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AN INTEGER LINEAR PROGRAMMING MODEL OF STAFF RETENTION AND TERMINATION BASED ON MULTIATTRIBUTE UTILITY THEORY

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Abstract—An integer linear programming formulation was used to model several staffing alternatives available to the director of a recreation therapy department. The utility function of the decision maker was assessed using two attributes of effectiveness: performance and experience. Two utility approximations were obtained for each staff member based upon the average performance rating and number of years of experience both as a recreation therapist and at the facility. The utility obtained was viewed as a proxy for, and a comparative measure of, effectiveness, which considers the criteria of training and experience. The individuals who comprise the most effective combination of therapists, given staff reductions, were obtained by maximizing the sum of staff utility values. The first constraint set involved a budgetary constraint, coverage constraints, and an EEOC policy restriction. The coverage restriction and the budget were varied to reflect changes in the department resources. The model was validated with the department supervisor for the case of a one-position, 10% budget decrease.

INTRODUCTION

The last few years have seen a dramatic increase in the number and diversity of studies concerned with staff reduction in an environment of declining resources and increased fiscal accountability [1, 2]. An environment in which this emphasis has been apparent is in the health care industry, where rising costs, shrinkage of secondary funding sources, and declining grant monies have forced many primary care and support services to consider reducing staff positions [1]. Of central importance, therefore, is how to plan for projected or real position decreases such that a comparable quality of service may be delivered with fewer resources. Most studies which deal with changes in the workforce number have been concerned with the selection process [3]. Little effort has been focused on the modeling of staff reductions. For the most part, studies which have dealt with layoffs have approached the problem as part of the seniority issue [4, 5] or have dealt with the problem in a subjective manner [1].

Staffing decisions and manpower allocations are easily studied using mathematical modeling techniques when the purpose is to assign or schedule staff or workloads. In general, the goal of such studies is to optimize a single objective such as minimization of cost or idle time, maximizing profit, etc. Multiple objective criteria studies have utilized goal programming to aid in the assignment of personnel [6] or to help in the allocation of staff work-hours to the implementation of a large project [7]. Mathematical models of staff reductions and their effects on staff effectiveness have not been forthcoming.

The choice of whom to terminate is a straightforward one in a situation where policy dictates "first hired, first fired" [4, 5]. However, in many settings seniority, although an important consideration, is not the final criterion for employee retention [8]. In these situations, a supervisor must invoke a complex set of criteria to make the best decision. The value of a staff member to a department must be determined within the context of the myriad objective and subjective factors, as well as the trade-offs among these factors, which impact on performance. The intent of this study is to model, for a single individual, how a staff retention decision could be made such that the optimal level of service is delivered given budgetary, minimal coverage, and retention policy restrictions. The study will model the effectiveness of employees using multiattribute utility theory (MAUT). MAUT allows the user to integrate both objective and subjective criteria of effectiveness into a preference structure. The structure is situation- and individual-specific and is therefore appropriate in a setting where the decision maker makes choices based on those preferences. A utility "value" may then be obtained for each staff member given the person's performance on the evaluation criteria used. The utility value so determined was used as a proxy for effectiveness. Some work by Casio [9] and Schmidt *et al.* [10] reviewed the applicability of utility theory in personnel selection. Landry *et al.* extended the work of Casio into the area of performance evaluation [11]; the focus was on assessing the utility value of some criterion of performance appraisal. In contrast, this study measures the utility of the individual staff member in the view of a single decision maker rather than the utility of the criterion used to evaluate that staff member.

Regardless of its complexity, the end result of any staff reduction decision is which position(s) or individual(s) to retain and which to terminate. As the objective here is to model the principal factors which affect such a decision, the decision process was modeled using a zero–one integer linear programming (ILP) formulation where the decision variables represent staff positions. A value of "1" represents retention of a position; a value of "0" represents termination. The constraints of the problem represent

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minimal coverage requirements and budget restrictions. The objective function maximizes the effectiveness of the staff retained. To our knowledge, use of a zero–one programming algorithm has not been used in the context of staffing decisions. A recent study by Baker *et al.* has used the approach of maximizing utility of personnel subject to budgetary and performance restrictions among emergency medical services [12]. The objective of the ILP model formulated will be to maximize the utility of the staff subject to the resource restrictions placed on the decision maker. The approach taken will be to assess the effectiveness of staff members using MAUT. Subsequently, an optimization model which maximizes the effectiveness of the department will be formulated and validated under several staffing strategies. The result will provide a valid, objective model for staff reduction/retention which may be used to provide input for personnel decisions.

UTILITY ASSESSMENT

The study was conducted using data from the Recreational Therapy department in a 1000 bed medical facility in the Southeastern U.S. The preferences of a single decision maker, the director of Recreational Therapy, were used for the analysis. The director does evaluation for all employees and makes all retention/termination decisions for an eight member department. Two categories of therapists compose the staff: Recreational Therapists (RT-I) and Arts and Crafts Therapists (RT-II). There are five RT-I staff and three RT-II therapists on staff. One RT-I position has been eliminated. The minimum coverage requirements based on the patient–therapist ratio are four RT-I's and three RT-II's. In the opinion of the director, the responsibilities of RT-I and RT-II are sufficiently general as to allow for mutual coverage in the event of severe cut-backs. RT's are evaluated on a semiannual basis.

Evaluation is based on a continuous five point scale where a "5" is the highest level of performance. The scale used in staff performance appraisal is behaviorally based or criterion referenced [13]. Short narrative descriptions of characteristic performance at each scale level are given and the employee, with the director, agree upon a performance rating. The scale and criteria are given in Table 1.

An assessment scheme was developed to obtain a utility surface for evaluation of the effectiveness of individual RT's. Based on the director's criteria of effectiveness, two attributes were selected for use in the assessment: performance and experience. The use of performance as a factor in effectiveness is self-evident [13]. However, the value of experience in effectiveness is less obvious. Certainly, a more experienced employee may perform more effectively as a result of that experience. A more experienced staff member may also provide a stabilizing effect on the department and help to foster greater effectiveness for all members [7]. The performance attribute (X_1) ranged from 1 to 5 following the scale shown in Table 1. The indication of experience (X_2) varied from 1 year to 10 years. One year was chosen as the lowest level because the first year represented a start-up period for new staff and is often atypical of performance. The two attributes, as defined, appear to be interrelated. It is assumed that if an individual has been working as an RT, the person's performance has been deemed (at least) successful. Secondly, having worked within this department or similar departments, an RT may attribute some effectiveness/performance to his or her interaction with the organization and other staff [4, 13].

A two-attribute preference surface was assessed using the basic lottery technique of von Neumann and Morgenstern [14]. After establishing attributes and attribute ranges based on the preferences of the decision maker, a format prepared by Keeney was used to test the independence assumptions [15, 16]. Preference for performance (X_1) was the same regardless of the level of experience (X_2), thereby verifying preferential attribute independence. When the assumption of utility independence was tested, however, results showed that performance ratings and experi ence were not independent [15–17]. Because utility independence could not be assumed, a holistic approach was taken to assessing the response surface rather than assessing preference for each attribute independently [18]. A sampling plan was generated based on the Box and Wilson design in [19]. This sampling plan, along with an approach developed by

Table 1. Performance scale

Rating	Performance	Description
1	Unsatisfactory	Poor attitude and performance.
2	Below average	Below minimum level of performance-cannot function without supervision-absolute minimum performance.
3	Average	Accomplishes tasks and duties satisfactorily-can work unsupervised if responsibilities are routine.
4	Above average	Accomplishes all assigned tasks-accepts responsibility willingly-can be left unsupervised-very desirable.
5	Superior	Most work is innovative in approach-exceptional performance-a rare employee.

Table 2. Attributes and attribute level

ATTRIBUTE	RANGE	LOW MEDIAN LEVELS	HIGH MEDIAN LEVELS
Performance Level (X_1)	1.0-5.0	1.0-1.25-2.5	2.5-3.75-5.0
Experience in years (X_2)	1.0-10.0	1.0-3.75-5.5	5.5-8.25-10.0

Ringuest and Gulledge [18] has been used to model emergency medical personnel planning decisions [12, 20]. Attributes were divided at the median into low-median range and high-median range. A 2^2 composite design was applied over both ranges (Table 2). The result generated combinations (bundles) of attributes X_1 and X_2 which were orthogonal. Twenty-five bundles were obtained in this manner. Orthogonality was not assumed over the whole range of both attributes.

The large number of points as compared to many holistic assessments and decomposed multiattribute utility assessments provide more information concerning the actual preferences of the decision maker and are designed to give equal weight to bundles over the entire range of both attributes. Lotteries were structured as in Fig. 1.

An indifference point was assessed for each bundle. Where possible, only one attribute was varied from Option I to Option II. The lotteries used indifference points, and the utility calculation for each bundle is shown in Fig. 2. The least preferred option, associated with $X_1 = 1.0/X_2 = 1.0$, was assigned a utility value of 0.0. The most preferred option ($X_1 = 5.0/X_2 = 10$) was assigned a value of 1.0. The calculated utility values are shown in Fig. 2.

The results of the assessment were consistent over the range of both attributes. The decision maker was found to be risk-averse, but only in the attribute range of 1.0–2.5 for X_1. Because of this inconsistency in risk over the range of bundles, a quadratic approximation to the utility surface was chosen. The form also allowed for interaction [19, 20]. The attribute bundles were regressed onto the utility values in Fig. 2 using least squares, and the parameter estimates of the quadratic fit were obtained. The estimated response surface is

$$\hat{U}_i = -0.613056 + 0.4148X_{1i} + 0.08271X_{2i} -0.01254X_{1i}X_{2i} -0.02554X_{1i}^2 + 0.0007565X_{2i}^2. \tag{1}$$

A plot of the response surface is shown in Fig. 3. The plot shows a highly linear response surface. Performance appears to "dominate" experience as a criterion of effectiveness, although over the linear ranges of both attributes this is less true. Presumably, a less experienced staff member is viewed as being more likely to improve in performance than a more experienced staff member.

DATA AND FORMULATION

Data were obtained on evaluation ratings, years of experience, and salary for each staff member (Table 2). Only the two most recent evaluations were used for the analysis. Evaluations were made at the same point in time for each therapist, so the effect of change due to a scale shift are minimized. The average performance rating and the years of experience, both at the facility and in total, were substituted into the response surface (eqn (1)) to obtain a utility approximation for each therapist (Table 3). The relatively high utility approximations were a reflection of a high-quality staff. Two utility ratings were ob-

OPTION I	OPTION II
PERF.=2.5/EXP.=5.5 yrs.	PERF.=5.0/EXP.=10.0 yrs.
	[x employees]
[10 employees]	PERF.=1.0/EXP.=1.0 yrs.
	[10-x employees]

How many employees would you have to have to be indifferent between options 1 and 2? (x = indifference point)

Fig. 1. Sample lottery.

PERFORMANCE (j)

Experience (i)	1.0	1.25	2.5	3.75	5.0
1.0	$P(X)=0.0$ $U(X)=0.0$	$P(X)_{10}=.2$ $U(X)=.0248$	$P(X)_9=.25$ $U(X)=.1238$	$P(X)_8=.55$ $U(X)=.475$	$P(X)_4=.9$ $U(X)=.9$
3.75	$P(X)_{17}=.175$ $U(X)=.00656$	$P(X)_3=.3$ $U(X)=.195$	$P(X)_{22}=.45$ $U(X)=.4281$	$P(X)_{21}=.65$ $U(X)=.713$	$P(X)_5=.92$ $U(X)=.992$
5.5	$P(X)_{16}=.25$ $U(X)=.0375$	$P(X)_{20}=.35$ $U(X)=.2556$	$P(X)_1=.65$ $U(X)=.65$	$P(X)_1=.65$ $U(X)=.8947$	$P(X)_6=.94$ $U(X)=.99952$
8.25	$P(X)_{15}=.30$ $U(X)=.15$	$P(X)_{18}=.5$ $U(X)=.5356$	$P(X)_{19}=.675$ $U(X)=.7959$	$P(X)_{23}=.775$ $U(X)=.9212$	$P(X)_7=.96$ $U(X)=.99998$
10.0	$P(X)_{11}=.5$ $U(X)=.5$	$P(X)_{12}=.6$ $U(X)=.8$	$P(X)_{13}=.7$ $U(X)=.94$	$P(X)_{14}=.8$ $U(X)=.988$	$P(X)=1.0$ $U(X)=1.0$

$P(X)_k$ = Indifference point for option in lottery number k.

$U(X)_{ij}$ = utility value calculated.

Fig. 2. Display at probability indifference points and utility calculations for outcomes $U(x)$.

tained for each therapist. U_1 represents the rating when years at the facility were considered, U_2 is based on total years experience as an RT-I or RT-II.

The ILP formulation is based on the information obtained during the interview and from the data provided in Fig. 2. A set of constraints is formulated for budget limitations. Salary was not linked to performance, but tended to increase with seniority and, slightly, with educational level. The difference among staff members, however, was not significant. Thus, salary did not appear to be a good discrimination factor in retention/termination decisions. Minimal coverage restrictions are introduced in two separate constraints; RT-I and RT-II coverage. Given the current patient load, the director felt that four RT-I's and three RT-II's represented minimal staffing requirements. A fourth constraint was introduced to enforce the institution's policy that at least 10% of the staff must be from a minority. Several contingency plans were enumerated which considered decreases in the department resources. The decision variable (X_{ijk}) represents the individual therapist retention ($X_{ijk} = 1$) or termination ($X_{ijk} = 0$). The resulting formulation is as follows:

MAX

$$\sum_{i=1}^{2} \sum_{j=1}^{2} \sum_{k=1}^{8} (U_{ijk} \cdot X_{ijk}) \qquad (2)$$

ST

$$\sum_{i=1}^{2} \sum_{j=1}^{2} \sum_{k=1}^{8} (C_{ijk} X_{ijk}) \le B, \quad \text{(Budget)} \qquad (3)$$

$$\sum_{j=1}^{2} \sum_{k=1}^{P_I} X_{1jk} = P_I, \quad \text{(RT-I coverage positions)} \qquad (4)$$

$$\sum_{j=i}^{2} \sum_{k=1}^{P_{II}} X_{2jk} = P_{II}, \quad \text{(RT-II coverage positions)} \qquad (5)$$

$$\sum_{i=1}^{2} \sum_{k=1}^{P_I+P_{II}} \ge p\left(\sum_{i=1}^{2} \sum_{j=1}^{2} \sum_{k=1}^{P_I+P_{II}} X_{ijk}\right), \quad \text{(EEOC)} \qquad (6)$$

$$X_{ijk} = 0,\ 1.$$

The following definitions apply:

U_{ijk} = utility value (Table 4)
C_{ijk} = salary
B = department salary budget
P_I = RT-I positions
P_{II} = RT-II positions
p = minority percentage of staff
i = type of therapist
j = minority status
k = staff member
i = 1 (RT-I), i = 2 (RT-II)
j = 1 (no), j = 2 (yes)
K = 1, 2, . . . , 8.

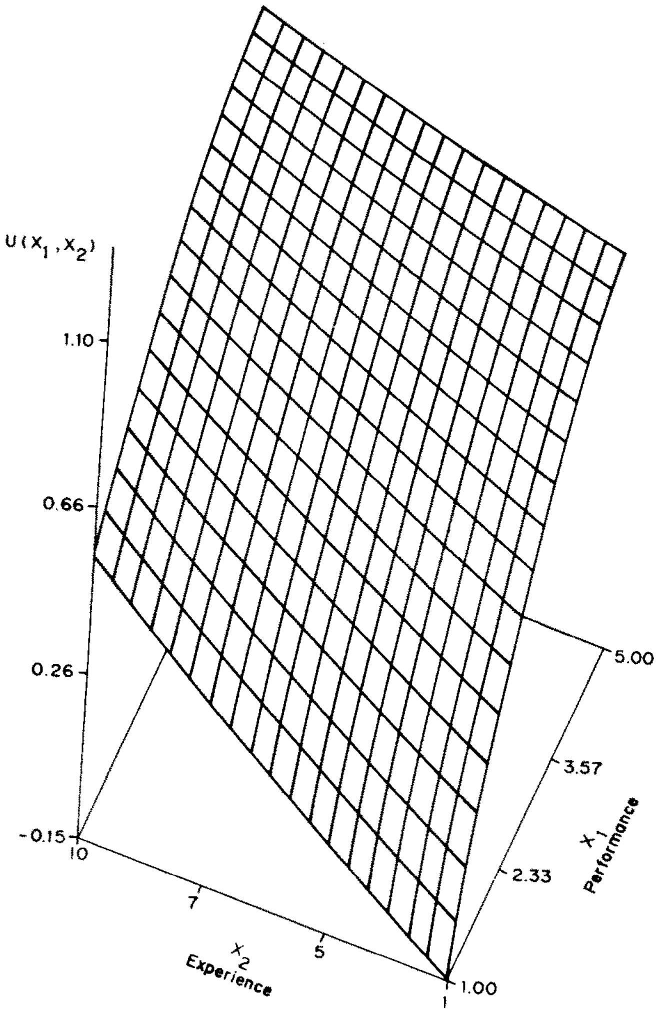

Fig. 3. Quadratic response surface.

Seniority was omitted from the constraint set initially. However, seniority was considered implicitly by estimating a utility value based on each staff member's number of years at the facility. The question of seniority was also considered explicitly by using total years of experience to estimate a utility value

Table 3. Staff evaluation and experience data

EMPLOYEE	TYPE	SALARY**	PERFORMANCE RATING[1]	YEARS EXPERIENCE	YEARS AT INSTITUTION	MINORITY	U_1	U_2
1	I	16,550	3.75	8.0	8.0	No	.9171	.9171
2	I	15,400	3.5	5.0	5.0	No	.7389	.7389
3	I	15,400	3.0	5.0	5.0	Yes	.6458	.6458
4	I	14,800	4.75	8.0	3.0	No	.8220	.9999
5	I	15,825	5.0	7.5	1.5	No	.8559	.9999
6	II	15,050	4.0	4.0	4.0	No	.7798	.7798
7	II	16,200	4.0	10.0	2.7	No	.7297	.9999
8	II	15,260	5.0	1.8	1.8	No	.8616	.8616

1-represents average performance rating for two consecutive periods

** Total Dept. Budget = 139,385 prior to position decrease.

U_2: Utility is based on total years experience as a RT-I or II.

U_1: Utility based on years experience in the department under evaluation.

Table 4. Selected budget/staff allocations

STRATEGY	MINIMUM COVERAGE	RT-Is	RT-IIs	TOTAL BUDGET *	TYPE DECREASE
1	Yes	4	3	$123,560	1 RT-I position
2	Yes	4	3	$125,446	10%; 1 RT-I
3	No	3	3	$111,508	20%; 2 RT-I
4	No	3	3	$125,446	10%; 2 RT-I
5	Yes	4	2	$111,508	20%; 1 RT-II
6	No	3	3	$125,445	10%; 2 RT-I
7	No	7		$125,446	10%; 1 position decrease

* Initial Department Budget was $139,385.

for each staff member, and introducing three additional constraints based on seniority. Because the facility does not follow a policy of "first hire/first fire," the constraints were added to give priority to staff members who had five or more years of experience in an RT-I position. In RT-II positions, one staff member had clear seniority over the remaining two staff members; therefore, this individual was given priority. The constraints were as follows:

$$X_{111} + X_{112} \geq X_{114} + X_{115}, \quad \text{(RT-I seniority)} \tag{7}$$

$$\left.\begin{aligned} X_{211} &\geq X_{212}, \\ X_{211} &\geq X_{213}. \end{aligned}\right\} \quad \text{(RT-II seniority)} \qquad (8)\ (9)$$

RESULTS AND DISCUSSION

The decision confronting the director of the department under study is, which of the five RT-I's should be terminated. The value of the objective function (eqn (2)) is used as a proxy for staff effectiveness. Prior to reduction, the upper board value of the linear program objective function was 5.649 for in-house experience and 6.2412 for total experience.

Seven possible strategies for staff and/or budget reductions were considered (Table 4). The list is not exhaustive, but includes the staff configuration when minimum coverage is not possible in either RT-I or RT-II positions. In addition, a strategy which considered a single position decrease without regard to the type of position was included. The solution was obtained for the seven strategies under three separate seniority statuses (Table 5). This empirical approach to the study of seniority under conditions of uncertainty is modeled on the work of Gordon and Fitzgibbons [4]. Status I shows results when no seniority retention policy is present. The objective is to maximize the utility of the staff, where the utility of each member is a function of total years of experience as

Table 5. Organization results for selected strategies and seniority constraints

	SENIORITY STATUS					
	I		II		III	
STRATEGY	TERMINATE	$Z=U^*$	TERMINATE	$Z=U^*$	TERMINATE	$Z=U^*$
1	$X_{112}=0$	6.204	$X_{112}=0$	5.612	$X_{115}=0$	5.943
2	$X_{112}=0$	6.204	$X_{112}=0$	5.612	$X_{115}=0$	5.943
3	$X_{112}=X_{111}=0$	5.287	$X_{112}=X_{114}=0$	4.790	$X_{115}=X_{112}=0$	5.204
4	$X_{112}=X_{111}=X_{211}=0$	4.5072	$X_{112}=X_{114}=X_{212}=0$	4.060	$X_{115}=X_{112}=X_{213}=0$	4.342
5	$X_{112}=0$	6.202	$X_{112}=0$	5.612	$X_{115}=0$	5.943
6	$X_{112}=X_{111}=0$	5.287	$X_{112}=X_{114}=0$	4.789	$X_{115}=X_{112}=0$	5.204
7	$X_{112}=0$	6.204	$X_{212}=0$	5.622	$X_{213}=0$	6.081

U^* = Optimal utility value for the 0-1 ILP; U^{**} = LP upper bound on utility w/coverage

I: No seniority Total # Years Experience (U_2) : $U^{**} = 6.241$

II: Implicit seniority-years at facility (U_1) : $U^{**} = 5.649$

III: Explicit seniority constraints (U_2 and equations 7-9) : $U^{**} = 6.163$

an RT-I or RT-II. Status II shows results when the utility is a function of years of experience in the staff member's present position. Here seniority is considered implicitly as a part of the objective function. Status III considers explicitly the effect of seniority status on retention. The policy adopted in this case was that the most senior members within each class should receive first preference over newcomers, or, if an employee has been at the facility for more than five years, then special consideration should be given to their retention. This appeared to be consistent with the intent of most seniority policies which were not "first hire, first fire" [5].

The model results were validated in a post-interview with the director. The first strategy which resulted from a decrease in one RT-I position was consistent with the decision of the director. When strategies did not assure minimum coverage (four RT-I's and three RT-II's), validation was more difficult. The strategy in which one unspecified position was removed (Strategy 7) caused an RT-II position to be terminated when seniority was considered. (Seniority Status II and III). In a situation where an RT-I may absorb the responsibilities of an RT-II, this strategy may be more realistic than specifying a constraint for each type of therapist. The type of constraint(s) used would depend on the type of department being modeled, but both contingencies should be considered for planning purposes.

For all strategies and seniority policies, the EEOC restriction forces that position into the solution. However, in terms of effectiveness, the marginal value is less for the individual concerned. The study by Gordon and Fitzgibbons reviewed the extensive literature written about the legality of competitive seniority status and equal employment opportunity [4]. The approach taken in this model was to restrict the staff to include at least a 10% minority employment. Because the constraint was explicit in the ILP, the model cannot address the subtleties of the seniority/EEOC controversy. The results do provide the decision maker with a "starting point" for such considerations. Being linear, the model considers effectiveness to be additive. An experienced work group is more likely to work effectively, being familiar with co-workers, responsibilities, etc. Thus, in part, performance of an individual is a function of seniority in a small, cohesive department. Although the objective function is linear, the utility value or effectiveness of each staff member includes the effect of professional and personal interaction.

In general, the performance criterion so dominated experience that a relatively small change in performance offset a large change in experience. When seniority was not considered (Status I), the same result was obtained when one position was omitted regardless of whether or not the type of technician was specified (strategies 1, 2, and 7). As the total number of positions was decreased, employees were terminated in order of their effectiveness, as measured by the utility coefficient.

Results obtained for the implicit seniority case (Status II) agreed with those of the no-seniority case only when the number of RT-I positions was restricted to three. The non-specified position decrease terminated an RT-II first. The utility values obtained for this status differed slightly from those of the first seniority status (Table 5). Therapists under Status II were terminated in order of their effectiveness. The difference between the results when an RT-I position was omitted and when a non-specified position was omitted yield only a slight difference in the value of the objective function. Practically speaking, the two strategies are equivalent and the optimal decision would be made based on additional considerations.

Status III considers the situation where seniority is imposed explicitly via a constraint set. Results differ significantly from the first two statuses. The disparity between the implicit and explicit seniority cases is in part a function of the lack of sensitivity of the utility surface to the experience attribute. Clearly, with so few therapists on staff, the seniority constraints (eqns (7)–(9)) dictate the staff retained. A point of comparison between the order of termination still exists for this status, however. The least effective therapist of the new staff members is the first terminated.

SUMMARY AND CONCLUSIONS

An ILP formulation was used to model alternative staffing strategies available to the director of a Recreational Therapy department given reductions in staff positions and/or budgets. The model tended to weight the performance attribute over experience, although there was interaction between the two attributes. The last discriminating constraint was the budget equation. Because little difference in the salaries existed, the constraint failed to help in the selection process. The coverage constraints, along with the EEOC constraint, chose therapists in order of whether their utility value was effective in the view of the director. When the question of seniority was considered, the optimal staff was found to result from a situation in which only the effectiveness of the therapist was considered, and individuals were released in order of performance. Explicit inclusion of a seniority policy in terms of constraints was found to significantly alter the solution set.

It is not clear whether the difference in utility may actually correlate with any difference in department effectiveness. The relationship between the objective function value obtained for each strategy of the three seniority statuses and performance is not directly at issue here. The value of the ILP lies in its ability to generate staff configurations under several contingency plans.

The intent of the analysis was not to develop a model which addresses all of the contingencies present in a termination decision. However, useful information can be obtained from the model, since it addresses possible options which may be used in the event of proposed decreases in positions or budget. The results of the model are somewhat predeterminable, owing to the rather small staff. In a larger department, however, where many staff members may have similar experience and/or performance evaluations, the model can provide valuable input into the decision-making process.

The optimization model was used to select the most effective staff for a Recreational Therapy department under conditions of financial cutbacks requiring decreases in the department's staff and budget. The purpose was not to isolate the supervisor from the staff involved, but to force the decision maker to clarify important criteria influencing retention/termination decisions. Taken in this context, decision modeling allows the supervisor to prepare for financial uncertainties, and allows for a contingency rather than a crisis approach to personnel management.

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