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GOAL PROGRAMING FOR LAND USE PLANNING

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ABSTRACT

A simple transformation of the linear programing model used in land use planning to a goal programing model allows the multiple goals implied by multiple use management to be explicitly recognized. This report outlines the procedure for accomplishing the transformation and discusses problems with use of goal programing. Of particular concern are the expert opinions often required to set up the programing matrix, the need for quantitative goals, the choice of relative weights for the goals, and the lack of explicit trade-offs. The relationships of goal programing to linear programing and the "satisficing" decision model are also discussed. Goal programming is not a panacea for poor planning and must be used with full recognition of its problems.

KEYWORDS: Management planning (forest), land use, National Forest development policy.

<u>Metric conversions</u>

1,000 acres	=	404.69 hectares
1,000 cubic feet	=	28.3 cubic meters
1 ton	=	0.9072 tonne
1 pound	=	0.4536 kilogram

INTRODUCTION

The purpose of land use planning on National Forests is "to promote the accomplishment of servicewide objectives and targets" subject to the land's potential and the public's desires (USDA Forest Service 1973a). To assure that this objective is met, the Forest Service has established guidelines for land use planning (USDA Forest Service 1973a). These guidelines are broad enough for considerable latitude in choice of planning tool. The National Forests in the Pacific Northwest Region have tried a number of comprehensive planning tools ranging from the computer complexities of Resource Capability System (USDA Forest Service 1973b) to the overlays proposed by McHarg (1969). However, the most common tool used is a formulation of linear programing (L-P) in which various average annual outputs are maximized or constrained according to alternative management schemes applied to specified acreages. In situations where a goal-oriented planning framework exists, modification of the L-P model to make it a goal programing model can provide increased flexibility in the land use planning process.

The purpose of this paper is to present a representative formulation of the L-P application and show how it may be modified for goal programing. In addition, various considerations and restrictions will be discussed so that land use planners and others interested in these techniques can become aware of the assumptions and problems involved in their application.

LINEAR PROGRAMING IN UNIT PLANNING

In land use planning on National Forests, each Forest is divided into large areas called planning units. For each unit, goals are established and a resource inventory is made. Then the planning unit is divided into homogeneous blocks of land or analysis units. These analysis units are separated on the basis of soils, stand types, elevation, etc., according to similarity of response to particular management programs.

Next, major present and potential outputs are identified for each analysis unit, and alternative management activities are drawn up emphasizing each output respectively but recognizing other outputs that jointly occur. The potential average annual outputs per acre and inputs are quantified for each activity. Table 1, which was developed for a particular analysis unit under present levels of inputs, shows an example of information produced by this procedure. The rows represent the major outputs, and the columns show the per-acre outputs associated with the alternative management activities. For instance, if we wish to emphasize grazing on an acre of this unit, we can expect to annually produce 150 pounds of forage, 0.5 potential visitor-days of dispersed recreation, 0.8 acre-feet

Table 1--*Example* of *an individual analysis unit output matrix*

Output per acre	Management activity		
	Dispersed recreation	Grazing	Wilderness
Timber (M fbm)	0	0	0
Forage (lb)	100.0	150.0	100.0
Dispersed recreation (visitor days)	2.0	5	.1
Water (acre-ft)	.8	.8	.8
Sediment (tons)	4.0	4.0	3.0
Wilderness (acres)	0	0	1.0

of water, 4.0 tons of sediment, and no wilderness.

The next step is to combine the results of the above procedure applied to each analysis unit into a matrix suitable for L-P such as is shown in figure 1. For this example, the three units to be analyzed are identified as 1A, 3A, and 6A. Unit 1A is similar to the unit shown in table 1. The column labels identify the primary output emphasis such as dispersed recreation, forage, and wilderness of the various management activities.

Next, the resource's productive potential is considered when desired output levels for the planning unit are established. These output goals are placed on the right-hand side of the matrix and set up as constraints below or above which the output is desired to be restricted. For example, in figure 1 the output of sediment has been restricted to less than or equal to 235,000 tons per year for the planning unit.

Finally., acreage and other special constraints must be added to the matrix. The acreage constraints require that the number of acres managed under the various management activities for a particular analysis unit .be less than or equal to the number of acres in that unit. In figure 1, the acres managed in units 1A, 3A, and 6A must equal 10,000, 15,000, and 20,000, respectively.

Additional special constraints may be set up, depending on other objectives that might not have been expressed explicitly. For example, in figure 1, rows 7 and 8 restrict wilderness to between 2,000 and 4,000 acres. Row 12, on the other hand, is set up to require 300 acres of modified timber management buffer zone (column 11) for each acre of developed recreation (column 10). Other constraints can be included as desired.

With the standard linear programing format, any row (output) may be chosen as the objective function and minimized or maximized as desired. However, it should be noted that only one objective function can'be specified at any one time with the other goals as constraints. For figure 1, the objective of maximizing timber production was chosen. After compilation of the matrix and specification of the objective function, the data are submitted to an appropriate computer program for solution.

The solution is expressed in number of acres in each analysis unit that will be allocated to the various management activities. For example, the solution (not shown) for the problem in figure 1 places 7,990 acres of unit 1A in the management activity which emphasizes dispersed recreation (column 1). In addition, the solution will also display total outputs of the planning unit. Alternative solutions are usually obtained by varying the objective function and the output levels.

At this point in the process we have quantitative estimates of acres assigned to each management activity and output levels for each alternative set of objectives and constraints. Although this is the end of the linear programing phase of the process, it is not the end of the total process. Still remaining is the assessment of the environmental, social, and economic effects of carrying out each alternative, informing the public of the alternatives and' their consequences, and finally making a decision and implementing it. During this process, the linear programing matrix may be modified and rerun at any time to show the consequences of different constraints and assumptions for input into the decisionmaking process.

ASSUMPTIONS IN PROGRAMING FOR UNIT PLANNING

The planner must be aware of several problems with the overall procedure. In addition to the often recognized problems of poor data, insufficient analysis, and failure to consider enough alternatives, some assumptions inherent in the linear programing formulation must also be considered.

First is the assumption that each analysis unit is homogeneous. That is, for each unit, every acre is the same as the average acre used in the analysis. This is generally not true; but to the extent that care is taken to select homogeneous analysis units, this problem can be minimized. In some cases, divisions of present units may be necessary to provide a greater degree of homogeneity. Dividing into

Output	Analysis unit of land													Right-hand side
	1A					3A			6A					
	Management activity by primary objective													
	Dispersed recreation	Forage	Wilderness	No management	Developed recreation	Maximum timber	Dispersed recreation	Forage	Maximum timber	Developed recreation	Modified timber management	Dispersed recreation	Forage	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	
	Units per acre													
1. TIMBER (M fbm)						0.25	0.22	0.24	0.15		0.1	0.12	0.14	= MAXIMUM OBJECTIVE
2. FORAGE (lb)	100	150	100	100	30	125	120	140	250		245	250	275	≥ 7,848,000
3. DEVELOPED RECREATION (visitor-days)					2.000					1,500				≥ 2,000
4. DISPERSED RECREATION (visitor-days)	2	0.5	0.1	0.1		0.5	0.75	0.5	5		6	5.5	0.5	≥ 135,000
5. WATER (acre-ft)	0.8	0.8	0.8	0.8	0.9	1.0	1.0	1.0	0.2	0.2	0.2	0.2	0.2	≥ 27,000
6. SEDIMENT (tons)	4	4	3	3	4	5	4.5	5	7	2	6	6	6	≤ 235,000
7. MAXIMUM WILDERNESS (acres)			1											< 4,000
8. MINIMUM WILOERNESS (acres)			1											≥ 2,000
9. 1A (acres)	1	1	1	1	1									= 10,000
10. 3A (acres)						1	1	1						= 15,000
11. 6A (acres)									1	1	1	1	1	= 20,000
12. RECREATION ZONE (acres)										-300	1			≥ 0

Figure 1.--Planning unit annual output matrix set up for linear programing for three land units.

many units, though, may create too many activities for the computer to process in a reasonable time period or the computer storage capacity may be exceeded. In other cases, aggregation of present units may result in expected deviations from average values that are entirely acceptable, thus reducing computer and model formulation workloads.

Second, it is assumed that the management program on one acre will not affect the output on a neighboring acre. In the case of timber management this may be fairly true, but a clearcut next to a campground could conceivably affect the number of visitor-days. In some cases, this problem may be surmounted by establishing special constraints to assure buffer zones between incompatible outputs such as was done in figure 1 for developed recreation.

Third, linear programing assumes linearity of coefficients. This means that if 1 acre provides for 5 visitor-days, 10 acres will provide for 50 visitor-days. Again, in the case of timber, water, and forage, this seems to be a reasonable assumption. However, in recreation for instance, a certain number of acres may be required before any visitor-days are produced. In some instances this problem can be solved by breaking the nonlinear relationship into a number of separate linear functions that approximate the original relationship.

Fourth, to keep the model simple and within the limits of available data, the effects of time and investments on the alternatives are ignored. That is, the outputs are expressed in terms of average annual potential rather than potential that varies with time or investment level. Furthermore, model simplification has compelled us to not plan for each acre individually. Thus, actually finding each acre for a particular management activity is not within the scope of the present model. These last two problems, although critical for unit planning concerned with general land allocation over the long run, are not considered within the L-P model and will need to be dealt with after the information available in the L-P solutions is obtained.

Fifth, as previously mentioned, linear programing allows only one objective or goal to be maximized or minimized. In the multiple use management required on National Forests, numerous (often conflicting) objectives exist. One solution to this fifth assumption is a technique called goal programing. For a discussion of other solutions, see Cohon and Marks (1975).

GOAL PROGRAMING FOR MULTIPLE USE DECISIONS

In situations where more than one objective exists, conflicts between the objectives are certain to arise when we seek optimal solutions. Charnes and Cooper (1961) proposed a technique called goal programing (G-P) designed to handle this type of situation. G-P is a unique approach to the problem of trying to achieve a set of simultaneously unattainable goals such as is often found in multiple use management. The approach consists of minimizing the difference between the solution and the goals instead of maximizing or minimizing the objective function in the traditional sense.

G-P has been applied on a few National Forests (Mount Hood, Tonto, Mark Twain). In each case the solution procedure involved specifying levels of production for timber, recreation, range, etc., which would be desirable and the production possibilities for the units of land involved under alternative management schemes. The G-P procedure then was used to allocate land to the various management schemes so as to achieve the desired levels of production as closely as possible. The following discussion outlines in technical terms how G-P may be applied and some of the problems that may be encountered.

There are a number of G-P formulations, but for our purposes an illustration of the linear equation form will be sufficient. Mathematically, this type of goal program can be expressed as:

$$\text{Minimize: } \sum_{i=1}^{n} (w_{1i}d_i^- + w_{2i}d_i^+)$$

$$\text{Subject to: } AX + Id^- - Id^+ = G$$

$$BX \leq C$$

$$X_j \geq 0 \quad j = 1, \ldots m$$

$$d_i^-, d_i^+ \geq 0 \quad i = 1, \ldots n$$

Where: d^-, d^+ = the vectors (n x 1) of the negative and positive deviational variables, respectively. These represent the solution's deviation from the goal vector, G(n x 1).

w_{1i}, w_{2i} = the weights and/or priorities for the deviational variables. Lee (1971) has proposed pre-emptive ranking, and Dyer (1972) has proposed subjectively determined cardinal scales.

A = the matrix (n x m) representing the relation between the decision variables vector, X(m x 1), and the goal vector, G(n x 1). In practice, the decision variables vector often represents inputs which are transformed by the A matrix to obtain the desired outputs or goals.

I = the identity matrix.

B = the matrix (c x m) of coefficients which relate the decision variables to the constraint vector, C(c x 1).

n, m, and c = the number of goals, decision variables, and constraints, respectively.

APPLICATION OF GOAL PROGRAMING TO LAND USE PLANNING

Several applications of goal programing exist in forestry, beginning with Field's (1973) general article in "Forest Science." Basically, two types of computer programs have been used in these applications, standard L-P and Lee's (1972) G-P. A standard L-P solution package has been used by Rustagi (1973) in analyzing reforestation decisions and by Porterfield (1973) in analyzing genetic programs. This procedure allows only valuing of goals according to their importance without considering pre-emptive priorities. Pre-emptive priorities are a procedure for ensuring that a goal of higher priority is completely satisfied before one of lesser priority is considered. The special G-P program by Lee (1972) allows one to set pre-emptive priorities for the goals in addition to the cardinal values or weights within a given priority level. Thus, Lee's program can do all the L-P version can and more. Unfortunately, the program is restricted to approximately 125 activities, whereas land use planners often develop over 1,000. It also requires considerable storage space and appears to be inefficient in its use of computer time. Modifications by Monteith and Colby (1974) and particularly Bottoms[1/] have partially overcome these size and efficiency problems.

The decision to use L-P for goal programing rests on a number of factors. First, L-P solution procedures are readily available whereas Lee's G-P may not be. Second, many land use planning problems are too large even for the expanded version of Lee's program. And finally, the use of pre-emptive priorities can be approximated by appropriate weights.

Application of the L-P solution procedure to goal programing in land use planning is relatively simple. Basically it involves adding an objective function and explicitly recognizing the deviational variables in the matrix formulation. As an example, figure 2 shows the results of this operation on figure 1. For each goal

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[1/] Kenneth E. Bottoms, Department of Range Science, Colorado State University, Fort Collins, personal letter, May 12, 1975.

output	Analysis unit of land.									
	1A					3A			6A	
	Management activity by primary objective									
	Dispersed recreation	Forage	Wilderness	No management	Developed recreation	Maximum timber	Dispersed recreation	Forage	Maximum timber	Developed recreation
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Units per acre									
0. OBJECTIVE										
1. TIMBER (M fbm)						0.25	0.22	0.24	0.15	
2. FORAGE (lb)	100	150	100	100	30	125	120	140	250	
3. DEVELOPED RECREATION (visitor-days)					2,000					1,500
4. DISPERSED RECREATION (visitor-days)	2	0.5	0.1	0.1	0	0.5	0.75	0.5	5	
5. WATER (acre-ft)	0.8	0.8	0.8	0.8	0.9	1.0	1.0	1.0	0.2	0.2
6. SEDIMENT (tons)	4	4	3	3	4	5	4.5	5	7	2
7. MAXIMUM WILDERNESS (acres)			1							
8. MINIMUM WILDERNESS (acres)			1							
9. 1A (acres)	1	1	1	1	1					
10. 3A (acres)						1	1	1		
11. 6A (acres)									1	1
12. RECREATION ZONE (acres)										-300

Figure 2.--Planning unit annual output matrix set up for linear programing

row (e.g., rows 1-5 in figure 2), one or two goal columns (e.g., columns 14-18 in figure 2) are added, depending on how deviations from the goal are perceived. If one is concerned only with minimizing underachievement, then the row can be set up as a "greater than or equal to" row and a 1 is placed where the goal row and deviational variable column cross. All the goals in figure 2 are set up in this fashion. Conversely, if one is concerned with minimizing overachievement (not shown), then the row should be a "less than or equal to" row and a -1 placed at the confluence of the goal row and column. If both overachievement and underachievement are to be minimized, then the row should be set up as an "equal to" row and both the plus and minus deviational variables should be added. In figure 2, the other necessary slack and artificial variables needed to achieve the solution are assumed to be added by the L-P computer program.

Finally, row 0 with the weights (e.g., 1,000, 100, 1, 10, and 10 in figure 2) for the deviations from the goals is specified as the objective; and the right-hand-side values for the goal rows are changed as necessary to show the desired output or goal levels. After this operation, the matrix is ready to be run using an L-P computer package to obtain the G-P solution. Alternative solutions may be obtained

Analysis unit of land' --Continued; 6A --Continued; Management activity by primary objective--Continued			Deviation variables					Right-hand side
Modified timber management	Dispersed recreation	Forage	Timber	Forage	Developed recreation	Dispersed recreation	Water	
(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	
- - - - - *Units per acre* - - -			*Value per M fbm*	*Value per lb*	*Value per visitor-day*	*Value per visitor-day*	*Value per acre-ft*	
			1,000	100	1	10	10	= MINIMUY OBJECTIVE
0.1	0.12	0.14	1					≥ 7,000
245	250	275		1				≥ 8,000,030
					1			≥ 2,003
6	5.5	0.5				1		≥ 135,000
0.2	0.2	0.2					1	≥ 27,000
6	6	6						≤ 235,000
								≤ 4,000
								≥ 2,000
								= 10,000
								= 15,000
1	1	1						= 20,000
1								≥ 0

with goal programing slacks **and objectives added** *for three land* **units.**

by varying goal levels, the deviation weights, or both as shown in table 2.

This particular example assumes that the goals are the five rows--timber, forage, developed recreation, dispersed recreation, and water--and that the right-hand-side values in figure 2 express the desired goal levels. Other types of goals could be added. Also, this formulation assumes that we are concerned with underachievement of these goals and that no penalty exists for overachievement.

COMPARISON WITH LINEAR PROGRAMING SOLUTIONS

To place **G-P** in perspective, it may be useful to compare it with other **L-P** formulations such as the "Resource Capability System" (**USDA** Forest Service 1973b) in an abstract sense. **L-P** will sometimes produce the same answers as those derived from **G-P**, but formulation of the problem is somewhat different. In both cases, units of output are weighted by relative values. However, with **L-P** we are concerned with the average value of the units over the range of outputs between zero and what is possible; in G-P, we are concerned with the values of the units that lie between our goals and what is possible.

Table 2--*Alternative* goals and weights and their associated outputs

Type of output	Units	Goal	Alternative weights[1]		
			A	B	C
Goal set 1:					
Timber	M fbm	7,000	6,019	6,375	6,019
Forage	Lb	8,000,000	8,000,000	8,000,000	8,000,000
Developed recreation	Man-days	2,000	2,000	2,000	2,000
Dispersed recreation	Man-days	135,000	135,000	115,752	135,000
Water	Acre-ft	27,000	27,000	27,000	27,000
Goal set. 2:					
Timber	M fbm	6,000	5,303	6,000	5,300
Forage	Lb	7,700,000	7,700,000	7,819,875	7,697,375
Developed recreation	Man-days	75,000	75,000	75,000	75,000
Dispersed recreation	Man-days	190,000	147,342	137,875	147,375
Water	Acre-ft	27,000	27,004	27,004	27,004

1/ The weights used for the objective function in column A were 10, 10, 10, 10, and 10 for timber, forage, developed recreation, dispersed recreation, and water, respectively; likewise the weights were 1,000, 100, 1, 10, and 10 for column B and 10, 10, 1,000, 1,000, and 500 for column C.

To the extent that these values are comparable, the two methods may produce similar results even though L-P maximizes the value of the output and G-P minimizes the difference between the goals and the outputs.

Yet, another qualifier must be added before the two methods will produce identical results--the goal used in G-P for a particular output must be close to the value that L-P will choose when it maximizes total benefits. To illustrate this point, look at figure 3 which represents a simple linear programing problem with two outputs, S and T, constrained by lines EF and CD and valued with prices represented by the slope of line AB. If we wish to maximize the value of S and T, we will produce OG units of S and OH units of T and operate at point Z. This is the solution an L-P type of formulation would show. If, for some reason such as political expediency or administrative decree, our goal is to produce OY units of S but none of T, then the G-P solution would be to produce OC units of output S and no units of output T. This solution minimizes the value of the discrepancy between the goal and what is possible if we assume the same price structure. Thus, situations exist where an L-P type formulation will produce a different solution from the G-P formulation even though prices are assumed to be linear with output.

IMPLEMENTATION CONSIDERATIONS

A number of points must be considered in the application of goal programing, but two extremely important ones are the problems of goal setting and weights versus priorities. Other points deal with the G-P portrayal of trade-offs between alternatives and the relationship of G-P to the decision-making framework called "satisficing."

Goal programing minimizes the discrepancy between the goals and their achievement, even when conflicts between goals exist. However, G-P says nothing about which goals or what levels are appropriate. Translating a broad objective such as "satisfying the needs of the Nation" into kinds of outputs and their relative values can be frustrating to say the least, but little help is available.

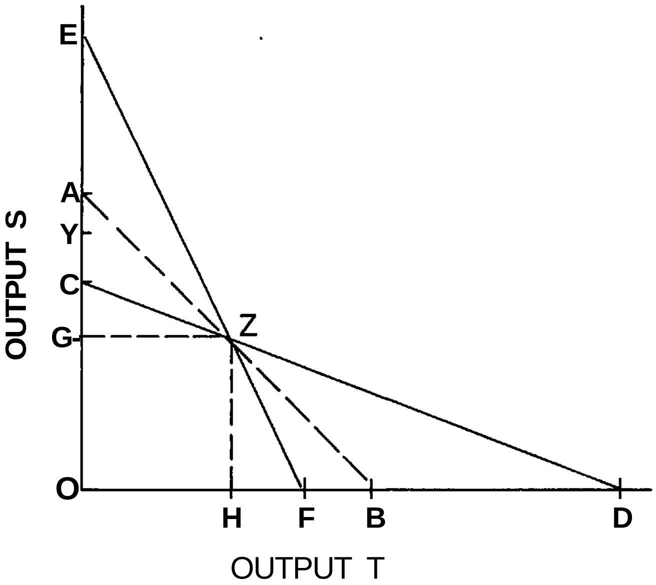

***Figure** 3.--Linear programing **formulation for two** outputs.*

GOALS

One way of setting the goals is to use the current output figures for the planning unit. This implies that the present situation is ideal, which may not be true. Another way is to solve the matrix with very low goal levels for the important outputs and see what outputs the solution produces. Then these outputs or biological capabilities can be modified by public opinion and the manager's input and can be used as the goals. Finally, the planner can avoid all responsibility by requiring the manager to construct some appropriate goals and their levels. This latter alternative may not be as bad as it sounds since the manager has the responsibility for setting the goals in the first place and is often in the best position to realize the desires of the public. In any case, the goals initially set need not remain fixed for all solutions but may be varied to test the sensitivity of the solution or may be modified if they are shown to be unrealistically low or high.

One caution should be discussed at this point. If goals are less than the possible outputs, then one may get an inferior or inefficient solution; that is, the solution outputs may be less than the maximum outputs for a given set of inputs. Figure 3, which displays a production possibilities curve labeled CZF, illustrates this point. When our goal is to produce OG units of output S and none of output T, then the solution which would be at point G is clearly inferior since we can get more of output S with no additional inputs. To avoid this situation, at least one goal should be set higher than the possible levels.

WEIGHTS

As discussed earlier, Lee's G-P program can handle priorities or weights or both, but the L-P formulation of G-P outlined in this paper can use only weights. In addition to expressing relative values, variations in the weights may compensate for goals stated in various kinds of units. This allows complete freedom to measure each goal in its appropriate unit such as dollars, board feet, acres, and visitor-days.

Priorities: Priorities are used to establish absolute dominance among goals. That is, a goal with a high priority must be satisfied (as far as possible) before any lower priority goals is considered. Contrary to Lee's (1972, p. 22) assumption, the application of priorities is not synonymous with ordinal ranking but requires the assumption that achievement of a high priority goal is more desirable than achievement of even a small amount of the goal at the next lowest priority. Ranking says nothing about the interval between priorities, but the use of priorities in goal programing requires an assumption regarding the interval.

Although the use of priorities relieves the planner of the task of establishing cardinal values for weights, few planners seem willing to let the computer determine the cardinal values. Because of this, some guidelines are needed for the establishment of the alternative method, the use of weights.

The Churchman-Ackoff Technique: One way to obtain relative weights for the deviational variables in the **G-P** objective is the Churchman-Ackoff (C-A) technique. This technique was originally developed by Churchman and Ackoff (1954) to obtain consistent relative values for alternative outcomes. It has been used subsequently by Turban and Metersky (1971) among others.

This technique, sometimes referred to as "two stage rating," is proposed here primarily because of the success others have had in similar situations. Other techniques classified as "multiple-regression" and "hybrid rating - regression" (see Huber 1974) have been developed. However, the C-A method seems preferable because it provides consistent relative values with minimum effort.

If (1) weights or values do exist, (2) these values correspond to the importance of the outputs, and (3) the addition of values can be associated with the addition of outputs, then the C-A technique is valid. Basically, the procedure which is necessary to develop consistent relative values involves the following process, illustrate# by a simple example:

1. Assuming we have four outputs, O_1, O_2, O_3, and O_4, to value; the first step involves ranking them by preference. In this case we will assume that the subscripts indicate our ranking with the lowest number being the most preferred.

2. The next step consists of associating numerical values with the outputs. The most preferred output.is valued at 1.00 and the others are assigned values less than 1.00, according to our relative preference for them. For instance, if a unit of O_1 is twice as desirable as O_3, then O_3 would be assigned a value of 0.5. Through this process we can assign values to O_2 and O_4 also. For our example we will initially assign the following unit values (V):

   $V_1 = 1.00$
   $V_2 = 0.70$
   $V_3 = 0.50$
   $V_4 = 0.40$

   where the subscripts correspond to the outputs.

3. Next we must establish that these values are consistent with our true preference scheme, so we compare combinations of outputs. First, we compare O_1 with $O_2 + O_3 + O_4$. If O_1 is preferred, then V_1 should be greater than $V_2 + V_3 + V_4$. If, as in our example, this is not the case, then adjustments must be made in V_2, V_3, and V_4 while maintaining their relative values. Now $V_1 = 1.00$, $V_2 = 0.40$, $V_3 = 0.25$, $V_4 = 0.15$. If O_1 was preferred, we proceed to a comparison of O_2 with $O_3 + O_4$.

4. If $O_3 + O_4$ is preferred to O_2, as in this example we assume it is, further adjustments in the values must be made to make. $V_2 < V_3 + V_4$. Now $V_1 = 1.00$, $V_2 = 0.40$, $V_3 = 0.30$, and $V_4 = 0.20$; each value is consistent with our preferences for its associated output. Since this is the final comparison we can make, the procedure is finished for our simple example. In cases where more outputs are considered, the procedure is continued until all the required comparisons have been made.

The values derived from this technique can now be used as the coefficients in the objective function of the **G-P** formulation, provided some precautions are observed. First, the values are not exact, since the technique allows some latitude in adjustments. Second, the values are relative and not absolute. And finally, the preferences for the outputs must be additive, which is not always the case.

Nonlinear Weights: In the discussion above, we assumed that the weights are linear--that is, the value is directly proportional to the amount of deviation from the goal no matter how much deviation occurs. Goal programing can handle situations in which this is not the case, as the following simple example illustrates.

Consider a situation in which a small deviation from a goal may not be very harmful but a large one may be disastrous. Figure 4 shows a loss function for this type of situation. Here, small deviations from the goal cost only 0.5 point per unit whereas

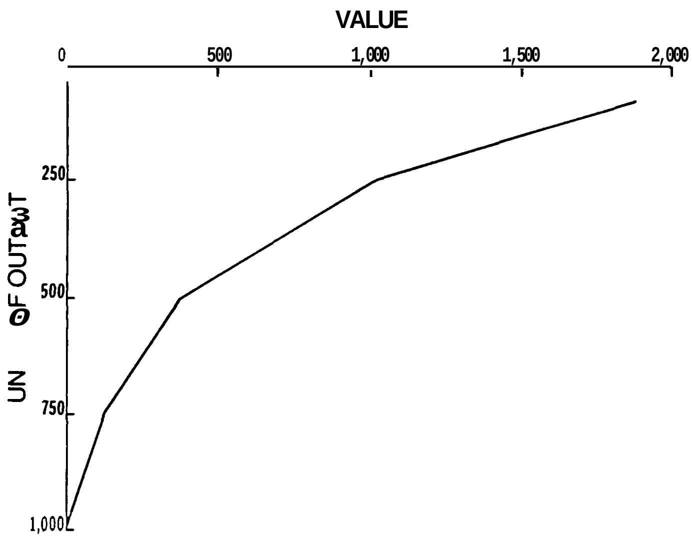

Figure 4.--Objective loss function for goal programing.

large deviations can cost up to 5.0 points per unit according to the slope of the line.

To set this situation up for G-P, we establish four output goals at different levels with their associated deviational variables (d_1, d_2, d_3, d_4) where "x" is the decision variable and "a" represents the relation between "x" and the output goals.

$$
\begin{aligned}
ax + d_1 &\geq 250 \\
ax + d_2 &\geq 500 \\
ax + d_3 &\geq 750 \\
ax + d_4 &\geq 1{,}000
\end{aligned}
$$

The weights for the deviational variables would reflect the loss function and would be incorporated into the objective function.

$$
\text{Minimize: } 2.5\, d_1 + 1.5\, d_2 + 0.5\, d_3 + 0.5\, d_4
$$

Other constraints and deviational variables could be added in the usual manner.

TRADE-OFFS

Goal programing has been faulted on a number of occasions for its inefficiency in showing trade-offs between alternatives. Cohon and Marks (1975, p. 214) state that the "decision makers are expected to supply the necessary data with no knowledge of what the feasible trade offs embodied in the noninferior set are." By this they emphasize the fact that with G-P the goals and their weights must be established outside the model, often without prior knowledge of possible alternatives.

This problem should have become apparent in the previous discussion on how to establish weights and goals. It can be alleviated only through numerous iterations of the G-P model in which the goals and their weights are allowed to vary. The results of these iterations, which will implicitly show some of the trade-offs, can then be used by the manager in deciding on appropriate weights and goals.

SATISFICING

Simon (1957) has proposed a behavioral decisionmaking model called "satisficing" which is achieving increased emphasis in present day decision models, e.g., Galbraith (1973). Basically, the model depends on the observation that decisionmakers react to uncertainty and lack of information by setting targets which they seek to achieve rather than by maximizing or minimizing an objective. With this model, alternatives can easily be measured in terms of whether or not they achieve the goals. This simple decision framework has great intuitive appeal; circumstantial evidence indicates that it has widespread use by decisionmakers, particularly in planning.

Lane (1970) suggests that goal programing provides a useful representation of the satisficing model which improves on the other representations using either simulation or fixed constraint levels. By requiring that targets or goals be established with penalties for nonachievement, G-P in essence duplicates the important attributes of the satisficing model. Thus, G-P can provide a behavioral approach to decisionmaking in land use planning.

CONCLUSION

Goal programing has generated considerable interest as a tool for land use planning in multiple goal situations. It does present problems in terms of somewhat difficult data requirements--linearity in its usual form, possible inferior solutions, and lack of explicit recognition of tradeoffs. Yet it also presents opportunities for handling complex situations, quickly portraying alternatives, allowing more than one goal, and simulating the satisficing decision framework. G-P has been used on a few National Forests and seems to have provided a useful service to the planners in analyzing their alternatives in these instances. However, it is not a panacea for poor planning and must be used with full recognition of its shortcomings.

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