Awarding Contracts at the National Institutes of Health: a Sensitivity Analysis of the Critical Parameters

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The National Cancer Institute (NCI) at the US National Institutes of Health (NIH) developed an initiative that will support tobacco prevention and control research in 17 states. The model that NCI used for choosing those states that would be funded is described in Hall et al. (Operations Research, Vol. 40, pp. 1040–1052, 1992). In this paper, we present sensitivity analyses of the critical parameters of that model, and we discuss the policy implications for nationwide tobacco control efforts.

Key words: smoking, tobacco, decision support, government

The American Stop Smoking Intervention Study (ASSIST), which commenced in 1992, is the largest public health project ever undertaken by the National Institutes of Health. The main goal of ASSIST is to put the nation on course toward meeting the Healthy People 2000 goal of a 50% reduction in smoking prevalence, from 30% in 1985 to 15% by the year 2000 (US Department of Health and Human Services, 1991, p. 140). To accomplish this goal, ASSIST will be conducted in a large number of entire states and will require combined financial resources of the federal government, state governments, and voluntary health associations. NCI initially contracted to contribute $114 million in federal funds; the selected states and associations will match this amount with a combination of in-kind and direct resources. ASSIST will attempt to demonstrate that a coordinated, comprehensive approach, structured around a state anti-tobacco coalition, and which includes a combination of mass media, policy changes, and cessation services, will produce a significant decrease in smoking prevalence.

To accomplish ASSIST goals, NCI determined that an appropriate mechanism was through the use of contracts. In the course of the standard federal contract review process, which included peer review, expert review, and budget negotiations, a list of 23 eligible states was compiled. The expert review resulted in a ranking of the states by a technical score that was based on the evaluation criteria and relative weights as described in the Request for Proposals (RFP).

The federal contracting process comprises a set of formal procedures into which many safeguards are built to preserve the fairness of competition between offerors. In general, contracts are awarded based on technical ability as reflected by technical score although the government always reserves the right to consider cost as a secondary factor. In the ASSIST RFP, language was included to make this a representative demonstration project, specifically by using two additional criteria, geographic distribution and smoking prevalence. Our work centered on refining the concepts behind these latter criteria, fitting them into a model with technical scores that would satisfactorily address all the criteria, and performing a series of sensitivity analyses.

The purpose of this paper is to describe in some detail the sensitivity analyses that were performed in the course of making the ASSIST site selection decisions. A detailed description of the model itself is provided in Hall et al. (1992) and is only briefly reviewed here.

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METHODS

The modeling process we used involved three stages: surveying and interviewing NCI decision makers on how to define geographic distribution and smoking prevalence, refining the decision makers' definitions, and building an optimization model to develop computer-generated solution sets. The first step used group sessions, mailed surveys, and personal interviews. This led to unanimous agreement that reaching a large number of smokers was an essential criterion for this demonstration project. There was also a consensus that a distribution of changes in smoking prevalence was preferable to selecting sites with only high or low rates of decline. When asked to explain this preference, the group cited a concern that the past smoking decline alone was not meaningful in predicting future trends in smoking prevalence.

In the next stage we used conjoint analysis to determine the relative weight each component criterion should have in making funding decisions, from the point of view of each decision maker. The results indicated that the following state attributes were important:

- number of smokers
- smoking prevalence
- a balanced mix of smoking prevalences among the states
- a balanced mix of smoking prevalence decline rates among the states.

We used a least-squares fit of the responses to determine the relationship of the first two attributes to overall preference. The best fit was given by the following function:

\[
\text{Preference score} = 2.07S - 0.45N,
\]

where \( S \) is the number of smokers and \( N \) is the number of nonsmokers, both in millions. Obviously, the function favors states with a higher prevalence rate and large states. The range of values for this function for all fifty states is shown in Fig. 1. This figure demonstrates that large states had an advantage in attaining a high preference score.

![Fig. 1. Preference scores for the fifty states by population.](image_url)

The second two attributes were addressed in a different way. We added constraints assuring that the solution set would have at least two states from each quartile for each of these two criteria, and then performed sensitivity analyses as discussed below.

The decision makers also felt that having adequate minority representation in the sample population was important, but we were prevented from including it as a criterion because it had not been explicitly mentioned in the RFP. We nevertheless documented minority information in presenting the results, and the final solution appeared relatively attractive in this regard.

The third step was to formulate and solve the optimization model. The first part of this step required converting the technical scores given by the review committee to a functional form. We
interviewed a key decision maker and determined that a function of the ranks of the technical scores satisfied this requirement. The objective function which transforms ranks into overall score has the form:

\[
\max \sum \frac{\exp(cx_i \delta_i)}{\exp(c)},
\]

where \(x_i\) is the rank of the \(i\)th proposal, \(c\) is the parameter that was estimated from the decision makers' responses, and \(\delta_i = 1\) if state \(i\) is selected and \(0\) if not (Hall et al., 1992). The value of \(c\) that best fit the data was \(c = 0.094\); the standard error of the estimate was \(0.022\).

In practical terms, our model was as follows:
- Given that we need at least 3 states per geographic region, and
- Given that we need at least 2 states in each quartile of smoking prevalence distribution, and
- Given that we need at least 2 states in each quartile of smoking decline distribution, and
- Given an estimated budget with the range of $110 to $118 million,

Which combination of states meets the primary objective of giving the maximum rank function score while equaling or exceeding a given preference score? (Hall et al., 1992)

To generate several solutions, we used a variety of different values in the constraints for the total preference score and the total budget. The model was solved using LINDO, version 5 (Schrage, 1991). We wrote a FORTRAN subroutine to interact with the software to solve the problem repeatedly for a range of input data.

RESULTS

To provide the context for the sensitivity analyses, we first summarize the results originally presented in Hall et al. (1992). Figure 2 shows the solution sets for a budget of $115.5 million. Each point in the figure represents a particular combination of states. The vertical axis is a measure of the ability of the funded states to achieve high technical scores. The horizontal axis represents the sum of the preference scores, defined earlier, for the funded states. Each point shows the maximum value on the vertical axis that can be achieved and still meet the preference requirement shown on the horizontal axis.

Our initial goal had been to stay within a $114 million budget, and we found a very competitive solution at $114 million. However, when we examined Fig. 2, we found a superior solution for less than 0.5% over budget ($114.485 million). This is point 6 in Fig. 2. This solution was quite attractive even when compared to other options with costs approaching $115.5 million.

![Fig. 2. Model's $115.5 million budget solution sets. See Table 1 for a description of these solution sets.](image-url)
Our model produced many solution sets. Solutions with the $114 million and $115.5 million constraints were shown to the decision-making team. The superiority of the $114.485 million solution, in terms of smokers reached and geographical balance, was obvious to the decision makers and thus contributed to this combination of states being awarded contracts. The selected solution set, however, was not an obvious one initially, and almost certainly would not have been discovered without the use of the model.

The details for some of the solution sets given to the decision makers are presented in Table 1. These details were essential for the analysis because they demonstrated the advantages and disadvantages of each point on the curve. The first two columns of data, ‘Straight 17’ and ‘Straight 18’, show what would happen if states were funded strictly by rank order. Both have serious problems. First, they do not meet the geographic distribution requirement. Second, funding the first 17 would fall well below the budget allocation but would miss about 1.5 million smokers that other solution sets would include. Funding the first 18 would require over $2 million more than originally allocated. These problems convinced the decision makers that funding solely by technical score would not meet the project’s objectives.

The solution sets we proposed based on our model offered clear advantages over rank-order funding, but we had to be able to justify violating the rank order. Each of the remaining solution sets in Table 1 have different qualities that make them attractive. All of them meet the geographic distribution requirement and all of them do so while not exceeding the budget by more than $1.5 million. All the sets also address at least as many smokers as ‘Straight 18’.

\begin{table}
\centering
\caption{ASSIST solutions: straight funding and model’s $115.5 million budgets sets}
\begin{tabular}{|c|c|c|c|c|c|}
\hline
Parameters & Straight 17 & Straight 18 & One* & Two* & Four* & Six* \\
\hline
# States & 17 & 18 & 18 & 18 & 18 & 17 \\
Budget$ & 108.87 & 116.30 & 115.146 & 115.298 & 114.973 & 114.485 \\
Total population$ & 83.51 & 86.75 & 86.84 & 87.16 & 87.14 & 90.12 \\
Total smokers$ & 18.15 & 18.88 & 18.87 & 18.98 & 19.08 & 19.78 \\
3 from region & No & No & Yes & Yes & Yes & Yes \\
Total Points & 70.32 & 71.92 & 70.99 & 70.43 & 69.56 & 67.95 \\
Preference Score & 16.45 & 17.12 & 17.13 & 17.30 & 17.59 & 18.28 \\
# Black, Quart-1$ & 4 & 4 & 4 & 3 & 4 & 4 \\
# Hisp, Quart-1$ & 3 & 4 & 3 & 5 & 4 & 4 \\
\hline
\end{tabular}
\end{table}

*not all solution sets are detailed in this table; these numbers refer to points in Fig. 3
$millions of dollars
$in millions
$number of states which are in the top quartile of minority population proportion

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Solution set Six, the one we most highly recommended, was chosen. This set funded states ranked 1–12, 14, 15, 19, 20, and 22, and includes a high number of smokers.

The first five solution sets in Fig. 2 were all more expensive than solution set Six while neither addressing as many smokers nor addressing as large a total population. The large gain in preference score seemed to justify the relatively small drop-off in total rank function score.

On the other hand, solution sets Seven through Nine in Fig. 2 all involved a precipitous drop-off in total rank function score, largely because some very highly ranked states would not be funded. None of these three alternatives, which cost up to $1 million more than solution set Six and yielded a relatively small increase in preference score, were viewed as being an efficient use of NCT's resources.

**SENSITIVITY ANALYSIS**

In addition to our analyses of different budget levels, we performed sensitivity analyses on the specification of the objective function (i.e., the specification of the vertical axis in Fig. 2) and on three separate groups of constraints in the model. In all instances, these sensitivity analyses were restricted to the cases involving a $115.5 million budget constraint. We describe the analyses and results in the next section.

*Sensitivity analysis of the objective function*

We first tested the sensitivity of the results to the value of $c$, which represents strength-of-preference for funding high- versus low-ranked applicants (see Methods). To do this, we re-ran the analyses with values of $c$ one standard error higher (more convex) and lower (less convex) than the base case of $c = 0.094$.

To show the three sets of results on a common scale, we standardized each total rank function. The highest value for each function was set equal to 1 and the lowest value was set equal to 0. Intermediate values were scaled proportionally. Thus, for example, for the base case with $c = 0.094$, the highest total rank function value of 70.987 was given a standardized value of 1, the lowest total rank function value of 57.14 was given a standardized value of 0, and each intermediate value $y$ was given a standardized value of $(y - 57.14)/(70.987 - 57.14)$. This standardization was possible since the two sets of states represented by the highest and lowest values were identical for all three values of $c$.

The results are shown in Fig. 3. Notice that the three curves are very similar. An analysis with any one of these three values of $c$ would have produced the same recommendation. The two curves for $c = 0.094$ and $c = 0.116$ each represent the exact same nine sets of states going from low to high

![Fig. 3. Sensitivity analysis.](image-url)
preference scores. (The curves do not exactly overlap because the exponential functions lead to small

differences between the standardized rank functions.) The conclusion from this figure is that an

increase in \( c \) has no effect on the solution sets. When \( c \) is decreased to 0.072, only one new solution is

introduced, and only one is eliminated. The switch occurs with the fifth point, going from left to right, on the two curves. However, neither of these points can be considered a strong candidate relative to

the sixth point on each curve which represents the final solution. We conclude that our solution is

robust with respect to the estimate of \( c \).

Sensitivity analysis of the constraints

We performed sensitivity analyses on three sets of constraints – those involving smoking decline

rates, smoking prevalence rates, and geography. The results are shown in Fig. 4.

As shown in Fig. 4a, the results are quite sensitive to the constraint that at least three states must

come from each of the Census Bureau’s four regions. When this constraint is relaxed to two states

from each region, or tightened to four states from each region, the ability to achieve the other

objectives of the program is markedly affected. It is interesting to note, however, that the line with

three states from each region and the line with two states from each region share the point that was

eventually chosen, point A in Fig. 4a (which is the same as point Six in Fig. 2). Thus the relaxed

formulation that required only two states from each region failed to provide a solution that

dominated the final choice.

The results for relaxing and loosening the constraints requiring at least two states from each

quartile of the distribution of smoking prevalence rates and smoking decline rates are shown in Fig.

4b and 4c. When the smoking prevalence rate requirement is increased from two to three per quartile,

there is a small shift in the curve downward and to the left. A shift downward reflects a lower rank

function score and a shift to the left indicates a lower preference function score, both of which are

undesirable. The advantages of point Six (small budget and large coverage of smokers and total

population) in Fig. 2 seemed to more than outweigh the advantage of having three states from each

smoking prevalence rate quartile. There is no shift when the smoking decline constraints are loosened

or tightened (Fig. 4c).

DISCUSSION

The federal government contracting process allows the funding out of technical score order in

situations where criteria are noted in the RFP, and this led to the model formulation described here

and in Hall et al. (1992). The NCI decision makers had to understand the nature of the tradeoffs of

funding out of order; this entire approach provided an optimal solution in the terms specified in the

RFP and revealed by the decision-making process.

We also tracked the number of minorities in each solution set and the number of states from each

of the top quartiles of black and Hispanic populations. In all solution sets, there were at least three

states from the top quartiles for both of these minority groups, thus addressing a concern of the

decision makers without including this as a formal constraint in the model.

The results of the sensitivity analyses affirmed the original parameterization of the model. This

provides additional confidence in the final solution chosen, and more importantly, provides

confidence in the process by which a final decision was reached. Our use of the rank function

approach was confirmed by the fact that the use of raw technical scores generated solution sets that

appeared unattractive.

One of the issues of interest in the sensitivity analyses was how our particular choice of rank

function affected the final recommendations. The objective function used in the model gave more

weight to differences in ranks between highly ranked states than between states that were ranked

farther down the list. The sensitivity analysis tested whether the amount of differential weighting

would matter in an important way. We found that, within the range we analyzed, the solution sets

were not affected when the differential weighting was increased. The only change at all in the list of

nine identified states was when the differential weighting was reduced. Here, some lower ranked
Fig. 4a–c. Model curves based on variations in three constraints. Note: X-axis is preference score; Y-axis is total rank function score; \( G \) = number required in each geographic region, \( P \) = number required in each smoking prevalence quartile, \( D \) = number required in each smoking decline quartile, A = solution set chosen by NCI.
states began to replace more highly ranked ones. Discussions with the NCI management and the NCI contracts office confirmed that such replacements would be inconsistent with the contracting standards for giving particularly heavy weight to the highly ranked states. Thus, the weighting and the sensitivity analyses reflected the decision makers' distinct preference for funding states which ranked highest on technical scores, although not at the complete expense of the other criteria.

The sensitivity analyses of the smoking prevalence and smoking decline quartiles also provided confidence in the model's results. The large budget, sufficiently generous to provide funding for about seventeen of the twenty-three qualified states, made these constraints less important than they had originally seemed. In fact, there was virtually no effect on the solution sets. NCI was fortunate in having a broad range of applicants that gave a good cross-section of the nation with respect to these two dimensions of smoking.

Geographic distribution had a strong effect on the results of the solutions. Both relaxing and tightening the geographic constraint had the effect of changing the solution sets that would have been presented to the decision makers. In fact, in early runs of the model, a less restrictive geographic constraint had been employed, and the solutions were not so appealing. We tightened the geographic constraint, therefore, to require three states from each Census Bureau region, better satisfying the intent of the language in the RFP.

The states that make up the ASSIST project contain a smoking population of approximately 20 million, or almost 40% of the total US smoking population. Whether ASSIST will meet its goals in 1998 of reducing smoking prevalence in this country remains to be seen, but we believe that the combination of states chosen for this project represent the best possible selection achievable, given the budget allocated, the states that applied, NCI's policies, and the goals of ASSIST.

REFERENCES