Attribute Importance in Supply of Aeromedical Service

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Multiattribute utility theory is used to investigate a supplier's value of offering aeromedical service. Using joint probability functions over net revenue, publicity, and medical benefit dimensions to capture the operating performance of the service and a multiattribute utility function with random parameters to capture the supplier's preferences, it is found that providing service is preferred to shutting down the program for all of the 1,000 sets of utility parameters generated. Using the analysis developed, however, it is evident that no one dimension is sufficient to justify service when the cost of providing the service is considered. The revenue dimension comes closest, but the roughly 50 percent chance of suffering financial losses and the strong aversion to these losses lead to the conclusion that revenues alone are not sufficient to continue operations. When using the analysis to look at pairs of dimensions, it appears that the revenue-medical benefit pair is sufficient to justify service for fewer than half of the 1,000 sets of utility parameters and that the publicity dimension is extremely important in motivating the supplier to provide service. The results are interpreted to form a working hypothesis that suppliers must either believe that flying emergency missions provides important publicity value to the sponsoring hospitals or be ensured of better financial security if they are to continue to provide this emergency medical service.

The number of aeromedical programs has been increasing since after the Korean War; in 1989 there were 200 programs in the United States (*1*). Aeromedical programs receive requests for immediate service, and aircraft fly medical crews from bases (usually hospitals or airports) to patients at accident scenes or, more frequently, at outlying hospitals with inadequate medical facilities. The patients are then secured in the aircraft and flown to hospitals in larger cities. Emergency care is provided by the medical flight team on the return flight, and speed in reaching the patients and flying them to the destination hospital is critical.

According to a recent study, Columbus, Ohio, ranked in the top five U.S. cities in terms of numbers of requests for emergency aeromedical service (*2*, p.12). Two helicopter-based programs serve this area: Skymed, which is a consortium of the Ohio State University hospitals and Children's Hospital in Columbus, and Lifeflight, an older program based at Grant Hospital in Columbus. These programs simultaneously compete and cooperate. They compete for "discretionary" patients who will be flown to the university hospitals if Skymed transports them and to Grant Hospital if Lifeflight transports them. In times when hospitals are competing for patients to generate the associated revenues, having access to these discretionary patients is thought to be important. The programs cooperate in that some patients must go to specific hospitals (e.g., burn patients are treated almost exclusively at university hospitals), and the program contacted first will transport such patients to the necessary hospital, even if it is the sponsoring hospital of the other program. In return, the transporting program receives only the flight revenues collected, which are generally small compared with the net inpatient revenue. The environment is also cooperative in that if one program receives a request that it cannot serve because its helicopters are flying other missions, it turns the request over to the competing program.

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The authors have presented a multiobjective analysis designed to help the director of Skymed determine the desirability of leasing additional helicopters to expand the fleet size of his program (*3*). Currently, Skymed operates one helicopter 24 hr/day. The results of the analysis, which was based on multiattribute utility theory (*4–6*), showed that expansion of fleet size was warranted, according to the primary dimensions of performance supplied: net revenues, publicity to the sponsoring hospitals, and medical benefits. Some novel features developed there showed, however, that the increased value associated with these performance dimensions was small enough that less technical aspects might govern the ultimate decision, and we could not argue strongly for expansion from one full-time helicopter.

In this paper, we look more closely at the individual performance dimensions in the context of deciding whether to supply aeromedical service or not. Later, it is shown that the probability distributions over the multicommodity bundles of revenues, publicity, and medical benefits are such that existing service is preferred to the distribution associated with shutting down the program. Then it is asked whether any one of the dimensions taken by itself is enough to offset the costs associated with supplying service; the answer is no. It is seen that, although the medical benefits are considered important, neither the medical-revenue pair nor the medical-publicity pair can justify service when the costs of producing these benefits are considered. The implication is that cost recovery and publicity are critical to providing service.

To make the exposition easier, we shall sometimes talk about the results as if they are general, but we recognize that they are based on one helicopter program. They are also based on the preferences of one individual (the executive director), who, in a slightly different application, was faced with preparing an analysis for the true decision makers of the problem. Nevertheless, as we shall argue, these results can serve as a benchmark for, if not a representative sample of, the industry, and we discuss the implications of our findings there. Before presenting the new study, however, we review the data on which it is based.

EVALUATION MODEL

The evaluation model is the expected utility model (*3,4,6,7*). In this procedure the analyst first determines a multiattribute vector $\mathbf{Y} = (Y_1, Y_2, \ldots, Y_n)$ of the important measures or outcomes by which the alternatives are to be evaluated. A utility function $U(\mathbf{Y})$ is constructed which maps $\mathbf{Y}$-vectors into real numbers between 0 and 1 representing preferences on an interval scale. Then, each alternative Xi is mapped into a probability mass function $P(\mathbf{Y}/Xi)$. (Although using continuous probability density functions is completely analogous, we use a discrete approximation to these functions to simplify exposition.) This gives the probabilities that the different combinations of $\mathbf{Y}$-vectors will result if alternative Xi is implemented. Valuation, then, is over the probability distribution $P(\mathbf{Y}/Xi)$, and the axioms of the theory imply that the distribution should be valued according to the mathematical expectation of the utilities of the attribute vectors. Letting EU_i represent this expected utility valuation associated with alternative Xi, we have

$$EU_i = \sum_{\text{all } j} p[\mathbf{Y}(j)/Xi] * U[\mathbf{Y}(j)] \quad (1)$$

where the sum is taken over all possible attribute vectors j, given that alternative Xi is implemented, and $p[\mathbf{Y}(j)/Xi]$ is the probability that vector $\mathbf{Y}(j)$ obtains when Xi is implemented. This approach is arguably the most popular for multiattribute evaluation when uncertainties are present because of the behaviorally appealing assumptions on which it is based, the consistency with the assumptions of the methods designed to obtain probability and utility functions, and the use of performing the expectation operation in Equation 1 and determining the functions (*4–7*).

The attribute vector $\mathbf{Y}$ was determined, and the probability distributions $P(\mathbf{Y}/X)$ and utility functions $U(\mathbf{Y})$ were estimated for a study to assist Skymed in evaluating the desirability of adding helicopters to its fleet (*3*). We will briefly review the aspects that will be needed for the present study.

Attribute Vector

We had several discussions with the executive director of Skymed and reviewed the aeromedical literature over the course of several months while defining the problem and developing analytical models. During this time we iterated several times on the definition of our attribute vector $\mathbf{Y}$. We eventually decided that although there were other considerations to the problem of deciding whether to add helicopters to the fleet (such as public perceptions and availability of funds in hospital programs), aeromedical operations primarily offer three types of benefit: (a) they produce revenues, from the flight charges and from the inpatient bills collected after treating a patient flown to the sponsoring hospital; (b) they offer publicity to the sponsoring hospital, which is important in times when there are empty beds and hospitals compete for patients; and (c) they provide medical benefits to the public by saving lives and decreasing morbidity. We also had to acknowledge that, since Lifeflight offers service in the area and since certain types of patients (e.g., burn patients) are flown to university hospitals even if Lifeflight transports them, some of the inpatient revenues associated with missions flown by Skymed would have been collected even if Skymed did not exist. Similarly, some of the medical benefits achieved by Skymed's transporting a patient would be achieved if Skymed shut down and the patients could be flown by Lifeflight. We handled these considerations by defining these attributes as the extra levels offered, where "extra" was taken to mean the amount of the attribute that would be generated if Skymed were to operate with a given number of helicopters in its fleet, minus that which would be generated if Skymed were to offer no service. On the other hand, the publicity associated with Skymed's operations would not be generated if Skymed did not operate, and we did not have to worry about the extra contribution in this case.

The costs associated with operations were primarily financial; they included the overhead costs of running the program, the fixed costs of leasing and staffing the helicopters, and the variable costs associated with flying the helicopter. They all would be avoided if Skymed did not exist and could, therefore, be subtracted from the extra gross revenues produced to form the extra net revenue generated. After many iterations, we decided that the number of patients flown by Skymed would serve as the best proxy variable to quantify the publicity dimension. We based our quantification of medical benefits in large part on pragmatic considerations of data availability. From an empirical study (*8*), we modeled the probability of helicopter transportation as being "essential" to a random helicopter patient's favorable outcome (probability .16), "helpful" to a random helicopter patient's favorable outcome (probability .10), or not contributing to the health state of a random helicopter patient (probability .74). From the descriptions of the categories (*8*) and discussions with the program director, we modeled the "essential" category as one in which the patient's life was saved because of the helicopter transport and the "helpful" category as one in which the patient would not have died without the transport but would have avoided a very bad outcome, such as losing a limb. We therefore quantified the medical attribute as a two-dimensional vector consisting of "extra lives saved" and "extra limbs saved."

In summary, then, our attribute vector $\mathbf{Y}$ was

$$\mathbf{Y} = [Y_1, Y_2, (Y_{3a}, Y_{3b})] \quad (2)$$

where

Y_1 = extra net revenue to the university hospitals generated from Skymed's operations,
Y_2 = number of patients carried by Skymed,
Y_{3a} = extra number of lives saved from Skymed's operations, and
Y_{3b} = extra number of debilitating injuries, such as losing a limb, avoided because of Skymed's operations.

Utility Function

We used the standard multiplicative utility function (*4,6*) to model preferences (*3*). Actually, as described there, we were helping the executive director synthesize the merits of the various expansion alternatives so that he could argue these

alternatives to the ultimate decision-making board. Therefore, he had to put himself in his boss's position when thinking through the preferences. Although he had no difficulty in doing this, the utility functions described in this section were elicited not from the decision makers directly responsible for the supply of service, but from their proxy. We believe these functions to be good first-order estimates of the ultimate decision-making board's preferences, however, especially because we model the parameters of these distributions as random variables. The multiplicative utility function $U_{\mathbf{Y}}$ can be written

$$\begin{aligned} U_{\mathbf{Y}}[Y_1, Y_2, (Y_{3a}, Y_{3b})] &= k_1u_1 + k_2u_2 + k_3u_3 \\ &+ K(k_1k_2u_1u_2 + k_1k_3u_1u_3 \\ &+ k_2k_3u_2u_3) + K^2k_1k_2k_3u_1u_2u_3 \end{aligned} \quad (3)$$

where

u_1, u_2, u_3 = unidimensional utilities associated with attribute levels $Y_1 = y_1$, $Y_2 = y_2$, and ($Y_{3a} = y_{3a}$, $Y_{3b} = y_{3b}$, respectively [i.e., $u_1 = u_1(y_1)$, $u_2 = u_2(y_2)$, $u_3 = u_3(y_{3a}, y_{3b})$];

k_1, k_2, k_3 = scaling constants, or "weights," of the financial, publicity, and medical dimensions, respectively; and

K = overall constant that ensures compatibility of the scales of individual dimensions with the multidimensional scale.

This multiplicative form can be shown to follow from certain properties of preferences, which appear to hold in many cases (*4,9*) and were shown to hold in our problem (*3*).

The utility function over the medical dimension u_3 was itself a two-attribute additive function:

$$u_3(y_{3a}, y_{3b}) = k_a u_a(y_{3a}) + (1 - k_a)u_b(y_{3b}) \quad (4)$$

This additive function is a special case of the multiplicative function, and follows from testable behavioral properties (*4,6*) that were found to hold in our problem (*3*).

The unidimensional utility functions $u_i(y_i)$ are scaled so that the least and most preferred attribute levels considered—call them y_i^l and y_i^m, respectively—have utilities 0.0 and 1.0 (i.e., $u_i(y_i^l) = 0.0$; $u_i(y_i^m) = 1.0$; $i = 1, 2, 3a, 3b$). Given this scaling, one can see from Equations 3 and 4 that $u_{\mathbf{Y}}[y_1^m, y_2^l, (y_{3a}^l, y_{3b}^l)] = k_1$; $u_{\mathbf{Y}}[y_1^l, y_2^m, (y_{3a}^l, y_{3b}^l)] = k_2$; $u_{\mathbf{Y}}[y_1^l, y_2^l, (y_{3a}^m, y_{3b}^m)] = k_3$; and from Equation 4 that $u_3(y_{3a}^m, y_{3b}^l) = k_a$. That is, the scaling constant k_i represents the utility of the multiattribute vector $\mathbf{Y}$, when all attributes are at their least preferred levels, except attribute Yi, which is at its most preferred level. In this way, the scaling constants have a meaning consistent with the underlying theory, and this interpretation leads to operational ways of determining these values (*3,4*).

The single-attribute utility functions can also be determined from methods compatible with the underlying expected utility theory (*4,6,7*). We approximated the functions with the following specifications (*3*):

$$u_1(y_1) = a_1\left[\frac{y_1 + 6(10^6)}{6(10^6)}\right]^{b_1} \qquad -6(10^6) < y_1 \le 0 \quad (5)$$

$$a_1 \qquad y_1 = 0 \quad (6)$$

$$a_1 + \frac{(1 - a_1)}{9(10^6)}y_1 \qquad 0 \le y_1 \le 9(10^6) \quad (7)$$

with

$$b_1 > 1.0 \quad (8)$$

$$0.7 < a_1 < 1.0 \quad (9)$$

$$u_2(y_2) = \left(\frac{y_2}{3{,}500}\right)^{b_2} \qquad 0 \le y_2 \le 3{,}500 \quad (10)$$

with

$$0 < b_2 < 1 \quad (11)$$

$$u_a(y_{3a}) = \frac{y_{3a}}{500} \qquad 0 \le y_{3a} \le 500 \quad (12)$$

$$u_b(y_{3b}) = \frac{y_{3b}}{300} \qquad 0 \le y_{3b} \le 300 \quad (13)$$

Because we had to determine least and most preferred levels for the attributes before completing our estimations of the probability mass functions, and because we wanted to allow for other options than those considered before (*3*), the least preferred level for the financial attribute [$-6(10^6)$\$] was lower than necessary, and the most preferred levels for the financial attribute [$+9(10^6)$\$], the publicity attribute (3,500 patients carried), and the medical subattributes (500 lives and 300 limbs saved) were higher than necessary. These "loose bounds" pose no problem, however, because the value of the scaling parameters k_i will vary with ranges of attributes used. This dependence on the attribute range is one reason that the scaling constants cannot be used by themselves to indicate attribute importance (*6*). (The least preferred levels of y_2, y_{3a}, and y_{3b} had natural levels of 0.)

The functional forms and constraints on the parameters also represented behavioral properties worthy of mention. The parameter a_1 represents the utility of breaking even in net revenue—that is, $U_1(0) = a_1$—relative to the utilities of \$6 million and +\$9 million. Constraint 9 represents that breaking even is extremely important. When it is combined with Constraints 5 through 8, one can see a strong decrease in marginal utility du_1/dy_1 once the break-even point is reached. Similarly, the convexity of u_1 in the net losses domain ($d^2u_1/dy_1^2 > 0$ for $y_1 < 0$) represents the increased importance of getting to zero, and the linearity in the net gains domain ($d^2u_1/dy_1^2 = 0$ for $y_1 > 0$) represents the constant marginal utility associated with increased revenues once the operation breaks even. These conditions came out of our general discussions of the relative value for revenues and were reflected in detailed and carefully designed utility assessments (*3*).

In determining the utility function for publicity, as quantified by the number of patients carried, we were careful to emphasize that the revenues and medical benefits were held constant, so that these indirect impacts of patients carried were not being valued in this function. Considering Equations 10 and

11, one notices decreasing marginal utility ($d^2u_2/dy_2^2 < 0$) for the number of patients carried, because this attribute contributes to the publicity dimension.

The linear utility functions ($d^2u_{3a}/dy_{3a}^2 = 0$) for lives saved represents that saving an extra life when 499 people, for example, have already been saved is just as important as when no one has been saved, and similarly for limbs saved. As described earlier (*3*), we were careful to frame the utility question to concentrate on medical benefits to the general public and to avoid valuing here the positive publicity associated with saving lives or limbs.

Once the values of the utility parameters are given, the utility functions are completely specified. We summarize these parameters as a vector $\Theta = [a_1, b_1, b_2, k_1, k_2, k_3, k_a, K]$. From the literature (*10–14*) and extensive experience with preference modeling, we knew we could not get exact values for these parameters. We therefore used a variety of methods to determine bounds on the parameter values and modeled a_1, b_2, k_1, k_2, k_3, and k_a as being random variables from a triangular distribution. That is, denoting any of these parameters by Θ_i, the lower and upper bounds of the distributions by LB_i and UB_i, respectively, and the mode of the distribution by $\hat{\Theta}_i$, we had

$$f_{\Theta i}(\Theta_i) = 0 \qquad \Theta_i < \text{LB}_i$$

$$\frac{2(\Theta_i - \text{LB}_i)}{(\text{UB}_i - \text{LB}_i)(\hat{\Theta}_i - \text{LB}_i)'} \qquad \text{LB}_i \le \Theta_i \le \hat{\Theta}_i$$

$$\frac{2(\text{UB}_i - \Theta_i)}{(\text{UB}_i - \text{LB}_i)(\text{UB}_i - \hat{\Theta}_i)'} \qquad \hat{\Theta}_i \le \Theta_i \le \text{UB}_i$$

$$0 \qquad \Theta_i > \text{UB}_i \tag{14}$$

where $f(.)$ represents the probability density of obtaining level Θ_i. We did not model b_1 as random, since the relative shape of the utility function in the net losses dimension would depend on a_1, which was modeled as a random variable. Also, the overall scaling constant K is determined from the values of the individual scaling constants k_1, k_2, k_3 (*4,6*) and did not need to be modeled explicitly. The parameter values of the distributions are given in Table 1.

TABLE 1 Parameter Value of Probability Distributions for Utility Function Parameters

Utility Function Parameter	Description	Lower Bound LB	Upper Bound UB	Mode $\hat{\theta}$
a_1	Unidimensional Utility of 0$	0.70	0.95	0.83
b_1	Exponent of Unidimensional Utility of Revenue Losses	Assumed	Deterministic	1.60
b_2	Exponent of Unidimensional Utility of Publicity Attribute	0.10	1.00	0.60
k_1	Scaling Parameter of Financial Attribute	0.43	0.81	0.68
k_2	Scaling Parameter of Publicity Attribute	0.04	0.43	0.20
k_3	Scaling Parameter of Medical Attribute	0.00	k_2	0.14
k_a	Scaling Parameter of Lives Saved Sub-Attribute	0.50	1.00	0.70
K	Overall Scaling Parameter for Multiplicative Function	Deterministic Function of k_1, k_2, k_3		-0.08

Probability Distribution

The probability mass functions $P(\mathbf{Y}/X)$ were obtained from Monte Carlo simulation and a series of stochastic models. Specifically, we encoded the director's subjective probability distributions (*15*) for the number of requests his program would receive in the upcoming year, conditional on the number of helicopters in the fleet. We then used Monte Carlo simulations to combine this distribution with a simulation model that we developed (*16*) to model the number of requests that could be serviced with given program configurations. This produced the density function for the number of patients carried—that is, Y_2—if Skymed were to operate X helicopters in the upcoming year.

We then simulated observations from this Y_2-distribution and input each observation into a stochastic model predicting extra net revenue (Y_1) and another stochastic model predicting the number of extra lives saved (Y_{3a}) and extra limbs saved (Y_{3b}). In determining the extra contributions, both models considered that some of the Y_2 (patients carried) would have been carried by Lifeflight had Skymed shut down. The revenue model also had to consider the likelihood that some of the patients that Lifeflight would have carried would have gone to university hospitals for the special treatments offered and some would be discretionary patients, going to the sponsoring hospital of the aeromedical program providing the transport. Once the appropriate number of extra patients was determined, revenues were determined from a stochastic model on the basis of past revenues and costs generated, and the number of lives and limbs saved was determined on the basis of probabilities given by Urdaneta et al. (*8*).

The specific numbers output from the revenue and medical models were then coupled with the specific Y_2-value input to them to form an "observed" attribute vector $[y_1, y_2, (y_{3a}, y_{3b})]$. We repeated this process 1,000 times, forming 1,000 $\mathbf{Y}(j) = [y_1(j), y_2(j), y_{3a}(j), y_{3b}(j)]$ vectors, $j = 1, 2, \ldots, 1{,}000$. Assigning probabilities of .001 to each of these vectors formed $P(\mathbf{Y}/X)$ for X helicopters. The attribute levels in the joint distribution are probabilistically dependent, since the values of Y_1, Y_{3a}, and Y_{3b} depend on the value of Y_2 input, but the marginal distributions can be formed. We present the 0.25, 0.50, and 0.75 percentile values of the cumulative marginal distributions for $X = 1.0$ in Table 2.

If the program were to shut down, the attribute vector would be $\mathbf{Y} = [0,0,(0,0)]$ with certainty, by definition of the attributes. This vector, therefore, characterized the probability distribution of offering no service.

TABLE 2 Quartile Values of Attribute Marginal Cumulative Density Functions

Attribute Y_i	Units	$F_{Y_i}^{-1}(0.25)$	$F_{Y_i}^{-1}(0.50)$	$F_{Y_i}^{-1}(0.75)$
Y_1: Extra Net Revenue	$\$10^6$	-0.20	+0.20	+0.40
Y_2: Patients Carried	people	850	1050	1100
Y_{3a}: Extra Lives Saved	people	55	75	95
Y_{3b}: Extra Limbs Saved	people	30	50	70

ATTRIBUTE IMPORTANCE

The model reviewed can be used to compare the supplier's value of the multicommodity (i.e., net revenue, publicity, medical) bundle offered by operating one helicopter in the upcoming year to his value of the multicommodity bundle offered if the program were to shut down. By operating one helicopter ($X = 1$), Skymed would produce more publicity and medical benefits than if it were to shut down ($X = 0$), but it would incur fixed and operating costs that could be avoided. Moreover, operating the program with one helicopter would generate important revenues (as long as insurance companies are willing to reimburse charges for a large enough percentage of the patients transported), but it is not obvious that these revenues would offset the costs.

To determine the value of operating one helicopter in the upcoming year, we use Equation 1 with the 1,000 $\mathbf{Y}(j) = [y_1(j), y_2(j), y_{3a}(j), y_{3b}(j)]$ vectors (each occurring with probability .001) and calculate the expected utility, which we call $EU(\mathbf{Y})$:

$$EU(\mathbf{Y}) = \sum_{j=1}^{1,000} 0.001 * U[y_1(j), y_2(j), y_{3a}(j), y_{3b}(j)] \tag{15}$$

The utility function U, given by Equations 3–7, 10, 12, and 13, depends on the vector of parameters $\boldsymbol{\Theta}$. (We do not explicitly write the dependence on $\boldsymbol{\Theta}$ to simplify the notation). Using the modes of the parameter distributions (i.e., $\hat{\Theta}_i$) from Table 1 as our best-guess estimates, which can be thought of as point estimates, we obtain $EU(\mathbf{Y}) = 0.65$.

The expected utility associated with shutting down (providing no service) is just $U[0,0,(0,0)]$, since $\mathbf{Y} = [0,0,(0,0)]$ would occur with certainty. Using the utility equations 3–7, 10, 12, and 13, we see that this expected utility is k_1a_1. Different $\boldsymbol{\Theta}$s give different k_1s and a_1s and, therefore, different expected utilities of the shut-down alternative. Using the best-guess $\hat{\Theta}_i$s gives $0.68 * 0.83 = 0.56$. This is less than value of $EU[\mathbf{Y}]$ determined above, meaning that when the best-guess estimates were used for the utility parameters, the multicommodity bundle associated with operating one helicopter is better than that associated with shutting down. That is, the program sees positive value in providing service.

To acknowledge the difficulties associated with determining the utility parameters $\boldsymbol{\Theta}$, we generated 1,000 observations from the distributions of the Θ_i parameters given in Equation 14, and Table 1, as described before (*3*). For each generated value we calculated the difference between the expected utility associated with operating one helicopter $EU[\mathbf{Y}]$ and that associated with operating no helicopters $EU[\mathbf{0}](= k_1a_1)$. We then had one $EU[\mathbf{Y}] - EU[\mathbf{0}]$ value for each of the 1,000 generated Θ-vectors. We present the distribution of these values for the first time in Figure 1. Note that all of the observations are positive, indicating that for all of the utility parameter vectors $\boldsymbol{\Theta}$, $EU[\mathbf{Y}] > EU[\mathbf{0}]$, and it would be better to operate one helicopter than to discontinue service.

Single-Attribute Analysis

Although the analysis shows that offering service is preferred to shutting down when considering the revenue, publicity,

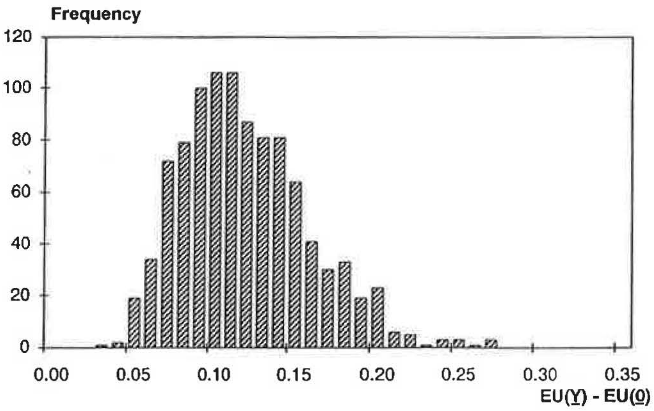

FIGURE 1 Distribution of [Y] − *EU*[0] values across 1,000 Θ-vectors.

and medical benefits together, we are interested here in determining whether any single attribute could justify providing service when the costs of providing this service are included. The fixed costs associated with operating one helicopter (*3*) are $1.75(10^6)$. The variable costs depend on the number of hours flown, and from the performance characteristics, we found that, conditional on flying y_2 patients, they could be approximated as a deterministic \$$735y_2$ (*3*). Therefore, the cost $[c(j)]$ of providing the service associated with attribute vector $\mathbf{Y}(j)$ in the probability mass function is

$$c(j) = 1.75(10^6) + 735y_2(j) \tag{16}$$

To determine the value of the individual service benefits provided by operating one helicopter, we first define the following:

$$EU[Y_1] = \sum_{j=i}^{1,000} 0.001 * U[y_1(j), 0, (0,0)] \tag{17}$$

$$EU[Y_2] = \sum_{j=i}^{1,000} 0.001 * U[-c(j), y_2(j), (0,0)] \tag{18}$$

$$EU[Y_3] = \sum_{j=i}^{1,000} 0.001 * U\{-c(j), 0, [y_{3a}(j), y_{3b}(j)]\} \tag{19}$$

$EU[Y_1]$ gives the expected utility of the revenues, combined with the costs (to form the net revenues y_1), generated from operating one helicopter, when there are no publicity or medical benefits (i.e., they are zeroed out). $EU[Y_2]$ gives the expected utility of the publicity, combined with the costs required to generate this publicity, when the revenues and medical benefits are zeroed out. $EU[Y_3]$ gives the expected utility of the medical benefits, combined with the costs required to generate these benefits, when the revenues and publicity benefits are zeroed out. That is, we consider the value of the individual attributes—revenues generated, publicity, medical benefits—along with the cost to produce them—by setting the other attributes to their alternative shut down levels. Given a vector of utility parameters $\boldsymbol{\Theta}$, it is straightforward to use our utility specifications to calculate these values.

To determine whether the attribute i is alone sufficient to justify service, we substituted $EU[\mathbf{0}]$ from $EU[Y_i]$ (both being

calculated with the same vector of utility parameters Θ_i). Because the utility function is internally scaled (*4,6,11*), the magnitude of the difference $EU[Y_i] - EU[\mathbf{0}]$ would be fixed up to the scaling imposed by $U[-6(10^6), 0, (0,0)] = 0$ and $U[+9(10^6), 3{,}500, 500, 300] = 1$ (*3*). These "dummy" vectors are not very meaningful, however (*17*). We therefore scaled the difference by $EU[Y_i] - EU[\mathbf{0}]$ to form RM_i:

$$RM_i = \frac{EU[Y_i] - EU[\mathbf{0}]}{EU[Y] - EU[\mathbf{0}]} \tag{20}$$

Because $EU[\mathbf{Y}] - EU[\mathbf{0}]$ is always positive (see Figure 1), the sign of RM_i would indicate whether the distribution of obtaining attribute i taken by itself (but considering the cost of obtaining the distribution) when providing service is better ($RM > 0$) or worse ($RM < 0$) than providing no service. The magnitudes of positive RM_is indicate how much (or little) of the increased value (expected utility) associated with the full set of attributes is obtained when only attribute i is considered, where the increased value is considered to be that above the value that would be obtained by providing no service. The magnitudes of negative RM_is give a feel for how far the value associated with attribute i falls short of the shut-down alternative, where the scale is again the increased value associated with operating one helicopter.

The distributions across the 1,000 Θs (Figure 2 and Table 3) show that RM_1, RM_2, and RM_3 overwhelmingly tend to be negative. That is, if considering any of the individual attributes in isolation, the preference would be to provide no service. This means that direct revenues are not sufficient ($RM_1 < 0$) to provide service. Moreover, the publicity or the medical benefits, when taken alone, do not offset the costs (RM_2, $RM_3 < 0$, respectively) of generating these benefits.

Importance of Revenue and Publicity

Service is provided to produce medical benefits. These results show, however, that the medical benefits alone do not outweigh the costs of providing service. To see if coupling the medical benefits (Y_3) with either the generated revenues (Y_1) or the associated publicity (Y_2) would be sufficient to justify service, we zero out the attribute not coupled. Specifically, we form

$$EU[Y_1, Y_3] = \sum_{j=i}^{1{,}000} 0.001 * U\{y_1(j), 0, [y_{3a}(j), y_{3b}(j)]\} \tag{21}$$

$$EU[Y_2, Y_3] = \sum_{j=i}^{1{,}000} 0.001 * U\{-c(j), y_2(j), [y_{3a}(j), y_{3b}(j)]\} \tag{22}$$

where U is the utility function used before and $c(j)$ is again obtained from Equation 16. As before, we subtract $EU[\mathbf{0}]$ and scale by $EU[\mathbf{Y}] - EU[\mathbf{0}]$ to form RM_{ij}:

$$RM_{ij} = \frac{EU[Y_i, Y_j] - EU[\mathbf{0}]}{EU[\mathbf{Y}] - EU[\mathbf{0}]} \tag{23}$$

and the interpretation is as before.

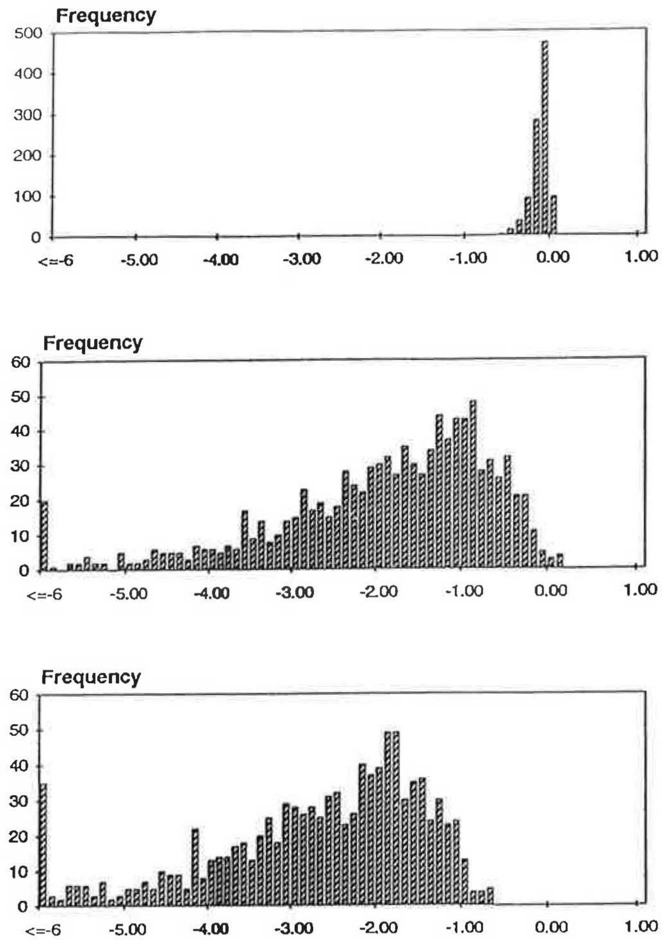

FIGURE 2 Distribution of relative value measures for single attributes RM_i across 1,000 Θ-vectors: *top*, RM_1 distribution; *middle*, RM_2 distribution; *bottom*, RM_3 distribution.

All of the terms in Equation 23 again depend on Θ-values, but they are easy to calculate once these values are given. In Figure 3 we present the RM_{ij} distributions across the same 1,000 Θ-values. The means and standard deviations of these distributions are presented in Table 3. There are only a few positive observations in the RM_{23} distribution, indicating that the combination of publicity and medical benefits would not be sufficient to justify providing service: Revenues must be generated to offset the cost of service. As seen by the RM_{13} distribution, the combination of revenues and medical ben-

TABLE 3 Means and Standard Deviations of *RM* Distribution Figures 2 and 3

Relative Value Measure	Distribution Mean	Distribution Standard Deviation
RM_1	-0.21	0.10
RM_2	-2.04	1.41
RM_3	-2.85	1.44
RM_{13}	-0.02	0.09
RM_{23}	-1.86	1.36

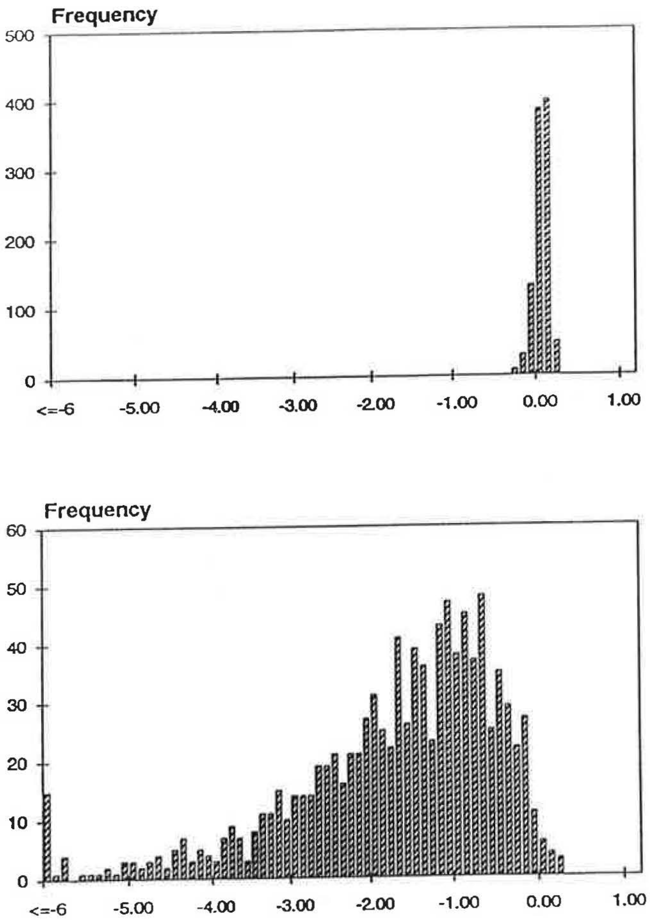

FIGURE 3 Distribution of (*top*) revenue-medical (RM_{13}) and (*bottom*) medical-publicity (RM_{23}) across 1,000 Θ-vectors.

efits might be enough to justify providing service, but the values are negative for many of the Θ-values, indicating that publicity might be needed to make service attractive in this setting.

DISCUSSION OF RESULTS

We emphasize again that these results must be considered preliminary, because the preference information was elicited from the program director, who put himself in the place of the real decision makers, for assistance in a slightly different problem (*3*). The director has worked with the decision-making board for several years, however, and has a good feel for its relative preferences in this area. Moreover, our experience in preference modeling and familiarity with the emergency medical industry has led us to believe that this preference information is representative of many service suppliers. The general results appear to be consistent across the great range of utility parameters allowed. The results may also be considered preliminary, since the performance side—that is, the probability distributions of the attribute vectors associated with providing service—is specific to one aeromedical program. We hope to investigate more programs in the future, but we have been impressed by the Skymed program and believe that our results would be representative of an efficient helicopter-based operation.

The results indicate that aeromedical service is truly multiobjective in nature. On the basis of revenue, publicity, and medical benefits offered, it was desirable to provide service for each of the 1,000 sets of preference values used. None of these service dimensions taken by itself was sufficient to justify operations, however, when the costs of supplying the service were considered. From an academic view, it is interesting to have identified a truly multiobjective service in this way. There are also more practical implications to this multiobjective nature.

First of all, the revenues generated are seen to be critical to the supplier. They make the greatest contribution to the positive value offered by the service. Without the revenues, Figure 3 (*bottom*) shows that the combined effect of publicity and medical benefits falls short of justifying supply of the service for all but a few (roughly 1 percent) of the vectors of utility parameters. Although the revenues make such an important contribution to the provision of service, the service cannot be considered a profit generator for the sponsoring hospital. Figure 2 (*top*) shows that, taken by itself, the net revenue is not enough to justify service. The median of the marginal cumulative net revenue function (Table 2) shows that there is a 50 percent chance of at least breaking even by providing service. Nevertheless, this is not considered sufficient because of the downside financial risks associated with, for example, low demand, bad weather, or lack of adequate insurance for an important percentage of the patients transported, and the aversion to losses shown in Equations 5 through 9. In the current system, the revenues are seen as a means to offset the cost of operations, not as profit.

To improve the revenue component of the service, the program could raise flight charges. Industry personnel believe that demand for transport is relatively price-inelastic. Raising charges would probably not be politically desirable, however, because of public concern with increasing health care costs. Moreover, it might have a negative net effect in the longer term if insurance companies decided that charges were too high and decided to stop reimbursing aeromedical transport completely. How much reimbursement could be cut before providing service becomes undesirable is an aspect we are now investigating.

If it would be difficult to increase revenues to the program, the financial desirability could be increased by decreasing costs. Fixed costs could be decreased by merging the two competing aeromedical systems in the area, an idea that definitely did not originate here. Countering this idea is, of course, the argument that competition increases long-term efficiency and could ultimately decrease costs. The results presented here do not contribute to this issue, either for or against. Our results show, however, that the publicity to the sponsoring hospital provided by flying emergency missions is perceived as real and important. Without it, Figure 3 (*top*) shows that the service would probably not be considered desirable. Merging programs would reduce, if not eliminate, the publicity dimension.

Finally, aeromedical service does provide medical benefits, and these contribute to the value of the service. When paired with the revenue contributions, there is roughly a 50 percent chance of making the service desirable [Figure 3 (*top*)]. If

costs could be recovered with certainty, the positive value associated with the medical benefits would, of course, be sufficient to justify service. Our model of the supply of medical benefits was based on the only relevant study (*8*) we could find, and there was a need to interpret the study for our needs. We are embarking on a sensitivity analysis of the results presented there, and we have noted a desire on the part of the industry to have more studies on the medical contributions of aeromedical transport. From Figure 2 (*bottom*), it appears, however, that medical benefits alone are far from sufficient to keep programs in the air, and if aeromedical programs are to continue to provide this life-saving service, suppliers will need to be ensured of improved financial security or continue to believe that the service is providing important publicity to the sponsoring hospitals.

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