Determining the Minimum Bid Price for Projects Involving Analysts from Multiple Locations

*Mohammad M. Amini**
*Gaylon Greer***

Abstract. **This paper presents a mathematical model and a solution methodology for determining the minimum fee, the best project duration time, and the optimal number of analysts for projects that involve travel to multiple sites or subcontracts with analysts from geographically dispersed locations. Computational experiments with the solution algorithm on twenty-seven randomly generated projects show that (a) the solution methodology efficiently provides an optimal solution, and (b) it provides decisionmakers with alternative next best plans through ex post sensitivity analysis.**

Introduction

Real estate analysis contracts are awarded by various methods, including competitive bids and negotiated fees. In all cases the firm must be aware of the approximate number of hours required by analysts to complete a proposed assignment, in order to establish a minimum bid price or a price below which a fee is not negotiable.

When a prospective assignment is of a routine nature, price determination is a fairly simple procedure incorporating the distilled wisdom of past experience. For proposals that are unique or are sufficiently large that analysts from other firms will have to be utilized, either in a joint venture arrangement or by subcontracting a portion of the work, fee determination becomes substantially more involved. The most common approach then involves spreadsheet calculations that incorporate "what-if" questions to compute the number of analysts and ultimate project costs. Although simple, this approach is time consuming. Moreover, for complex assignments, its efficacy is limited.

The complexity of cost determination grows geometrically when assignments involve multiple properties that are geographically dispersed or when subcontractors must be drawn from multiple locations. The trial-error approach, normally by spreadsheet software, to such a task may cause the firm to lose potentially lucrative opportunities due to having overestimated total project costs. Perhaps more seriously, it may result in acceptance of assignments with fee structures such that the firm actually suffers economic losses. Moreover, spreadsheet analysis cannot accommodate

*Department of Management Information Systems and Decision Sciences, The Fogelman College of Business and Economics, Memphis State University, Memphis, Tennessee 38152.
**Department of Finance, Insurance, and Real Estate, The Fogelman College of Business and Economics, Memphis State University, Memphis, Tennessee 38152.
Date Revised—July 1992; Accepted—October 1992.

the trade-off relationship between total project costs, the size of the project team, project duration, and related practical constraints.

Firms that vie for these complex assignments need a systematic managerial decisionmaking model that accounts for costs, contraints, and trade-offs. This article presents a general optimization model that incorporates all cost elements, interrelates the decision variables, and includes restrictions confronted by the firm. Also, it presents an algorithm that efficiently determines the minimum project price, the optimum project duration time, and the optimal number of appraisers or analysts to be assigned to a project where the work involves analysts' travel from multiple locations. The article concludes with a summary of computational experiments with the solution methodology, utilizing a set of randomly generated project parameters.

Previous Research

There is no evidence in the literature that the project bidding problem has ever been modeled or solved with mathematical programming technology. The most closely related research is in the area of manpower planning, specifically audit staff planning for public accounting firms. The research on audit staff planning has been focused on developing single-period or multi-period models by employing linear goal programming or multiple objective linear programming approaches.

Price, Martel and Lewis (1980) surveyed previous research on the topic. Early modeling efforts reported by Bailey, Boe and Schnack (1974), Killough and Souders (1973), Summers (1972) and Welling (1977), used the linear goal programming approach to model single-period audit staff requirements for Certified Public Accounting firms. Weaknesses in the goal programming approach (i.e., a priori determination of weights or priorities by decisionmakers) encouraged researchers to approach the problem by multiple objective linear programming methodology. To include the realism of staff requirement fluctuations, the planning horizon was increased from single to multiple periods by Balachandran and Steuer (1982), Gardner, Huefner and Lotfi (1990), and by Silverman, Steuer and Whisman (1988).

All of these researchers applied existing mathematical programming modeling and solution methodologies to model and solve the project staff planning problem. The minimum cost bid problem (MCB) is concerned with a managerial decision that is different from the staff planning problem in that: (1) in the MCB problem we search for a minimum bid price; (2) a new mathematical programming model (a nonlinear, integer model with a single objective) is applied to formulate the problem; (3) there is no existing methodology to solve the problem.

Model Development

The project minimum bid price computation incorporates categories of associated costs and constraints, and key trade-offs. The size of the project team affects project duration and related costs, so the optimal number of analysts is interrelated with the optimal project duration and the number of sites that must be visited or the number of locations from which analysts must travel. Furthermore, project completion time should be evaluated such that: (1) total project cost is minimized by minimizing the number of periodic home visitations and/or travel time between site, (2) the project is completed before the deadline, and (3) analysts' living costs at the project site are minimized.

We pose the problem as follows: Determine the best allocation of available analysts to complete the project within the time frame set by the prospective client, at minimum total costs.

Model Objective Function

The total cost function may be presented as:

$$
\begin{aligned}
F(P,E) = {} & [\sum_{i=1}^{I} a_i E_i + [\frac{P}{\Delta_v}] \sum_{i=1}^{I} a_i E_i] + \\
& [(\frac{P}{7}) ws \sum_{i=1}^{I} E_i] + \\
& [mP \sum_{i=1}^{I} E_i - \lfloor \frac{P}{\Delta_v} \rfloor mv \sum_{i=1}^{I} E_i] + \\
& [hP \sum_{i=1}^{I} E_i - \lfloor \frac{P}{\Delta_v} \rfloor hv \sum_{i=1}^{I} E_i] + \\
& [cP \sum_{i=1}^{I} E_i - \lfloor \frac{P}{\Delta_v} \rfloor vc \sum_{i=1}^{I} E_i] + [f d],
\end{aligned} \qquad (1)
$$

where the model notations and conventions are defined in Exhibit 1. The problem's decision variables are P, the number of days to complete the project, and E_i, the number of analysts from different locations assigned to the project. The parameters are specified by the firm and its prospective client.

The following additional assumptions are made:

- P includes the entire project duration, including weekends and visitation periods,
- home visitations are during weekends,
- each site visit requires the same average amount of time,
- a project starts on the first day of a week.

The components of the total bid cost equation, equation (1), may be explained as follows:

Airfare Costs. One of the major costs in determining a bid on a large out-of-town project is the round-trip airfare cost of the analysts who must do site visitation. Airfare costs are defined by the first set of bracketed terms in equation (1):

Exhibit 1
Model Variables and Conventions

n	=	maximum number of days to complete a project,
P	=	number of days to complete a project (including weekends and home visitation periods),
f	=	total number of sites to be visited in the same geographical region (city),
I	=	index set associated with the independent analyst's home sites available for a project,
E_i	=	number of analysts assigned to a project from location (i.e., branch, city, etc.) i,
u_i	=	maximum number of independent analysts available at location i,
r	=	average number of days to inspect each property,
w	=	number of working days per week,
v	=	number of days each analyst visits home on each trip,
Δ_V	=	number of days between two subsequent home visits,
s	=	analysts' average daily salary,
a_i	=	round-trip airfare from location i to the project site,
m	=	analysts' average daily meal and incidental costs,
h	=	daily hotel cost per analyst,
c	=	daily rental car cost,
d	=	overhead allocation per site visited or per analyst drawn from another location.

The following conventions are defined:

$\lfloor . \rfloor$	=	the smaller nearest integer value.
$\lceil . \rceil$	=	the larger nearest integer value.

$$[\sum_{i=1}^{I} a_i E_i + \lfloor \frac{P}{\Delta_v} \rfloor \sum_{i=1}^{I} a_i E_i].$$

The first term represents the cost of the initial round-trip to the project site; the second accounts for periodic home visits. Obviously, the number of home visits must be an integer variable.

Salary. Regardless of the location, analysts are offered the same average daily salary, which is the second set of bracketed terms in equation (1):

$$[(\frac{P}{7}) ws \sum_{i=1}^{I} E_i].$$

The term represents the total average salary of analysts while working at a project site; analysts are not paid for weekends or for home visitation periods. Average salaries are incorporated to simplify the presentation of the algorithm; the formulation can be easily modified if different salary arrangements are involved.

Meal and Incidental Costs. Each analyst has a fixed allowance for meals and incidental costs during his/her stay at the project site. The third set of bracketed terms in equation (1) represents this cost:

$$[mP \sum_{i=1}^{I} E_i - \lfloor \frac{P}{\Delta_v} \rfloor mv \sum_{i=1}^{I} E_i].$$

The first term accounts for the costs throughout the project duration, but the analysts would not be reimbursed for the period of home visitations. This latter adjustment is represented by the second term.

Hotel Costs. The fourth set of bracketed terms in equation (1) presents the total hotel costs for the project (the first term), adjusted (the second term) for home visits during which there are no hotel charges:

$$[hP\sum_{i=1}^{I}E_i - \lfloor \frac{P}{\Delta_v} \rfloor hv\sum_{i=1}^{I}E_i].$$

Car Rental Cost. Each analyst is assumed to rent a car while working at a site, and these costs are expressed by the fifth set of bracketed terms in equation (1). Anytime an analyst returns home for a visit, the car would be returned to the rental company. Car rental cost for the total site inspection period is formulated by the first term; the second term adjusts for the home visitations period:

$$[cP\sum_{i=1}^{I}E_i - \lfloor \frac{P}{\Delta_v} \rfloor vc\sum_{i=1}^{I}E_i].$$

Administration Costs. The last bracketed term in equation (1) defines fixed costs for inspecting each property. This is allocation of overhead, d, for secretarial work and office operations.

To simplify the notation in equation (1), the following substitutions are employed:

$$X = \lfloor \frac{P}{\Delta_v} \rfloor, \tag{2}$$

$$Y = \sum_{i=1}^{I}E_i \tag{3}$$

and

$$T = \frac{P}{7}. \tag{4}$$

The variable X represents the number of home visitations during the project duration; the variable Y denotes the number of analysts selected for the project team; and the variable T indicates the project duration in terms of weeks.

Substituting these into equation (1) gives the following reformulation:

$$F(E,P,T,X,Y)=[(1+X)\sum_{i=1}^{I}a_iE_i]+[TwsY]+$$
$$[(P-vX)mY]+$$
$$[(P-vX)hY]+$$
$$[(P-vX)cY]+[fd].$$

or

$$F(E,P,T,X,Y)=[(1+X)\sum_{i=1}^{I}a_iE_i]+[TwsY]+$$
$$[(m+h+c)(P-vX)Y]+[fd]. \tag{5}$$

Model Constraints

The total cost function, equation (5), is a nonlinear and mixed integer function that is to be minimized over *E, P, T, X,* and *Y*, subject to some major constraints. First, the number of analysts drawn from different locations in the country cannot exceed the available number at each location. Second, the optimal project period cannot stretch beyond the deadline determined by the client. Third all the sites and buildings for a given project must be inspected within the project duration. Fourth, values for all the decision variables must be non-negative and integer.

It should be noted that although in practice it takes longer to complete some site inspections than others, the model uses an overall average (r) to represent the productivity of analysts per day.

Given these constraints, the Minimum Cost Bid (MCB) model may be stated as,

$$\textit{Minimize} \quad F(E,P,T,X,Y)=[(1+X)\sum_{i=1}^{I}a_iE_i]+[TwsY]+$$
$$[(m+h+c)(P-vX)Y]+[fd], \tag{6}$$

Subject to:

$$E_i\leq u_i, \quad i=1, \quad ..., I \tag{7}$$

$$P\leq n, \tag{8}$$

$$wTY\geq rf, \tag{9}$$

$$T\geq 0, \tag{10}$$

and

$$E, P, X, Y, \geq 0 \text{ and all integers.} \tag{11}$$

The MCB is a nonlinear, mixed integer mathematical programming model, in the sense that equation (6) is a nonlinear and mixed integer function, equation (9) is a nonlinear and mixed integer constraint, four of the decision variables are integer and one, T, is real. The remaining constraints are integer and linear. Note that administrative overhead allocation, the last term in equation (6), is a fixed cost and may be dropped without any affect on the optimal solution of the problem.

A Solution Methodology

A search has shown that there is no specific algorithm or procedure in the literature that solves the MCB problem. The difficulty is that none of the existing solution procedures for nonlinear or/and integer programming models are capable of dealing with models that contain noncontinuous and nonlinear functions combined with the condition imposed on X by equation (2). If these conditions are relaxed, then a Lagrangian relaxation approach (Fisher, 1985) may be applied to provide a "good" solution to the model or at least a lower bound on the optimal solution. It was decided to devise a new, simple and efficient algorithm that can take advantage of the practical characteristics of the problem to obtain the optimal solution with a "reasonable" computational effort.

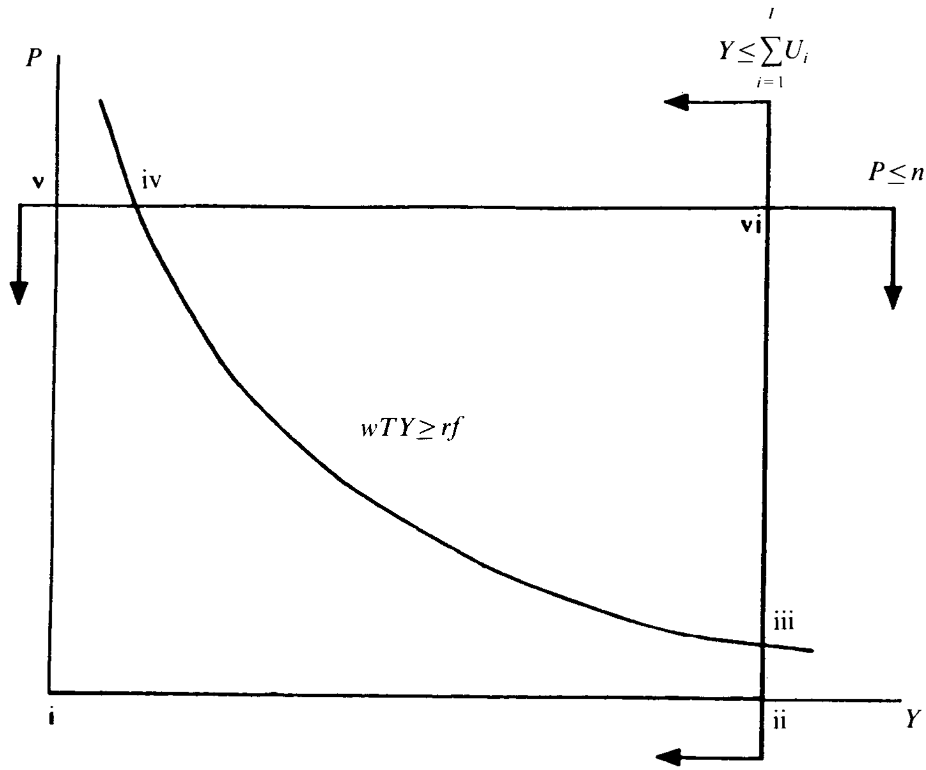
An aggregation of the constraint set, equations (7) through (11), generates a solution region depicted in two dimensions by Exhibit 2. The feasible solutions to the problem include all integer combinations of the decision variables above the hyperbola defined by the constraint in equation (9).

The combinatoric nature of the model and conditions specified in equation (2) and (3) make this appear to be a difficult problem, but the model's practical characteristics make it possible to design a simple optimal search solution method that can efficiently be implemented on a personal computer. These practical characteristics are:

- The model includes few decision variables, and simple constraints.
- In practice the decision variables are bounded tightly. For example, the project's allowable duration is usually set by the client's time frame for accomplishing other aspects of the program that prompted the consulting assignment, and hence the optimal project duration certainly cannot exceed the client's specification. Also, the number of locations and the number of analysts in each location are bounded tightly.
- Finally, and most importantly, the only cost that would encourage the firm to select subcontractors from some locations and ignore some others is the airfare cost. The other related costs are independent of the home locations of the selected analysts.

The aforementioned characteristics permit an efficient enumerative algorithm design, hereafter referred to as Brute Force Search Method (BFS). For a given

Exhibit 2
Solution Region for the MCB Problem



project, this approach suggests a *partial enumeration* of feasible integer combinations of the pertinent decision variables within the areas labeled (iii, iv, vi) in Exhibit 2 while ignoring the infeasible solutions within the areas labeled (i, ii, iii, iv, v).

Given the parameters associated with a project, the BFS method may be summarized as follows:

Step I: Rank Available Analysts' Home Sites

a. Rank airfare costs (a) in an ascending order along with the analysts' home sites

b. Let $i = 1, \ldots, I$ denotes the home site location rank.

Step II: Determine the Minimum Required Number of Analysts

a. Compute the minimum number of analysts required to complete the project within n days, Y_{min}, as $Y_{min} = [rf / (1/7.)wn]$.

b. Compute the total number of available analysts, Y^*, as

$$Y^* = \sum_{i=1}^{I} u_i,$$

c. If $Y_{min} > Y^*$ then set $TC^* = \infty$, and go to *Step VI.*

d. Let i^* denote the home site rank of the analyst $Y_{\min}$, and u^*_i denote the number of analysts selected from location i^*.
e. Set $i=i^*$, $u=u^*_i$, $Y=Y_{\min}-1$, and $TC^*=\infty$, and go to *Step IIe.*

Step III: Add an Additional Analyst
a. Set $i=i+1$.
b. If $i>I$, then go to *Step VI.*
c. Set $u=0$.
d. Set $u=u+1$.
e. If $u\leq u_i$, then set $Y=Y+1$ and go to *Step IV*; otherwise, go to *Step IIIa.*

Step IV: Check the Feasibility Conditions
a. Set $P=rf/(1/7.)wY$.
b. If $P>n$, then solution is *infeasible*; go to *Step IIId.*

Step V: Update the Improved Feasible Solution
a. Applying equation (6), commute F^* (E^*,P,T,X,Y), where $E^*=\{E_j$: $J=1,2, \ldots, i\}$ and $a^*=\{a_j$: $j=1,2, \ldots,\}$; applying equations (2) and (4), compute X, and T.
b. If F^* $(E^*,P,T,X,Y)>TC^*$, then go to *Step IIId.*
c. Set $TC^*=F^*(E^*,P,T,X,Y)$, $P^*=P$, and $E^*=\{E_j$: $j=1,2, \ldots, i-1\} \cup u$.
d. Go to *Step IIId.*

Step VI: Check the Optimality Conditions
If $TC^*=\infty$, then the problem is *infeasible*; otherwise, the *optimal solution* is at E^* and P^* with the minimum bid cost of TC^*. Terminate!

In *Step I,* the algorithm starts by sorting the analysts based on their round-trip airfare costs. The sorting process ranks the analysts in an ascending order of the round-trip airfare costs. The main reason for sorting is to be sure that in Step II the project team members are selected from the locations with the lowest airfare costs so that total airfare cost will be minimized.

To determine whether available analysts are capable of completing the project within the client's time frame, *Step II* computes the minimum number of required analysts; if it exceeds the number available, then the problem is infeasible and the procedure is terminated. Otherwise, the algorithm moves to the next step.

In *Step III,* the algorithm attempts to build up the project team. The selection process adds one analyst at a time using the location-ranked list. If the number of the project team members selected from one location exceeds the available number, then the algorithm moves to the next ranked location; otherwise, it proceeds to check the feasibility conditions. This step assures satisfaction of constraint (7).

Step IV answers the following question: How many days are required for the current project team to review the sites? If the required period plus weekend and home visitation periods exceeds the given deadline, then the present team is not capable of completing the project; the algorithm goes back to *Step III* and adds an additional member to the team. If the project team can complete the inspection process before the deadline, then BFS proceeds to the next step. Satisfaction of constraints (8) and (9) are assured by this search procedure.

If the project can be completed with the current project team, then *Step V* applies equation (6) to compute the associated total bid cost. Next, the quality of the new solution is compared to the best previous solution. If the new solution has a lower objective function value, then it is substituted for the older best solution and the program returns to the *Step III* to continue the search for the least costly project team.

After all available analysts are added to the project team in this iterative fashion, *Step VI* determines if the optimal solution is obtained. The algorithm terminates with the optimal solution or indicates that the problem is infeasible.

Convergence Proof

Theorem: The BFS algorithm converges to the optimal solution within $Y^* - Y_{\min} + 1$ iterations.

Proof: Assume that there exist at least a feasible solution. There are I ranked locations and each location i consists of u_i available analysts. Starting with $Y_{\min}$ available analysts from the highest ranked location and moving toward the lowest ranked location, the algorithm selects one analyst at a time to build the final project team. For each location the selection proceeds until all the available analysts at the location are included. With addition of each team member, the procedure checks the possibility of completing the project within n days. The search is continued until all analysts in I locations are included in the team, Y^*. Hence, the algorithm arrives at the optimal solution at most within $Y^* - Y_{\min} + 1$ iterations. ■

Obviously, the BFS algorithm rate of convergence depends on the problem parameters. The number of iterations is a function of f, v, w, r, n, and Y. Knowing the three facts that: (1) in practice, the values for these problem parameters are "small"; (2) the bound on the number of iterations is finite and "small"; and (3) at each iteration a new solution is visited, ensures the convergence of the algorithm within a "reasonable time interval". This is shown in the next section.

Computer Implementation of the BFS Algorithm

To examine and simulate the performance characteristics of the BFS algorithm, a testing system was designed. The major components of the testing system include: (1) a random project generator, (2) the BFS algorithm, and (3) a report generator.

The BFS testing system works as follows: given a random seed number and intervals for the values of problem parameters, the project generator can create a random project. Then the minimum cost bid is determined by the BFS algorithm, and the project input characteristics and the solution results including the next best solutions are reported.

A portable FORTRAN program was developed to implement the BFS testing system on the ZENITH Z-386 SX PC computer. A uniform random number generator was applied to generate (1) airfare costs from each location to the project site, and (2) the maximum number of available analysts at each location. The BFS software is portable on any other PC.

An Example Project

Using the BFS testing system and the following real-world parameters, a random example project was generated and the optimal solution was determined:

$n=20$,	$u=[1 \text{ to } 3]$,	$d=250$,
$I=6$,	$a=[100 \text{ to } 400]$,	$f=20$,
$s=150$,	$w=5.5$,	$M=60$,
$r=2$,	$v=2$,	$h=70$,
$\Delta_V=12$,	$c=50$,	

useed = 42088129, and *aseed* = 46354671.

For this project using the seed number *useed*, the number of analysts in each location was randomly selected between one to three. As a result, a total of nine analysts were available at six different locations. Also, the round-trip airfare costs from each location to project site were generated randomly, where it varied from $100 to $400. The random seed number used was *aseed*.

The optimal solution and the two next best solutions are shown in Exhibit 3. The optimum solution was found in nine iterations and indicates that with eight analysts the project can be completed within six days with the minimum total costs of $22,005. The efficiency of the algorithm was shown to be incredible. On the ZENITH Z-386 SX, it took less than one minute to obtain the optimal solution.

Exhibit 3
The Optimal Solution and the Next Best Solutions for the Example Project

Variables	Optimal Solution	First Best Solution	Second Best Solution
Analysts	8	5	4
Project duration	6	11	17
Airfare	$1,165	$537	$856
Salary	$7,200	$11,625	$15,600
Incidental	$2,880	$3,300	$3,600
Hotel	$3,360	$3,850	$4,200
Car	$2,400	$2,750	$3,000
Administration	$5,000	$5,000	$5,000
Total Costs	$22,005	$27,062	$32,256

A Computational Experiment

To experiment with the BFS testing system, a set of projects were randomly generated. The following parameters used to create the test projects are selected based on the real-life projects:

$n=10{,}15{,}20$, $u=[1 \text{ to } 3]$, $d=250$,
$I=4{,}6{,}8$, $a=[100 \text{ to } 400]$, $f=20{,}30{,}40$
$s=150$, $w=5.5$, $m=60$,
$r=1$, $v=2$, $h=70$,
$\Delta_V=12$, $c=50$,

$useed=42088129$, and $aseed=46354671$.

A total of twenty-seven projects were randomly generated and the optimum solutions were obtained. The optimal solutions for each of the twenty-seven projects was obtained in less than one minute on the ZENITH Z-386 SX. Exhibit 4 depicts the information on the optimal solutions. Note that all twenty-seven projects had the same costs parameters, except that airfare costs for each project were generated randomly. Also, the number of analysts available at each location were randomly generated.

The following observations can be made. As the number of locations (I) was

Exhibit 4
Optimal Solution Data for the Set of Randomly Generated Projects

Project	*n*	*I*	*f*	Available Analysts	Iter.	Optimum Analysts	Optimum Duration	Optimum Cost(s)
1	10	4	20	5	*	*	*	*
2	10	4	30	6	*	*	*	*
3	10	4	40	5	*	*	*	*
4	10	6	20	8	6	8	6	23,481
5	10	6	30	7	*	*	*	*
6	10	6	40	8	*	*	*	*
7	10	8	20	9	7	8	6	22,463
8	10	8	30	11	8	9	10	44,843
9	10	8	40	12	8	12	10	60,778
10	15	4	20	6	5	5	11	27,491
11	15	4	30	4	*	*	*	*
12	15	40	40	6	*	*	*	*
13	15	6	20	8	7	8	6	27,770
14	15	6	30	8	6	8	11	43,698
15	15	6	40	8	*	*	*	*
16	15	8	20	12	11	8	6	22,048
17	15	8	30	10	8	8	11	43,483
18	15	8	40	10	7	10	11	55,186
19	20	4	20	4	4	4	17	33.148
20	20	4	30	7	6	6	17	51,144
21	20	4	40	*	*	*	*	*
22	20	6	20	9	9	8	6	22,005
23	20	6	30	8	7	8	11	44,166
24	20	6	40	*	*	*	*	*
25	20	8	20	10	10	8	6	22,316
26	20	8	30	9	8	8	11	43,662
27	20	8	40	9	7	8	17	65,372

*project infeasible

increased: (i) a number of projects were found to be infeasible (indicated by the "*"). This means that if the number of available analysts were not capable to complete the review process within the deadlines then the project is declared to be infeasible. To remove the infeasibility we need to increase the pool of the available analysts or/and increase the project duration; (ii) Given n and I, as the number of sites or properties (f) to be visited was increased the optimal project duration and total project cost were increased. Also, the optimal number of analysts was increased or stayed unchanged. In many instances, the projects were completed a few days before the deadlines and in some cases met the maximum durations.

Summary and Conclusions

A major problem when bidding on large projects that require the use of subcontractors from geographically dispersed locations is to determine the minimum fee that will cover the firm's costs, including its normal profit margin, yet provide a reasonable chance of submitting the winning bid. The risk is twofold: A too-high fee risks losing out on potentially profitable assignments, but a too-low fee risks winning assignments that prove to be unprofitable.

To address the minimum cost bid problem confronted by appraisal or consulting firms, we formulated a nonlinear and mixed integer mathematical model. The model accounts for the major cost parameters and also the constraints involved. A new optimization algorithm to determine the minimum cost bid is presented. The algorithm was implemented on a ZENITH Z-386 SX personal computer. Computational experimentation with the BFS code has shown that the algorithm can efficiently (in less than one minute) determine the optimal total bid cost along with the optimal number of analysts from diverse locations to a single assignment or the number of analysts from a single location to dispersed sites, and the optimal project duration time.

The model and algorithm presented in this paper are powerful managerial tools. The stochastic nature of the parameters and changes in the pool of the available analysts are a major concern of management in evaluating a project and preparing a bid. The BFS algorithm and the computer code have the capabilities to look into different scenarios and efficiently perform sensitivity/post optimality analysis to offer alternative optimal plans and their associated costs.

From a practitioner point of view, the simplicity of the BFS algorithm and its implementation (MINBID) allow the software to port on mainframe, micro, or PC computers and provide quality and fast answers to the managerial questions regarding a bid.

References

Bailey, A. D., W. J. Boe and T. Schnack, The Audit Staff Assignment Problem: A Comment, *Accounting Review*, 1974, 69:3, 572–74.

Balachandran, R. K. and R. E. Steuer, An Interactive Model for the CPA Firm Audit Staff Planning Problem with Multiple Objectives, *Accounting Review*, 1982, 57:1, 125–40.

Fisher, M., An Applications Oriented Guide to Lagrangian Relaxation, *Interfaces*, 1985, 15, 10–21.

Gardner, J. C., R. J. Huefner and V. Lotfi, A Multiperiod Audit Staff Planning Model Using Multiple Objectives: Development and Evaluation, *Decision Sciences*, 1990, 21:1, 154–70,

Killough, L. N. and T. L. Souders, A Goal Programming Model for Public Accounting Firms, *Accounting Review*, 1973, 68:2, 268–79.

Price, W. L., A. Martel and K. A. Lewis, A Review of Mathematical Models in Human Resource Planning, *OMEGA*, 1980, 8, 639–45.

Silverman, J., R. E. Steuer and A. W. Whisman, A Multi-Period, Multiple Criteria Optimization System for Manpower Planning, *European Journal of Operations Research*, 1988, 34, 160–70.

Summers, E. L., The Audit Staff Assignment Problem: A Linear Programming Analysis, *Accounting Review*, 1972, 67:3, 443–53.

Welling, P., A Goal Programming Model for Human Resource Accounting in a CPA Firm, *Accounting Organization and Society*, 1977, 4, 307–16.

We acknowledge the support of Bill Alread with the First Mortgage Strategies Group, and Glenda McNeal, president of the McNeal Mortgage Co., who introduced us to the bidding evaluation and process. They also provided data to test the solution methodology and validate the model and the algorithm.