonable, logical, and/or useful groups to improve the clarity and utility of the model and to create properly proportioned subcategories. This organizational structure helps to ensure that not only are all important criteria included, but that each criterion receives its proper weight in the decision. As demonstrated in this article, the creation of an appropriate hierarchy is both a process unto itself and a part of the process of refining the decision. Third, the AHP is an *analytic* tool to help measure the user's perceptions in addition to physically quantifiable facts like weight, size, or cost. The AHP uses "pairwise comparisons" to help the users express the perceived relative importance of every criterion against every other criterion within each hierarchical group Pairwise comparisons establish the proportional weight each criterion should receive in the decision.

The AHP also uses the relative importance of each criteria group to establish that group's weighted importance. Every criterion must have an evaluation system established as well, which will be used to assess the relative performance of each alternative for that specific criterion. Several different evaluation modes may be used for this. The first, most basic mode uses pairwise comparisons of the alternatives' relative performance for each criterion. For example, in this mode, the users would compare each product's performance within a single criterion by evaluating how much better or worse each product meets that criterion (e.g., the users could decide that Product *A* is half as easy to clean as Product *B*.) If there are many products and many criteria, this could become a very tedious process, so other modes have been provided. A second mode allows users to create scoring or rating categories, and each category is then assigned the appropriate relative proportion for meeting a criterion's goal (e.g., if a product is "hard" to use, it might receive one-quarter of the weight of a product that is "easy" to use). A third mode allows use of an equation to convert numeric performance of an alternative into a relative performance value. This mode can be a bit more complicated to use, though. If, for example, the supply costs for a product varied widely, an equation might be used to give very low weights to expensive products and much higher weights to inexpensive products.

Pairwise comparisons can be time consuming, especially if there are many pairs. If there are seven criteria, Figure 1 shows that as many as 21 pairwise comparisons are needed to determine the criteria weights. While 21 comparisons are not too difficult to perform, if ten alternatives are then evaluated

	modes	alarm systems	treatment delivery options	heat and humidification	daily maintenance	human factors	ease of transport
modes		1.0	1.2	1.2	1.4	1.5	2.0
alarm systems			1.1	1.2	1.4	1.5	2.0
treatment delivery opt				1.1	1.2	1.4	2.0
heat and humidificatio					1.2	1.5	2.0
daily maintenance						1.2	2.0
human factors							2.0
ease of transport	Incon: 0.00						

Fig. 1. Twenty-one pairwise comparisons are needed for seven criteria.

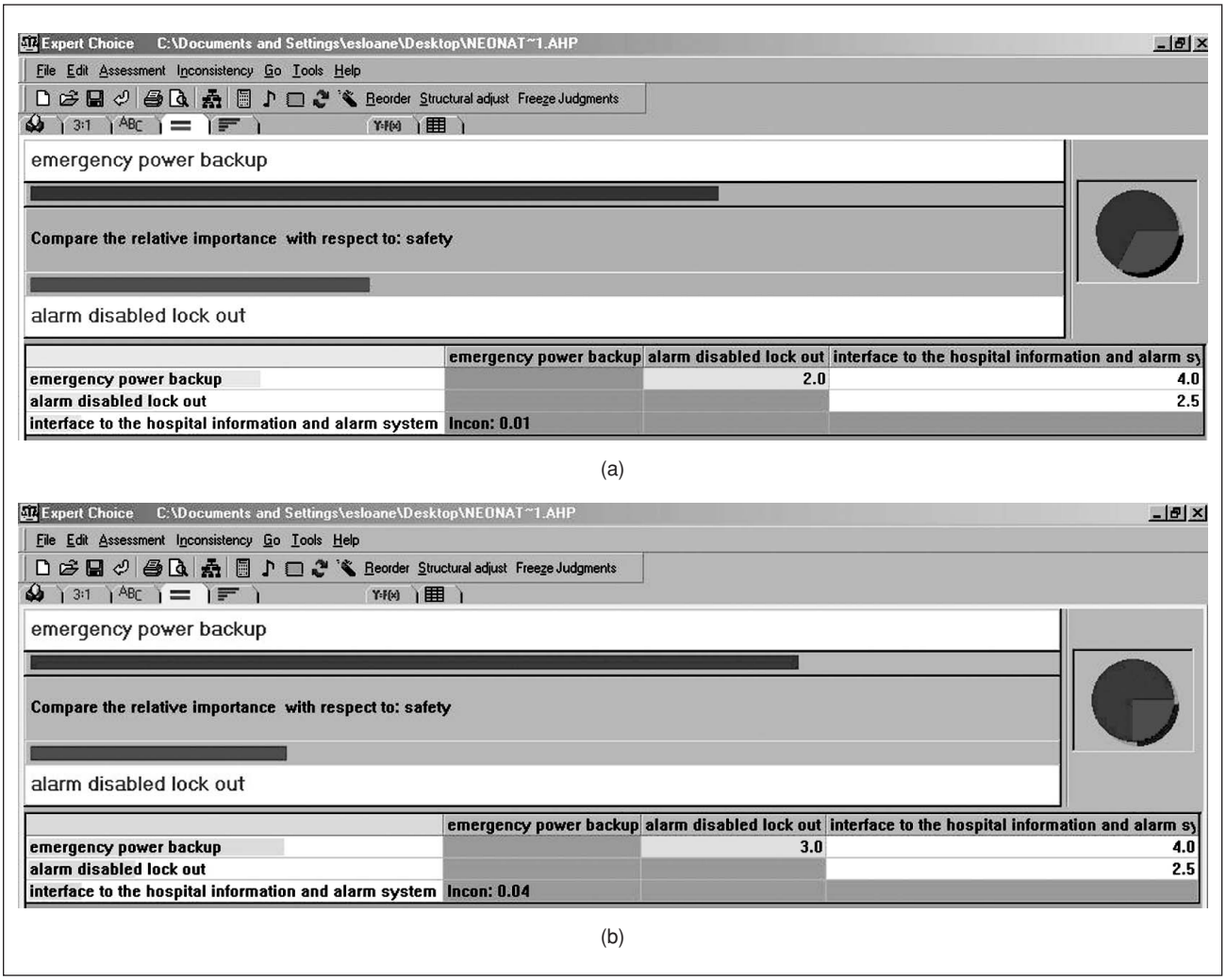

Fig. 2. (a) Example of pairwise comparison (2:1) with bar and pie charts. (b) Example of pairwise comparison (3:1) with bar and pie charts.

for each criterion, there would be 10 × 21, or 210 additional pairwise comparisons needed! (For a criteria such as "alarm volume," for example, the alarm volume for every alternative product would need to be pairwise compared against all other products.) Even if pairwise comparison is fairly simple, each one would still take time to discuss and weigh. Therefore, in situations where many alternatives must be compared against many criteria, the second or third modes described above might be preferable. Rating categories illustrating the application of the second mode are used in this article.

A pairwise comparison simplification has recently been published that deserves brief discussion. In [49], an elegant, simplified paper-based method for determining patient preferences in a prostate cancer screening program is described. A portion of the patients had very limited education, and the process was designed to make the task much easier to explain and use. The researchers carefully limited the patient's choices to only three simply expressed but well-described important criteria, and the patients were asked to then rank the criteria. An AHP decision scale was predefined by the researchers to ensure accurate analysis and, again, to simplify the patient's decision. A counselor helped the patient make their decisions and then entered the scores into a programmable calculator for processing. This non-PC approach allowed the investigator to give the patient an immediate personalized score and strength of preference for deciding whether or not to undergo prostate cancer screening. This innovative implementation made AHP accessible for rapid decision making by a lay person. It simplified the user's effort by severely limiting—and weighting—the choices in advance. It required very careful design, implementation, and training for success. If this type of simplified AHP approach is incorrectly designed for a different situation, however, the results could well be erroneous.

A Simple AHP Example

In the present cost-constrained healthcare situation, a reliable and easily used decision support tool to select the best health technology could help save money as well as ensure that a safe and effective technology is selected. A simple HTA example can serve to illustrate how AHP uses a pairwise comparison process to create an accurate tool for selecting the best technology. Take, for example, a hospital that is trying to choose between three different battery-powered defibrillator/monitor systems, Defib-1, Defib-2, and Defib-3. One important selection criterion for the defibrillator/monitors might be the battery duration when using the system for patient transport. Let's say that Defib-3 can monitor for twice

as long as Defib-2. This, then, is the first pairwise comparison. If we know that Defib-2 can run for three times as long as Defib-1, that is the second pairwise comparison. There is no need to compare Defib-3 to Defib-1, though, because one can easily calculate that Defib-3 runs six times longer than Defib-1. The ratio of Defib-1:Defib-2:Defib-3 is 1:3:6. If one were to scale the results to 100% of the combined group ($1 + 3 + 6 = 10$), one could give Defib-1 a score of 0.1, Defib-2 a score of 0.3, and Defib-3 a relative score of 0.6. Because the battery function is a physical, testable quantity, we would have little need for more DSS sophistication.

Many important criteria are quite subjective, however, and these subjective factors may have more variability. If we stick to the same defibrillator/monitor selection problem, we might identify ease of training as another important selection criterion, but criterion that is more subjective than battery life. Even if we were to establish that Defib-3 is two times easier to learn than Defib-2 and Defib-2 is three times easier to learn than Defib-1, there might be glaringly significant differences when comparing Defib-3 and Defib-1. We cannot merely use a 1:3:6 ratio if there is other, conflicting information or merely additional complexity. Suppose that the arrangement of the controls and the setting of alarms on Defib-3 are found to be ten times easier to learn than Defib-1. The AHP allows this inconsistency to be incorporated in the model by adding a third pairwise comparison. (Defib-1:Defib-3 = 10:1). The AHP program uses matrix mathematics to convert this new product assessment into the relative weights of 0.077, 0.274, and 0.649 for Defib-1, Defib-2, and Defib-3, respectively. Thus, we can see that, compared to the battery-life example above, AHP has increased Defib-3's relative score and decreased Defib-1's relative score to account for the inconsistency. Note that the AHP computation also slightly reduced Defib-2's score with respect to Defib-3, which factors in the relative strength of Defib-3's performance in this criterion. After each pairwise comparison, the AHP algorithm also computes an important inconsistency variable to help detect if it threatened the utility of the evolving model. Typically, an inconsistency measurement of greater than 0.1 is considered too high for reliable decisions. (See [45] for an explanation of the approach used to compute these weights and inconsistency values.) Fortunately, in the above case the AHP algorithm computes an inconsistency level of 0.03, which would be acceptable.

Every HTA decision may involve dozens of criteria, each of which must be carefully examined and pairwise compared from alternative to alternative. Each AHP model can be expanded easily by adding additional criteria or groups of criteria. The AHP is used to increase the value of the decision model by using the same pairwise comparison method to quantify the relative importance of the different criterion. In doing so, the AHP is meticulously computing the relative importance of each criterion to the decision and the relative performance of each alternative for each of the criterion. At the same time, the AHP keeps track of the accumulating inconsistency to ensure that the computations maintain acceptable validity.

Figures 2(a) and (b) show how the integrated graphics feature of Expert Choice 2000 can make this process a bit easier for the user. As can be seen, Expert Choice simultaneously displays the pairwise comparison relationships in bar-chart and pie-chart formats to help the user visualize the resulting weights. Any change to a number simultaneously changes the pie and bar sizes. Alternately, the user can choose to adjust the length of the bar by dragging the right edge of a bar to the left or right, which simultaneously changes the numbers and pie chart. Note also that the inconsistency value, on the bottom line of Figures 2(a) and (b), automatically changed from .01 to .04. This immediate feedback can help the user avoid building models that exceed the recommended 0.1 inconsistency threshold, which can help prevent making a decision based on an inherently defective analysis.

AHP Decision Support for Groups of Stakeholders

We are in an era of continued pressure to move patient care from hospitals to subacute facilities and home care settings and a rapid employee benefit shift towards copayment for services [8]. Because of legal and regulatory pressures, patient copayment for products and services, and other factors, doctors, hospitals, and/or insurance companies no longer solely dictate the "right" technology decision, and the community of stakeholders (a.k.a., decision makers) extends all the way to patients and families. The AHP can, in fact, be used to support patient-focused decisions, but the author's current research is directed at hospital applications. It addresses the types of microassessments that hospitals need to do throughout the year. As will be discussed, many hospital stakeholders are usually involved in these projects, and any selected decision support tool must be able to appropriately factor all stakeholders' perspectives into the final decision.

Fortunately, there are many methods used to facilitate group decision making when using the AHP [33], [40], [47], [48]. Several common group decision-making options that exist are shown in Table 1. In many of the cited references in Table 1, the options were combined in different ways to facilitate reaching a consensus. These options can be combined to solve very complex group decision problems. In fact, Saaty and Alexander [50] show examples of ways that the AHP might contribute to resolving important global conflicts by allowing affected parties to directly and actively participate in building a problem resolution model that incorporates and weighs each party's needs and perspectives. Although hospital decisions

Table 1. Several group decisions support techniques.

1) Face-toface or electronic dialog among the participants to reach a resolution (33, 34, 35, 36);
2) Applying an arithmetic or geometric mean, or another computation to integrate individuals' opinions (37, 38, 39, 40);
3) Using the Delphi technique, in which questionaires and result feedback facilitates an iterative process of converging to an acceptable consensus (27, 46, 47);
4) Assigning higher weights to the decisions of one or more of the participants for one or more of the criteria (40, 49); and
5) Performing two or more separate analyses for independent teams/individuals and then discussing the outcomes to achieve a consensus decision (34, 36, 47).

HTA is not solely an issue for the wealthy countries, as even the smallest of countries is affected by changing clinical and epidemiologic trends; world loan reforms and global economics; donations of drugs, devices, and supplies; and technological advances.

might seem easier than global conflicts, in reality the competing political and economic factions in hospitals (and integrated health networks) can be quite intense. Therefore, it is important to consider the common practices for addressing such challenges.

The first option from Table 1 is to use group meetings to develop consensus decisions about the importance of various features and criteria. This cannot be done by software alone, as it involves thoughtful, detailed human dialog. Facilitating an emotionally charged discussion can be challenging, and translating the key technical issues to the stakeholders can require a broad understanding of technology and a strong ability to communicate with different people. Though many clinical engineers have the necessary broad technology knowledge and valuable institutional insight, they may need to polish their communication skills and/or partner with a skilled facilitator. This option was used in the studies discussed in this article but the other group decision alternatives are discussed below.

In the advanced team versions of the Expert Choice 2000 software used in this study, a built-in function implements the second of the procedures listed in Table 1. In the team version of Expert Choice 2000, a facilitator can allow multiple participants to enter their own votes using a wireless keypad, and the software will automatically compute the individuals' geometric mean decision. This has the advantage of being mathematically accurate and "fair," but useful interpretation and application may not always be easy. The resulting geometric mean may not adequately create a truly acceptable selection for any stakeholder. Take, for example, a situation described by an expert negotiator, Herb Cohen [51]. He points out that two people who compromise on a vacation by selecting an obscure and boring destination in a cornfield in the middle of the United States that lies midway between each desired destination on opposite coasts are not likely to be satisfied with their mediocre result. In an HTA situation, relying on a geometric mean may result in choosing a product that is only mediocre for everyone and not really suitable for anyone!

In the case of a medical technology decision, there is an ethical obligation to try to honor the patient's needs and beliefs first and foremost, but other stakeholder perspectives and needs must also often be considered. To this end, one can build separate AHP models for each stakeholder or stakeholder group and then integrate those results into a final model by giving appropriate proportional weight to each stakeholder's model (Option 4 in Table 1). Though more complicated than this present discussion, such an approach can help create a composite AHP model that meets the specific need much more precisely.

The benefits of building such a mathematically robust model must be weighed against the cost, too. In many cases, virtually the same result may be obtained by carefully facilitated group consensus meetings. In fact, these two methods can often be combined with good results, as mentioned in Option 5 from Table 1. A voting system can be used to help the group identify areas of discord. An advantage of this hybrid approach can be speed: voting may allow the easier topics to be readily identified without wasting time on discussion. Thereafter, the remaining resources can be focused on the areas of discord. This approach, if competently used, can lead to effective discussion, research, and consensus. If the results of the voting are merely applied without review or discussion, however, there is a good chance the result may be mediocre in one or more important areas.

The third technique from Table 1, the Delphi survey method, enables a large number of individuals who may be geographically dispersed to express their private opinions without the interference of others. Feedback to the group can stimulate further individual reflection, which can be used to drive follow-up questionnaire results to a closer consensus. Again, however, this sort of aggregation may mask critical outlying opinions that should not be overlooked in order to appease the majority opinion, so the Delphi technique should only be applied where and when appropriate.

This process of using iterative refinement of decision models to facilitate organizational change is seen in healthcare and other studies [52], [53]. Murphy, et al. [27] discussed many ways that group decision-making methods can be used when making clinical decisions and illustrated the complex issues that needed to be considered in healthcare settings. There are usually many important, and sometimes conflicting, interdisciplinary and multidisciplinary issues and perspectives to be considered, including the following:

1) A variety of experts' opinions must be considered. For example, the nursing staff will often have the best understand-

ing of the operational and educational challenges that a particular technology may incur. The physicians may require specific performance and/or features that they believe will give the best outcome for their patients. The clinical engineers will have the best understanding of the complications that a specific technology may introduce to the installation, maintenance, and repair/support processes. The administrative team may be best equipped to anticipate the impact of new procedures on other variables such as income, staffing costs, unintended cost shifting between departments, space, or the impact on other existing expensive technological investments.

2) Legal and regulatory agencies can have complex and sometimes conflicting requirements. For example, a few cities require one or more special safety certifications for electrical devices that are purchased for use within their jurisdiction. Devices that meet those requirements may need to be ordered specially and may bear additional costs.

3) Many medical technologies have strong interactions with other technologies. For example, a certain infusion pump may not be accurate enough for administering low doses of morphine for pain control. In another example, a specific surgical technique, such as minimally invasive endoscopic surgery, may limit the size and quantity of surgical instruments that can successfully and safely be used.

4) Hospitals now have many subspecialized patient care settings, which create conflicting demands. A piece of physical therapy equipment that is built to be durable for heavy daily use may be too heavy or bulky for patient home care.

5) As a final example, the cost of procuring, using, and maintaining a medical technology may have diffuse budgetary impacts. The capital investment and depreciation may come from a central funding pool, the operational staffing costs may come from multiple departments, the training costs may come from a central nursing budget, necessary pharmaceuticals may be allocated to the pharmacy, special facility expenses like cooling or water supplies may come from the general facility budget, and the maintenance and repair expenses may come from the clinical engineering budget. The complexity of such diffusion of cost is compounded in the managed-care era, in which the hospital may only receive a fixed payment per patient for whom they are caring, regardless of the procedure and technology that is used.

In the case study described below, a combination of the first and fourth group decision techniques from Table 1 were used to decide on the criteria weights because of the benefits and risks associated with medical devices. The open iterative discussion of contested or misunderstood criteria allowed rapid consensus when needed. Often, however, different parties were satisfied to be given the privilege of asserting the final vote on criteria that was more in line with their expertise or specific responsibility. In part, this may be due to the strength of the existing organizational responsibility and authority structure in this particular hospital. Other health systems, hospitals, departments, individuals, or medical technologies might not yield to these direct techniques. It seemed clear, however, that the inherent hierarchical organization of AHP encouraged clear segregation of criteria and allowed open consideration of the importance and "ownership" of each. Because all of the criteria were visible in their totality, the participants were able to ensure that their own perspectives and critical issues were not only included but were also given fair weighting in the final model.

Planning to Successfully Apply the AHP for a Hospital Health Technology Assessment Project

In order to apply AHP successfully for hospital health technology assessment, several factors needed consideration. First, to do a microassessment the ideal hospital should be actively planning to make a significant purchase, to justify the investment of hospital staff time and to assure that the issue is given realistic and accurate consideration. Alternatively, if a macroassessment is being done, such as a decision to offer homeopathic treatment alternatives in the hospital, the hospital should be committed to make an implementation decision when the analysis is complete due to the large investment of resources that will be needed. In addition, the hospital should be representative of other similar hospitals so that the results may be generalized more effectively. It is not clear why this is important. Third, the technology chosen should be clinically interesting and valuable so that the evaluation is medically useful. Fourth, the health technology evaluated should have significant variations among the various alternatives. Selection of a generic item, such as a standard needle or syringe, might not yield any measurable differences other than pricing. The fifth factor is the ability to identify the appropriate stakeholders at the hospital and to confirm the availability of the appropriate experts to participate in the model. The final factor is the actual active participation of these experts in the building the whole AHP model.

The following sections describe the hospital, technology, and participants in this case study. A detailed explanation of the evolution of the AHP model follows.

The AHP Case Study: Neonatal Ventilator Selection

The research hypothesis was that if the AHP was properly applied with an interdisciplinary hospital team, it could help the clinical engineer to identify the best health technology alternatives for the specific situation and the needs and preferences at that hospital. In particular, this application of the AHP closely paralleled the actual hospital situation because pairs of multiple criteria had to be weighed against each other, and this was done before any device was evaluated. This process of pairwise comparisons between criteria ensured that consideration of the trade-offs between each criterion was given rational independent consideration before the technologies themselves were actually examined. Also, using the AHP modeling process in an iterative fashion to include multiple stakeholders' viewpoints helped put an end to the sometimes endless and circular arguments between different hospital departments. It made the logic behind the individual and collective decisions transparent and allowed the participants to see how they ranked and weighed each criterion. Then, it used a scoring system derived from pairwise comparisons that allowed measuring each of the alternatives being considered against the criteria the hospital set for itself. Once the hospital had an objective scoring system for the alternatives, it was free to negotiate the best deal on one or more of the best alternatives to the final purchasing decision. Lastly, the Expert Choice 2000 AHP implementation we used had integrated sensitivity analysis tools. Easy sensitivity analysis provides a tool to allow rapid interpretation of complicated option, price, and feature concessions that might arise during the negotiation period. This overall process is seen to follow Hogarth's [7] recommended structured problem approach to decision making.

In a DSS tool that does not use a ratio measurement basis, the quantity of outright scoring and computational errors can quickly destroy the model's validity.

The Hospital and the Technology That Were Selected

The hospital in this case is a 500+ bed tertiary care teaching institution in the suburbs of one of the top ten U.S. cities (by population). The hospital was founded in the early 1900s and has succeeded as one of the few successful independent health systems in the region. The hospital enjoys many thriving specialized services, including a large in-vitro fertilization (IVF) program. The hospital has one of the largest obstetrics programs in the area, and in 2000 there were approximately 4,400 deliveries. Of these, there were 425 admissions to the 25-bed neonatal intensive care unit (NICU), which also includes transfers from other area hospitals. The IVF program contributes to the NICU admissions as well, as some of these parents are older, higher-risk couples who have a greater tendency towards high-risk pregnancies. Newborn children at risk are often referred to as *neonates* in the hospital setting, to help distinguish their special physiological condition and needs from more stable babies and children.

Their NICU has a state of the art design, minimizing unnecessary noise, activity, and other stresses to critical and fragile neonates and their families. A wide range of technologies is integrated into the NICU environment, including incubators, bassinettes, phototherapy, infusion pumps, central-station and portable physiological monitors, resuscitators, and specialized neonatal ventilators for infants who are unable to breathe successfully or safely on their own. These technologies require training, knowledgeable use, inspection and maintenance programs, and appropriate supplies and drugs for effective use. Since many of the devices have built-in alarms, a related concern is selecting devices whose alarms work well together so that informational alarms don't mask serious ones and so that the overall noise level is not more intrusive and disruptive than absolutely necessary.

Due to the growing IVF, birthing, and general women's health issues, the hospital has purchased a nearby piece of land to build a new women's health hospital. This facility will provide the opportunity, and the need, to identify the proper technologies for many expanded departments, including the NICU. While some of the existing equipment is likely to be used, some devices are no longer being manufactured. Older, used products might be purchased and refurbished for the new NICU, but the hospital also would like to consider new technologies in order to incorporate new care practices where and when appropriate.

The neonatal ventilator is one critical device that the hospital needed to evaluate, and that became the focus of this AHP investigation. Neonatal ventilators are, in fact, quite unique. The small size of premature babies (as small as 0.5 kg, or about 1 lb, presents many demanding electromechanical requirements. For example, the tiny premature infant's lungs are often incompletely developed and may be quite stiff and fragile. Neonatal ventilators must be able to precisely deliver rapid, tiny puffs of precisely blended air and oxygen. An infant's lungs may only be the size of an adult's small finger, and any over-inflation may result in either rupturing the lungs or blocking the blood that the heart is trying to pump through the lungs. These precise volume control requirements are further complicated by the need to deliver rapid inhalation/exhalation cycles of 100 breaths/min or more. In addition, the neonatal ventilator is called upon to synchronize with the weak inspiratory and expiratory efforts of the infant. The ventilator's sensitivity to the neonate's efforts is sometimes a life-or-death balance; if the ventilator requires too much muscular or metabolic resource for the baby, it may fail to thrive or survive. Lastly, the general physiology, and limited access to the neonate's arteries and veins, sometimes makes it useful to be able to deliver the precisely metered inhaled drugs with the breaths, which requires careful management and control. Some drug regimens are so critical that they cannot be interrupted once initiated without causing serious risk, which adds to the already-tight reliability criteria.

Ventilators that can be used for neonates range in price from around $18,000 to nearly $40,000, and each manufacturer and model has widely differing features. Also, the ventilators have a very significant life-cycle cost of ownership due to supply and maintenance requirements; these can dwarf the initial purchase price. The hospital may need to purchase as many as two dozen or more units for the new NICU. When combined with five-to-ten-year life cycle costs of supplies, maintenance and repairs, the purchasing decision for 24 neonatal ventilators rapidly becomes a million-dollar commitment. In addition, competent clinical and technical training and support is needed for a decade for safe and effective patient care, so the staffing factors are very significant. Because of these investment consequences, the clinical engineering and respiratory therapy departments agreed to participate in an AHP evaluation process to help them make the best selection.

This study was viewed by the hospital as an evaluation of the AHP process itself, too, not just a purchasing technique for neonatal ventilators. The hospital will need to buy many tens of millions of dollars of medical technology for the new hospital. In addition, however, large investments in physical plant, information systems, and other infrastructure will be required. The directors wished to consider the AHP for other parts of the new hospital project. If it proved valuable for the neonatal ventilator selection and did not impose unreasonable learning and application demands, then the AHP process might be recommended for consideration to other departments.

Identification of the Necessary Hospital Staff Expertise for This Project

These senior departments were identified for this project:
1) Respiratory Therapy—provides the routine clinical staffing to support the patients; selects appropriate technology to meet the relevant physicians' requirements (e.g., neonatologists, pulmonologists and cardiologists); also manages the capital and operating budgetary decisions
2) Clinical Engineering—evaluates, installs, inspects, repairs, and maintains the devices; manages device accidents, incidents, recalls, and updates; responsible for meeting safety criteria of local, state and federal agencies.

The director of respiratory therapy (RT), with 26 years of clinical experience and 15 years at the hospital—agreed to be the primary clinical liaison. The clinical engineer (CE), who is the assistant director of the Biomedical Engineering department, had 26 years of experience, including 11 years at the hospital. He had an in-depth technical understanding of a broad range of medical device design and oversaw the daily support of the hospital's complex medical technology inventory. He had access to numerous information sources about devices, and this individual agreed to coordinate the project and to gather resources as necessary.

The expertise of these two team members allowed the ongoing versions of the model to be carefully and thoroughly developed. (Note: less-experienced project leadership in other institutions may necessitate starting with a larger team from the outset.)

Development Stages (Iterations) of the Complete AHP Model

A recent ECRI ventilator evaluation, an ECRI product comparison system ventilator report, and the Ventworld Web site were used to assemble a baseline set of potential criteria for the model [54]–[56]. The author assembled an initial prototype AHP model using Expert Choice 2000, based on these sources of data and his prior clinical engineering experience. This initial AHP model, shown in Figure 3, was then used as a bootstrap model to initiate critical review and discussion with the CE. Five additional meetings with either the CE, RT, or both, lead to the final criteria and weights shown in Figure 4. An illustrated, detailed discussion of the model's iterations is available [57].

Thus, there were six stages of evolution of this AHP model:
1) The CE met with the researchers to learn how to refine the model.
2) The CE put in the remainder of his revisions.
3) The CE and RT reviewed and revised the criteria and hierarchy together, focusing on areas where they shared knowledge.
4) The CE rank ordered all of the criteria and assigned pairwise comparisons.
5) The CE reviewed the model and rearranged some of the rank orders (at this time, the "cost" category was demoted to the least influential one).
6) The RT refined the clinically related pairwise comparisons and approved the model.

Each of the six iterations proceeded quickly, taking between 1.5 and 2.5 h. As the CE and RT became more familiar with the AHP terminology and Expert Choice 2000's features, they were quick to make changes that suited their preferences.

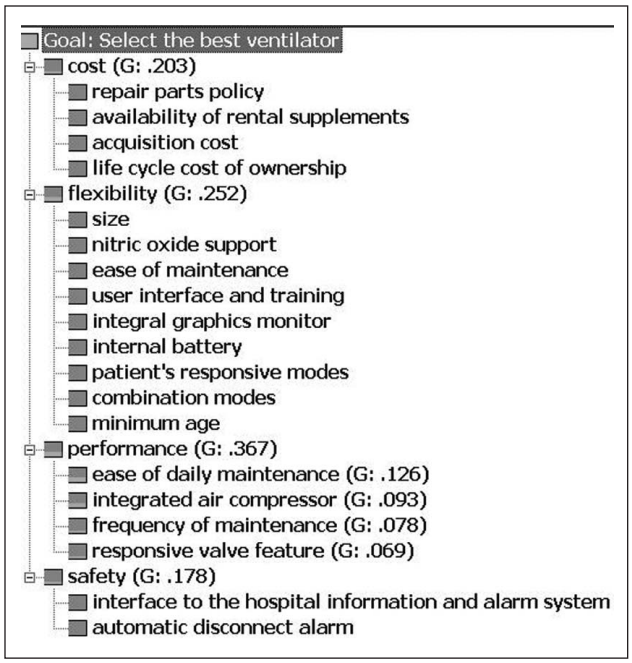

Fig. 3. Iteration 1: The initial bootstrap prototype.

Once the AHP criteria and weights for this HTA were resolved, a slightly different AHP approach was employed to evaluate the performance of the individual neonatal ventilator alternatives for each bottom-level criterion. The AHP offers two major choices for evaluating the alternatives: pairwise comparison of the alternatives for each bottom-level criterion or a ratings approach. The ratings approach differs from pairwise comparison of alternatives in that ratings intensities (i.e., the weight for each rating category) are carefully defined for each criterion, and then the ratings categories can be used instead of repeated pairwise comparisons. After consideration of the relatively large number of bottom-level criteria in the final model (46), and the potential number of alternative neonatal ventilators that could be considered (as many as one dozen or more), pairwise comparing the all of the alternatives over all of the criteria was judged to be too time intensive. Therefore, we decided used the AHP rating system.

The participants created meaningful categories for each criterion to describe the expected performance the alternatives could offer. The weights for the rating categories themselves were created by pairwise comparison, which allowed the directors to assess the relative importance of each rating by using a format they were already quite familiar and comfortable with. To illustrate, the rating categories "multiple," "some," and "few" were selected to describe the available "combination" breathing modes available within the "modes" subcriteria, which was itself within the group of "clinical factors" criteria.

As seen at the top of Figure 5, each of those ratings received a weight of 1.0, .602, and .106, respectively. If each of the alternative devices being considered, Ventilators 1, 2, and 3 were found to have "some," "multiple," and "few" of these modes, respectively, then in the synthesis of Ventilator 1's total performance it would receive 100% of the weight assigned to that criterion. Ventilator 2 and Ventilator 3 would only receive 60.2% and 10.6%, respectively. This clearly illustrates the robust ratio basis foundation of the AHP. Ventilator

1 is the best performer in this criterion, but it can only earn 100% of the weight allocated to that criterion. If all criteria and ratings are accurately weighted and all alternatives are accurately assigned the appropriate rating, then the final score for each alternative will show the proportional advantage or disadvantage between the alternatives.

Operationally, for reliable use in evaluating the alternatives, all of the ratings were arranged so that they were ordered from most preferred rating to least preferred. This simply helped ensure consistency when moving from one criterion to the next because, as known from human factors research, such basic consistency helps prevent mistakes [58].

Fig. 4. Final AHP model following all iterations.

Analysis and Observations

This iterative process allowed the final review and approval of an AHP selection model for the hospital's neonatal ventilators. The process was efficient and often only involved one expert at a time, focusing on that person's area of responsibility. The two participating directors can reapply the pairwise comparison techniques to other HTA tasks.

As might be expected when using an iterative approach, the model's structure did not stabilize into its near-final form until multiple iterations had been completed. The iterative refinement process shows the communication and collaboration value of the AHP in this situation. The hierarchical structure of criteria makes the model easy to understand as it evolves. Both stakeholders found that using the bar and pie charts to interactively display the relative weight for each criterion—as shown in Figures 1(a) and (b)—helped to reinforce their confidence in the results. It helped them decide "yes, that looks about right," or "no, that still looks wrong." This value of iterative refinement of models, enhancement from graphical feedback, and organizational change using modeling is also seen in healthcare and other studies [52], [53].

It is interesting to also note that the cost factors dropped to the lowest group of criteria by the time the model was completed. Several factors contributed to this:

1) Excellent support of high-risk pregnancies is of strategic importance to this hospital. Not only does it support the hospital's perceived leadership role in the community, but it is also a critically important part of the success of valuable programs like IVF.

2) In the hospital's experience, they have generally been able to secure cost-competitive bids from most manufacturers because of the economic pressures in healthcare today.

3) Good risk management strategy reinforced the value of considering safety and performance of the devices ahead of economics.

4) This particular hospital has strong community funding and endowments that enable it to maintain its focus on quality and service despite the economic pressures (e.g., this hospital is one of the few that are building new facilities in the area, even while other hospitals are being closed).

The modest 16% weight this team allocated to cost is much lower than seen in other published models [14], [22], [59]. A more extreme situation was found (0% allocated to cost) in a later hospital study for IV pump selection [30]. Certainly, with the dire economic pressures in healthcare, many hospitals may have little choice but to give cost more weight in their consideration. These two situations may be exceptions, or, it may turn out that in many cases cost cannot, or should not, dominate an HTA if it leads to a mediocre or poor clinical outcome.

Lastly, a brief discussion about handling criteria that ultimately have very little net weight in the final model is worthwhile. For example, in this case the cost of "refurbishing" contributes only 0.4 % of the decision, as seen near the bottom of Figure 4. Technically, practitioners may elect to dismiss such a small criterion as irrelevant to avoid wasting time and effort evaluating the alternatives against those criteria. In healthcare, however, there could be a value in leaving in all categories to ensure that even the most minimally important economic, safety, and clinical factors remain in the model. In a courtroom, the decision to eliminate a feature might even be construed as criminal negligence if it is later asserted that it was willfully dropped because of convenience or greed. In the

group stakeholder decision process, leaving some or all of these otherwise trivial criteria in the model may also prevent revisiting previously negotiated topics. This example shows those small criteria for the sake of completeness. In practice, the clinical engineer may elect to drop them from the final development of rating categories or pairwise comparison of alternatives. It would be wise, however, to first document the consent of all affected stakeholders to avoid problems later.

In this case study, AHP worked well in a hospital setting with the participation of two key knowledgeable stakeholders. The approach developed can be readily applied to a range of well-understood and accepted medical technologies such as medical imaging, laboratory, and surgical devices. Other situations that may require more iterations include:

1) Emerging technologies can have complex and poorly understood characteristics.
2) Inexperienced participants may not have enough expertise to quickly or accurately identify, organize, or weigh the important criteria.
3) Larger numbers of stakeholders may cause longer and more complicated debates about criterion, hierarchical structure, weights, and alternatives being considered.
4) Interdependent technologies and/or criterion will require very careful analysis to find ways to separate them, or the AHP model may need to be supplemented with additional DSS tools that can deal with the interdependencies.

The AHP process does not replace other health technology selection aids such as ECRI's Health Devices evaluations, government and academic HTA's, or NPV analysis. The AHP is an integrative tool that should be used to accurately evaluate all available information within the context of the individual hospital's specific needs. The AHP should be attractive to clinical engineers because it helps bring order, documentation, and collaboration to the HTA process.

Opportunities for Future Research and Applications

The study is limited in that only a single medical technology was evaluated. There are many additional questions that healthcare experts are addressing that have much broader criteria to consider. Many of the decisions in healthcare span a much larger collection of clinical, technical, economic, cultural, and legal disciplines than addressed in this study. For example, emerging genomic-engineered drug decisions are likely to be much more complicated than device selection.

Such complex analyses may also move the focus of discussion to macroeconomic health technology assessment. These projects will confront the further complexities of defining, organizing, and effectively measuring and representing trade-offs such as risks, reliability of available scientific evidence, legal and ethical ramifications, and similarly complex and important criteria. Although the precision and structure of the AHP process is an important strength, using it demands competent expertise and the willingness and ability to make concrete decisions out of what may be uncertain or vague knowledge. In principal, though, the AHP should be a viable DSS tool for macroeconomic HTA for emerging technologies.

Another level of complexity occurs at the regional, national, and international health-system levels. One important consideration at the international level is that cultural and political collaboration, negotiation, and consensus styles vary substantially [60]–[62]. An open and documented DSS like the AHP

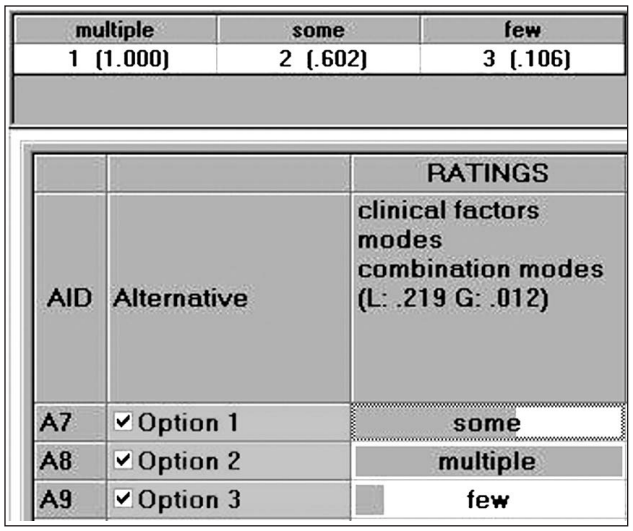

Fig. 5. Rating categories ("multiple," "some," "few"); their respective weights for the criterion ("clinical factors," "modes," "combination modes"); and the user's perceived performance of Option 1, Option 2, and Option 3.

may not be easily sustainable in cultures where saving face or assertion of total control dominates. Because ethical and economic value systems may vary considerably, health technologies that are used in integrated economies like the European Union it may prove very difficult to create acceptable universal models. "Harm reduction" programs that aim to reduce HIV and hepatitis by distributing clean needles and syringes, condoms and other birth control technologies, and the emergent challenge of access and distribution of AIDS drugs in Africa are some worthy examples to consider.

Future studies could consider examining the following AHP health technology applications:

1) How can this model be adapted to support selection of complex, interconnected, or hybrid medical technologies in which the configurations are highly customized?
2) Can this model be extended to allow effective trade-off decisions when limited funding forces choosing to purchase only a one or two new technologies? (For example, should new neonatal ventilators be purchased this budget year or should a new cardiac surgical suite be built?)
3) Do other hospitals, health systems, or health delivery paradigms such as home care make similar decisions using similar criteria, or are there significant differences? (Can generic boilerplate models be developed to support medical technology acquisitions?)
4) How do the U.S. selection criteria compare with countries that have nationalized medical care (e.g., Canada, the U.K., or Germany), or developing countries (e.g., Nepal, Romania, or Kenya)?
5) Can the AHP assist in the complex decisions underlying actual health technology trade-off decisions? [For example, should a hospital (or country) select stem-cell therapy, surgery, drugs, radiation, or some combination of these to treat breast cancer?]
6) Should a hospital buy, lease, or rent a specific health technology? The economic trade-offs vary, as do the benefits and risks of long-term ownership.
7) Can and should the criteria with very little weight (e.g., less than 1%) be eliminated? Under what circumstances

would the stakeholders accept this simplification? In the current medico-legal climate, could elimination of such factors be construed as willful negligence, for which criminal and civil penalties might apply?

These and other health technology assessment questions should benefit from the organization, consensus-building, and rational analytic capabilities of the AHP. The potential value, efficiency, and effectiveness of the AHP in addressing these important health technology assessment issues should be carefully compared to existing practices and methodologies. Few such tools are currently being applied, which leaves this important field vulnerable to arbitrary, incomplete, or biased decision making. The AHP tool affords a clear communication and project organization structure, and the software implementation used in this study makes the results easy to understand and discuss.

Conclusion

This article describes just a single healthcare application of one of a wide range of tools and techniques that are researched and taught in business schools throughout the world. Such techniques have been very well developed in the fields of economics, management, management information systems (MIS), marketing, and OR/OM. Such tools have already been adopted in many other industries by market leaders like American Express, Dell, Disney, General Electric, Procter and Gamble, Siemens, Wal-Mart, and many others.

This article illustrates the application of a specific example of a single tool, DSS. This author has found that many business tools and techniques appear quite relevant—and potentially very important—for the healthcare field. The following brief list of sources illustrates several such topics that may be considered for adaptation to the pressing needs in healthcare. Each item also shows a likely department in a business school where research expertise is likely to be found. Business schools differ greatly, though, and these subjects may be taught in more than a single department:

1) diversity and ethics in leadership (Management Department): principled leadership, human resources, recruitment and retention, and team building
2) eBusiness (MIS Department): including business process-oriented implementation of standard software, customer relationship management, collaborative and peer-to-peer technologies, data mining, data warehousing, DSS, enterprise research management, knowledge management, supply chain management, systems analysis, and total cost of ownership
3) forecasting (Marketing and Economics Departments): data mining and forecasting of consumer demand and manufacturing capacity
4) process optimization (OR/OM Department): DSS, linear programming, statistical process control, project management, quality function deployment, six-sigma design and manufacturing, and systems theory.

There is a well-documented global need for improving the efficacy, efficiency, quality, and safety of healthcare. This should provide ample reason, and opportunity, for biomedical and clinical engineers to seek ways to learn to deploy these tools and techniques throughout the healthcare field. Few business school researchers understand the medical field, but it has been encouraging to see how often they can quickly identify and apply their portfolio of well-documented tools and techniques once they understand a healthcare problem.

Acknowledgments

I would like to acknowledge and thank my colleagues at the Villanova University College of Commerce and Finance and the Department of Decision and Information Technologies for their tireless support and commitment. They have provided invaluable insight, guidance, and time from their own very extensive and busy research and teaching activities. Their generous help has allowed me to begin to adapt their expertise and portfolio of tools and techniques from many other industries for clinical engineers and others to use in the improvement of healthcare.

Elliot B. Sloane received his B.S.E. from Cornell University College of Engineering in Ithaca, New York in 1975, with a dual concentration in electrical and biomedical engineering. He also earned two graduate degrees from Drexel University in Philadelphia, Pennsylvania: in 1982 he received an M.S.E.E., majoring in digital electronics and computer systems engineering, and in 1999 he completed his Ph.D., majoring in information sciences and information technology. His doctoral dissertation and research were in the area of computer display, domain expert relevance judgment, and human visual cognition.

From 1975 through 1990, he practiced as a biomedical, clinical, and computer systems engineer as a vice president of ECRI. From 1990 through 2000, he was vice president at MEDIQ/PRN, responsible for nationwide clinical engineering, quality assurance, and medical device and drug regulatory and manufacturing activities. He entered academia in 2000, and is on the Decision and Information Technology faculty at Villanova University in Villanova, Pennsylvania. As a volunteer consultant and faculty member for American College of Clinical Engineering (ACCE), ECRI, MEDIQ, the WHO and PAHO, and Carelift International, he has provided healthcare technology management training and support in Brazil, Bulgaria, Cuba, Dominica Mexico, Moldova, Mongolia, Nepal, Romania, and Slovakia. He has published in the Clinical Engineering and Decision Support literature and the *Handbook of Clinical Engineering*, and he presents papers annually at AAMI, AMCIS, DSI, IEEE Engineering in Medicine and Biology Society, and HIMSS annual conferences. Current research interests include clinical DSSs, biomedical informatics and health systems engineering, and integration of heterogeneous medical information databases and systems.

Dr. Sloane was president of the ACCE in 2001–2002 and serves as the ACCE liaison to IEEE and the HIMSS/RSNA Integrating the Healthcare (IT) Enterprise Strategic Development Committee. He is also on the board of two computer industry professional societies, AITP and the CIO Forum. He is a 2004–2007 At-Large Board Member in the IEEE EMBS), has served as EMBS Annual Conference 2003 and 2004 track co-chair, and is chair of the EMBS Clinical Engineering Liaison Committee. (Note: The Expert Choice 2000 AHP data files for this and similar HTA applications may be obtained directly from the author by e-mail at no charge.)

Address for Correspondence: Dr. Elliot B. Sloane, Villanova University, 800 Lancaster Avenue, Villanova, PA 19085 USA. Phone: +1 610 519 6432. Fax: +1 610 519 5015. E-mail: ebsloane@ieee.org.

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