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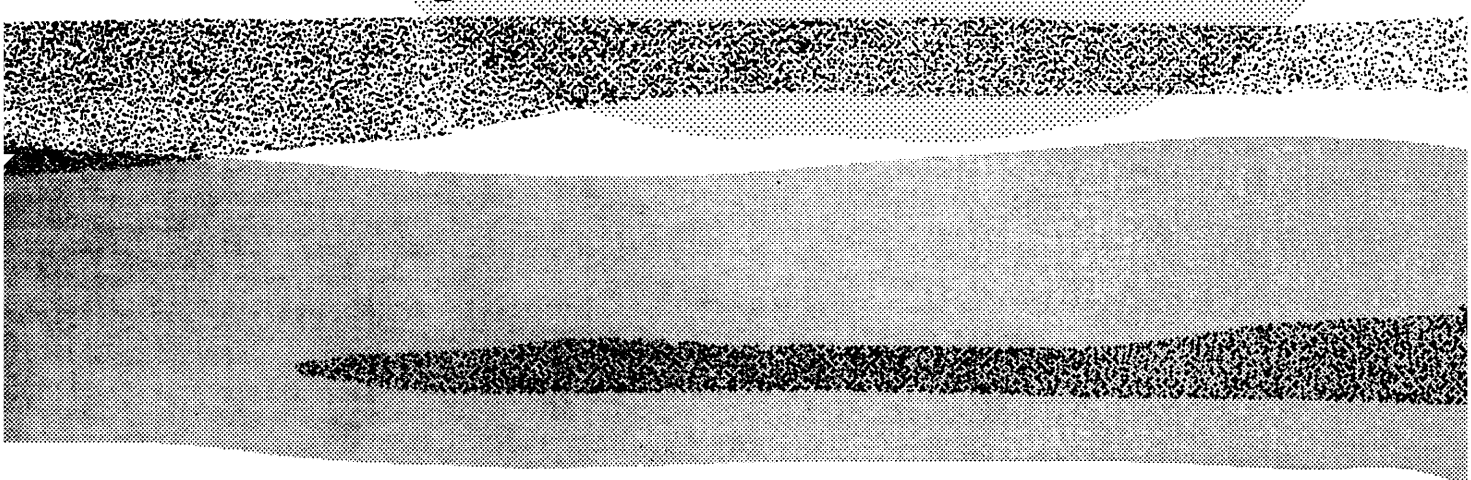
selecting forest residue treatment alternatives using goal programing



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ABSTRACT

The use of goal programing for selecting forest residue treatment alternatives within a multiple goal framework is described. The basic features of goal programing are reviewed and illustrated with a hypothetical problem involving the selection of residue treatments for 10 cutting units. Twelve residue-regeneration treatment combinations are evaluated, using physical, economic, and environmental goals. Empirical results are reported for four different goal priority sets. An interpretation of the sensitivity of the optimal treatment schedule associated with each priority set is also presented. Results indicate that goal programing offers considerable promise as an operational decisionmaking tool. Unresolved problems include: the selection of decision variables and the quantification of goal attainment levels, goal preferences, and the relationships between forest residue treatment methods and managerial goals.

Keywords: Forest residues, computer programs.

Much attention has been focused on the problems associated with the generation and disposition of forest residues in the Pacific Coast States. Concerns range from:

a. The volume of logging residues left following harvesting (Howard 1973), to

b. The economic and environmental impacts associated with a variety of residue reduction treatments (Bare and Jayne 1973, Cramer 1974), to

c. The feasibility of using logging and mill residues as potential sources of electrical energy generation and as raw material for forest products (Grantham et al. 1974).

The central objective of many of these and other studies has been the analysis of alternative methods of residue reduction. This paper focuses on the problem of examining selected economic and environmental impacts associated with alternative residue treatment methods; the specific objective is to demonstrate the potential use of goal programing.

Because of the dynamic nature of a forest ecosystem, almost any action taken to modify or dispose of forest residues has an impact or influence on other forest resources. Thus, the forest manager must evaluate the tradeoffs between residue reduction alternatives and their subsequent impacts on the environment, other forest resources, and people. Unfortunately, it is usually difficult or impossible for a manager to adequately evaluate these tradeoffs because the benefits and the undesirable effects of alternative treatments are seldom understood, the relationships between residues and other forest resources are not well documented, and few of the above consequences can be well quantified. The complexity and natural variability inherent in residues-related problems also add to the difficulty of evaluating treatment alternatives.

Pierovich and Smith (1973) have proposed a general framework for decisionmaking, concerning the evaluation of residue reduction alternatives. They emphasize that any operational framework should allow a decisionmaker to analyze treatment alternatives within a multiple use context.

The objective of this paper is to explore the utility of goal programing as an operational decisionmaking tool for analyzing selected forest residue treatment alternatives within the multiple use framework proposed by Pierovich and Smith. Since goal formulation is an integral part of multiple use management, any operational tool must have the flexibility to accommodate diverse sets of objectives. Goal programing provides this capability to resource managers.

Following an introduction to, and discussion of, the goal programing technique, an illustrative residue treatment application is presented. The paper concludes with a summary and statement of recommendations for future work in this area.

INTRODUCTION TO GOAL PROGRAMING

Goal programing is a variation of linear programing. As such, it retains the same basic assumptions of proportionality, additivity, and divisibility. Also, goal programing, like linear programing, is a deterministic decisionmaking technique. However, goal programing differs in having the capability of incorporating multiple objectives. This is accomplished by establishing a set of goals to be attained. Goal programing then seeks an allocation of resources which minimizes the sum of the deviations from these specified goals.

A preference structure for ranking and/or weighting goals is also incorporated within the goal programing procedure. This allows a decisionmaker to explicitly specify the importance of attaining any particular goal in comparison with any other goals he may be considering. In summary, goal programing translates a multiple objective. planning problem into a single objective function problem by focusing on the minimization of deviations from specified goals.

The term "goal programing" was coined by Charnes and Cooper (1961), whose concept of "goal attainment" evolved as a means for solving previously unsolvable linear programing problems. The goal programing literature has expanded rapidly since then. Presently, the texts of Ijiri (1965) and Lee (1972) provide the only complete treatments of the theoretical concepts underlying goal programing.

Use of goal programing within a forest management planning context is also recent. Both Rustagi (1973) and Field (1973) have demonstrated the potential and the limitations in this respect. Lyon[1/] has applied goal programing to a hypothetical accounting problem in the forest industry, and Porterfield (1973, 1974) has used goal programing in studying the efficiency of tree improvement programs. Romesburg (1974) has applied goal programing to the scheduling of recreation and wilderness areas. The U. S. Forest Service has published a goal programing user's manual with illustrative examples (U. S. Department of Agriculture Forest Serivce 1974). The manual is intended for those who wish to use Lee's (1972) simplex-based algorithm for solving goal programing problems on a computer. No applications of goal programing to evaluate residue reduction treatment alternatives have been found in the literature,

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1/ Lyon, Gary. 1974. Applications of goal programming and accounting for control in the forest industry. Unpublished manuscript. Res, Pap., 53 p. Coll. For. Resour., Univ. Wash., Seattle.

The general formulation of a goal programing problem (after Lee) is:

$$\text{Minimize } Z = w_1 d^- + w_2 d^+$$

subject to:

$$Ax + Id^- - Id^+ = b$$

$$Bx \{\leq, =, \geq\} h$$

$$x_j \geq 0 \text{ for all } j = 1, 2, \ldots, n$$

$$d_k^- \geq 0 \text{ for all } k = 1, 2, \ldots, m$$

$$d_k^+ \geq 0 \text{ for all } k = 1, 2, \ldots, m$$

$$d_k^+ \cdot d_k^- = 0 \text{ for all } k = 1, 2, \ldots, m$$

where

w_1, w_2 = (1xm) vectors of priority factors (P_k, k = 1, 2, . . . , m) for ordinal ranking and differential weights ($a_{i,k}$, i = 1, 2, . . . , m; k = 1, 2, . . . , m) for cardinal weighting within a given priority rank. These weighting vectors, therefore, can be expressed as: $w_\ell = (\alpha_{1,k} P_k, \alpha_{2,k} P_k, \ldots, \alpha_{m,k} P_k)$, $\ell = 1, 2$ and $k = 1, 2, \ldots, m$

d^-, d^+ = (mxl) vectors of negative and positive deviational variables representing negative and positive deviations from goals.

b = (mxl) vector of desired goal levels
A = (mxn) matrix of coefficients which relate the technical relationships between decision variables and goals
x = (nxl) vector of decision or choice variables
I = (mxm) identity matrix
B = (rxn) matrix of coefficients which relate the technical relationships between decision variables and constraints
h = (rxl) vector of constraint levels
n = index referring to the number of variables
m = index referring to the number of goals
r = index referring to the number of constraints

Except for the restriction, $d_k^+ \cdot d_k^- = 0$, it is readily apparent that this problem can be solved with the simplex method of linear programing. Since d_k^- and d_k^+ are linearly dependent, the simplex algorithm automatically ensures that the above stated constraint is always satisfied. Therefore, these latter constraints will be ignored in the remainder of this paper.

As formulated above, the problem is to minimize the sum of positive and negative deviations from a set of specified goal levels subject to a set of constraints. Hence, it is assumed that all goals are to be as closely attained as possible. Many times, however, overachievement of a particular goal is an acceptable outcome. In such cases, the positive deviational variable can be deleted from the objective function. In this case, the objective is to minimize the underachievement of a goal by driving the negative deviational variable to zero. However, the positive deviational variable in solution is free to take on any value ≥ 0. If underachievement of a goal is an acceptable outcome, the negative deviational variable is deleted from the objective function. In this case, the objective is to minimize the overachievement of a goal by driving the positive deviational variable to zero. However, the negative deviational variable in solution is free to assume any value ≥ 0. If, as originally stated above, exact achievement is desired, both the positive and negative deviational variables must appear in the objective function.

One of the key features of goal programing is its ability to allow a decisionmaker to ordinally rank goals according to his own preference structure. The effect of this ordinal ranking in the solution process is to force the goal with the highest priority to be satisfied as closely as possible before the next lower ranking goal is considered. Several goals may be assigned the same priority factor. A set of preemptive 'priority factors is assigned to goals to indicate the desired ranking. These priority factors are defined such that $P_k >>> P_{k+1}$, which implies that a goal ranked at P_k is more important than a goal ranked at P_{k+1}. ,This relationship among goals holds throughout the entire solution process, In particular, at any point in the computational process, a variable cannot enter the solution and, hence, improve the attainment of a goal at a given priority level at the expense of a goal assigned a higher priority.

In addition to the ranking of goals through the assignment of priority factors, deviational variables within a given priority level may be assigned differential weights. These weights express the relative opportunity cost or regret associated with one unit of unsatisfactory deviation from the goal level (Ijiri 1965). These so-called "coefficients of regret" are assigned to deviational variables associated with a common goal and assigned a common priority factor. The challenging problem is to define these "coefficients of regret." Arbitrary assignments of weights are valid only so long as other decisionmakers agree. In the end, each decisionmaker must pass judgment on the appropriateness of assigned weights and priority factors.

ALGORITHMS FOR GOAL PROGRAMING

The simplex algorithm of linear programing can be used to solve goal programing problems. However, if more than one priority level is involved, the preemptive priority factor must be converted to numerical values to preserve the desired ranking. Field (1973) has suggested a "priority factor algorithm" for determining these numerical values, thus permitting use of the standard simplex algorithm.

Lee (1972) has modified the standard simplex algorithm in such a way that numerical coefficients for the different preemptive priority factors are not required. Instead, his method accepts the ordinal ranking of goals as provided by the decisionmaker. This preference structure is subsequently incorporated into the simplex algorithm by maintaining a matrix of $Z_j - C_j$ values[2/] instead of the customary row vector, Each row of the matrix contains $Z_j - C_j$ values for a particular priority level. At each iteration of the simplex algorithm, the row of the matrix corresponding to the highest priority factor currently being considered is used to determine the column vector entering the solution. Only after a goal is attained "as closely as possible" is the next lowest priority level considered. However, as previously stated, a variable, which may be a candidate for entering the solution, cannot enter if it will be done at the expense of a goal assigned to a higher priority.

In other words, all $Z_j - C_j$'s associated with a column vector must be considered before an entering column vector can be selected. Charnes and Cooper (1961) have suggested a third alternative for including priority factors in a goal programing model. However, since their method increases the size of the problem by adding constraints on deviational variables and because it may not produce the true optimum solution, it will not be further discussed in this paper.

In comparing the first two alternatives presented above, Lee (1972, p. 127) states:

> ...some researchers have used the conventional linear programming package by converting the preemptive priority factors to numerical values. However, the use of linear programming by estimating the numerical values of multiple conflicting goals brings us right back to where we started. Conceptually, goal programming is based on ordinal solution on the basis of priority of goals. Consequently, the use of linear programming... not only defeats the very purpose of the goal programming approach, but also violates the basic rule of goal programming.

[2/] $Z_j - C_j$ is common terminology for the evaluation row of the simplex tableau used to determine the column vector that should enter the basis to minimize the objective function at the fastest rate.

Field (1973) also acknowledges this: "His [Lee's] approach appears to represent the only completely satisfactory means of guaranteeing a desired ordinal ranking." The basic issue, of course, is that as soon as preemptive priorities are converted to numerical values, a cardinal rather than an ordinal measure is adopted, and one goal becomes X-times as important as another.[3/] However, if the preemptive priorities can be correctly converted to numerical values, the solution is unaffected.

Lee's modified simplex procedure was used to solve all goal programing problems presented in this paper. A version of this algorithm, modified to run on the CDC 6400 computer system, was obtained and implemented.[4/] According to Lee (1972), the program has been completely tested and debugged. However, occasional problems were encountered, requiring corrective code. An obvious limitation of Lee's program concerns the maximum size of the problem that can be solved. This results because all matrices are retained in central memory during the computational process. For example, approximately 32,000 decimal words of central memory were required for the illustrative problem presented below. As formulated, this goal programing problem allowed up to 9 priority levels, 40 constraints and/or goals, and 180 variables.

AN EXAMPLE OF GOAL PROGRAMING

The following example is intended to illustrate features of goal programing as applied to a specific multiple use decisionmaking problem; namely, the selection of alternative residue reduction treatments consistent with certain prespecified goals.

The problem involves the selection of an appropriate combination of residue and regeneration treatment alternatives for 10 cutting units located on the western slopes of the Washington Cascade Range, such that certain goals are attained as closely as possible while simultaneously satisfying all constraints. Relevant characteristics of these 10 cutting units are shown in table 1.[5/] Some of these data were extracted from reports describing the current condition of recently logged cutting units'on the Skykomish Ranger District of the Mount Baker-Snoqualmie National Forest. Other data were fabricated for this example.

[3/] Technically, Lee's preemptive priority factors imply an infinite value ratio and hence a cardinal relation between two goals. However, his algorithm is <u>conceptually</u> based on an ordinal ranking and yields an ordinal solution.

[4/] This program was obtained from Kenneth Bottoms, a management analyst in the Land Use Planning Group, U.S. Forest Service, Fort Collins, Colo.

[5/] See the last page of this report for conversion factors for metric units.

Table 1--*Description of cutting units requiring treatment*

Cutting unit number	Acreage	Slope	Residue	Elevation	Aspect	Condition of slash[1]
		Percent	*Tons/acre*	*Feet*		
1	15	90	80	1,500	South	Dry
2	10	20	100	1,600	North	Green
3	56	10	80	2,800	Flat	Dry
4	19	25	100	2,500	South	Dry
5	25	90	100	1,900	West	Green
6	2	25	80	3,100	South	Dry
7	70	20	80	3,200	West	Dry
8	49	40	40	4,000	Northwest	Dry
9	20	25	100	3,700	South	Green
10	50	90	80	2,000	Northeast	Dry

[1]Dry = Dry slash without needles.
Green = Green slash with needles.

Four alternative residue reduction treatments and three alternative regeneration treatments were considered. These treatment combinations and their respective cost and success ratios[6/] are given in table 2. In addition to these treatment alternatives, two sets of constraints and six sets of goals were included.

Table 2--*Residue-regeneration treatment combinations*[1]

Residue alternatives	Residue, cost/acre	Regeneration alternatives					
		Natural		Hand plant		Aerial seed	
		Cost/acre	Success	Cost/acre	Success	Cost/acre	Success
	Dollars	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*
Do nothing	0	0	20	200	65	15	50
Broadcast burn	80	0	45	110	75	15	65
Machine pile and burn	160	0	55	90	80	15	70
Hand pile and burn	250	0	40	90	70	15	60

[1]Assumptions are (1) machine piling and burning not feasible on cutting units with slopes greater than 35 percent, and (2) success ratios are reduced 20 percent for cutting units over 3,000 feet in elevation on southern exposures.

[6/] Success ratios measure the chance of achieving a fully stocked stand within 3 years of the initial residue-regeneration treatment.

CONSTRAINTS

The first set of constraints specifies that each of the 10 cutting units be completely treated by one or more of the above listed treatment alternatives. The second set specifies that machine piling and burning is not feasible on cutting units with slopes over 35 percent.

GOALS

Six types of goals are included in the example. These are:

a. An annual residue budget goal
b. An annual regeneration budget goal
c. A success ratio goal for each unit following stand establishment
d. A rate of spread goal for each unit following treatment
e. A particulate matter goal associated with residue burning
f. A set of goals for soil loss resulting from each residue treatment method.

These goals, along with the constraints and the various treatment alternatives, are transformed into a goal programing framework as follows.

PROBLEM FORMULATION

Let x_j be the proportion of a cutting unit subjected to one of the feasible residue-regeneration treatment combinations. For clarity, these treatment combinations are listed and numbered in table 3.

Table 3--*List of possible residue-regeneration alternatives*

Treatment combination number	Description of combination	
	Residue treatment	Regeneration treatment
1	Do nothing	Natural
2	Do nothing	Hand plant
3	Do nothing	Aerial seed
4	Broadcast burn	Natural
5	Broadcast burn	Hand plant
6	Broadcast burn	Aerial seed
7	Machine pile and burn	Natura1
8	Machine pile and burn	Hand plant
9	Machine pile and burn	Aerial seed
10	Hand pile and burn	Natural
11	Hand pile and burn	Hand plant
12	Hand pile and burn	Aerial seed

Since a total of 12 treatment combinations exists for each of the 10 cutting units, the problem involves a maximum of 120 variables. However, because machine piling and burning is not a feasible alternative on cutting units 1, 5, 8, and 10, due to the maximum slope constraint, only 108 variables actually are needed.

In addition to these 108 choice variables, the negative and positive deviational variables must also be considered. **For** example, variable x_{33} represents the proportion of the third cutting unit to be treated using hand piling and burning as the residue treatment and aerial seeding as the regeneration method.

The constraint set for the problem can now be expressed as shown in equations 1-10:

$$\sum_{j=s}^{t} x_j = 1 \qquad \begin{array}{l} t = 9,\ 21,\ 33,\ 45,\ 54,\ 66,\ 78,\ 87,\ 99,\ 108 \\ s = 1,\ 10,\ 22,\ 34,\ 46,\ 55,\ 67,\ 79,\ 88,\ 100 \end{array} \qquad (1\text{-}10)$$

Goals to be included in the problem have been listed. The first goal, the annual residue treatment budget, can be written as:

$$\sum_{j=1}^{108} a_{1,j}\, x_j + d_1^- - d_1^+ = b_1 \qquad (11)$$

The $a_{1,j}$ coefficients represent the total cost of treating the residue on a cutting unit using one of the feasible treatment alternatives. For example, consider coefficient $a_{1,28}$ = \$8,960. This is the total cost of treating the residue on cutting unit 3 (56 acres) by machine piling and burning at a cost of \$160 per acre. The two deviational variables in equation 11 reflect the underachievement or overachievement of a given residue budget goal (b_1). The residue budget goal presented here is merely a target level which a land manager believes is a realistic cost for accomplishing a job. This is also true for the regeneration budget goal.

The annual regeneration treatment budget can be expressed as:

$$\sum_{j=1}^{108} a_{2,j}\, x_j + d_2^- - d_2^+ = b_2 \qquad (12)$$

The $a_{2,j}$ coefficients represent the total cost of regenerating the cutting unit using one of the feasible alternatives. Consider coefficient $a_{2,18}$ - \$150. This is the total cost of aerial seeding the second cutting unit (10 acres) at a cost of \$15 per acre following machine piling and burning of the residue. The deviational variables in equation 12 represent the underachievement or overachievement of a given regeneration budget goal (b_2).

The third set of goals (i.e., goals 3-12) concerns the success ratio for newly established stands. With data displayed in table 2, these goals are formulated as:

$$\sum_{j} a_{k,j}\, x_j + d_k^- - d_k^+ = b_k, \quad \text{for all } k = 3, 4, \ldots, 12 \qquad (13\text{-}22)$$

The index of summation (j) in the above goals is as previously defined in equations 1-10. For example, for the fourth cutting unit, the goal is:

$$\sum_{j=34}^{45} a_{6,j}\, x_j + d_6^- - d_6^+ = b_6$$

The $a_{k,j}$ coefficients represent the success ratio for newly established stands and are as listed in table 2. The b_k terms represent the success ratio goals for each of the 10 cutting units.

The fourth set of goals (i.e., goals 13-22) concerns the potential rate of spread of the fuels left on the cutting unit following the selected residue treatment. These goals are expressed as:

$$\sum_{j} a_{k,j}\, x_j + d_k^- - d_k^+ = b_k, \quad \text{for all } k = 13, 14, \ldots, 22 \qquad (23\text{-}32)$$

The index of summation (j) is as defined above. The $a_{k,j}$ coefficients in equations 23-32 represent the potential rate of spread of the perimeter of a fire in chains per hour. These coefficients were estimated as a function of the slope of each cutting unit, the feasible residue treatment alternatives, and the condition of the slash. Because this type of information was not readily available, it was necessary to use postulated values and relationships. Consequently, base line rates of spread were assumed for slopes of 10-30 percent. These figures were doubled for slopes of 31-60 percent and redoubled for slopes of 61-90 percent.[7/] Table 4 contains the resulting assumed values. The rates of spread identified with each feasible residue treatment on each cutting unit were computed using these values--for example, $a_{14,10} = 15$. Thus, if the green slash on cutting unit 2 is left untreated, a potential rate of spread of 15 chains per hour is expected. The b_i values for equations 23-32 represent the rate of spread goals specified for each cutting unit.

[7/] Other factors likely influencing the rate of spread include solar radiation, moisture content, temperature, and size, shape, and distribution of the residues. However, additional experimentation and analysis are needed before these and other factors can be incorporated into any comprehensive land management decisionmaking process.

Table 4--*Assumed potentia2 rates of spread (perimeter increase) affected* by *slope, residue treatment method, and condition of slash*

(In chains per hour)

	10-30	31-60	61-90
No treatment:			
Dry slash	22.5	45	90
Green slash	15	30	60
Broadcast burn	2	4	8
Machine pile and burn	1	2	(1)
Hand pile and burn	3	6	12

[1]Not considered feasible.

The fifth set of goals to be formulated (i.e., goals 23-26) concerns the particulate matter released into the atmosphere as a result of burning. For this example, it was assumed that the 10 cutting units were clustered into 4 groups. Further, it was assumed that it was advantageous to burn residues on four different occasions. Cluster one contained cutting units 1-3, cluster two contained cutting units 4 and 5, cluster three contained cutting units 6-8, and cluster four contained cutting units 9 and 10. The particulate matter goals are expressed as:

$$\sum_{j=1}^{33} a_{23,j}\, x_j + d_{23}^- - d_{23}^+ = b_{23} \tag{33}$$

$$\sum_{j=34}^{54} a_{24,j}\, x_j + d_{24}^- - d_{24}^+ = b_{24} \tag{34}$$

$$\sum_{j=55}^{87} a_{25,j}\, x_j + d_{25}^- - d_{25}^+ = b_{25} \tag{35}$$

$$\sum_{j=88}^{108} a_{26,j}\, x_j + d_{26}^- - d_{26}^+ = b_{26} \tag{36}$$

The $a_{k,j}$ coefficients in equations 33-36 represent hundreds of pounds of particulate matter released into the atmosphere as a result of burning residue on a specified cutting unit. The total pounds of particulate generated from broadcast and pile burning were comp'uted by multiplying the amount of residue on each cutting unit as reported in table 1 by the conversion coefficients shown in table 5. These coefficients are only rough approximations and are used here for illustrative purposes only. The resulting coefficients for each of the 10 cutting units were computed using these data. For example, coefficient $a_{23,27}$ = 268. 8 pounds of particulate (hundreds of pounds). Thus, if the third cutting unit is completely broadcast burned, a total of 26,880 pounds of particulate will be emitted into the atmosphere (i.e., 80 tons/acre X 56 acres X 6 pounds of particulate/ton). The b_k values (k = 23, 24,. .., 26) for equations 33-36 represent the particulate level goals for clusters of cutting units which will be treated simultaneously. The basic assumption in these equations is the additive effect realized by burning several cutting units. However, this assumption is likely not valid and will be discussed later.

Table 5--*Assumed amount of particulate matter generated for each residue treatment method and condition of slash*

(Pounds per ton)

Residue treatment	Dry slash	Green slash
Do nothing	0	0
Broadcast burn	6	24
Machine pile and burn	4	17
Hand pile and burn	4	17

The sixth and final set of goals (i.e., goals 27-30) concerns the assumed soil loss generated from each residue treatment method. These losses are considered to be only short term (i.e., 3 years or less). This set of goals is formulated as:

$$\sum_j a_{k,j} x_j + d_k^- - d_k^+ = b_k, \text{ for all } k = 27,\ 28,\ 29,\ 30 \qquad (37\text{-}40)$$

The index of summation (j) is as previously defined in equations 33-36 since the effects of soil loss are assumed additive for each cluster of cutting units as it is treated. The $a_{k,j}$ coefficients in equations 37-40 represent the soil loss generated on each cutting unit after a specific residue treatment. These coefficients were obtained by multiplying the number of acres on each cutting unit as reported in table 1, by the conversion coefficients shown in table 6. These conversion coefficients, like the particulate conversion coefficients, are approximations and used only for illustrative purposes. Soil loss was estimated for each residue treatment for cutting units with slopes of 31-60 percent. These estimates were reduced by 10 percent for slopes of 10-30 percent but increased by 15 percent for slopes of 61-90 percent. Thus, if cutting unit 1 is broadcast burned, a total of 7.545 tons of soil will be lost over a 3-year period (i.e., 15 acres X 0.503 ton/acre). The b_k values (k = 27, 28, 29, 30) for equations 37-40 represent the soil loss goals for the cutting units treated together.

Table 6--*Assumed soil loss generated by residue treatment method for a given slope class*

(Tons per acre)

Residue treatment	Percent slope		
	10-30	31-60	61-90
No treatment	0,338	0.375	0.431
Broadcast burn	.394	.438	.503
Machine pile and burn	.422	.469	([1])
Hand pile and burn	.373	.414	.476

[1]Not considered feasible.

RESULTS OF TRIAL RUNS

To demonstrate the sensitivity of the optimal solution under varying goal priority structures, four trial runs were conducted. The goal levels, deviational variables, priority factors, and differential weights assumed in these trial runs are given in table 7.

The first trial run involved 108 decision variables, 30 positive deviational variables, and 40 negative deviational variables, for a total of 178 variables, (Note that a negative deviational variable was associated with equations 1-10.) A total of 40 rows (10 constraints and 30 goals) was also involved.

In the first trial run, each goal was given a priority of P_1 and a differential weight of 1. Either or both negative and positive deviations from their corresponding right-hand side values were allowed for each goal in each of the trial runs. Both negative and positive deviations from residue and regeneration budget goals were specified in the objective function, indicating that exact attainment of each goal was desired. Recall that the residue and regeneration budget goals referred to here are merely target costs which a land manager would consider realistic to accomplish a job. The positive deviational variables for the regeneration success goals were omitted from the objective function, denoting that overattainment was acceptable. Similarly, the negative deviational variables for the rate of spread, particulate emission, and soil loss goals were omitted from the objective function, indicating that underachievement was acceptable. The goal levels are shown in table 7.

Table 7--*Priority structure of goals for trial runs*

Goal number	Goal description	Goal level	Priority of deviational variables[1]							
			Run 1		Run 2		Run 3		Run 4	
			d_k^-	d_k^+	d_k^-	d_k^+	d_k^-	d_k^+	d_k^-	d_k^+
1	Residue budget (dollars)	50,000	P_1	P_1	P_1	P_1	P_3	P_3	P_3	P_3
2	Regeneration budget (dollars)	20,000	P_1	P_1	P_1	P_1	P_3	P_3	P_3	P_3
	Regeneration success (percent):									
3	Unit 1	75	P_1		P_1		P_2		P_1	
4	Unit 2	75	P_1		P_1		P_2		P_1	
5	Unit 3	75	P_1		P_1		P_2		P_1	
6	Unit 4	75	P_1		[2]0.25 P_1		P_2		P_1	
7	Unit 5	75	P_1		P_1		P_2		P_1	
8	Unit 6	75	P_1		P_1		P_2		P_1	
9	Unit 7	75	P_1		P_1		P_2		P_1	
10	Unit 8	75	P_1		P_1		P_2		P_1	
11	Unit 9	75	P_1		P_1		P_2		P_1	
12	Unit 10	75	P_1		P_1		P_2		P_1	
	Rate of spread (chains):									
13	Unit 1	0		P_1		P_1		P_2		P_2
14	Unit 2	0		P_1		P_1		P_2		P_2
15	Unit 3	0		P_1		P_1		P_2		P_2
16	Unit 4	0		P_1		P_1		P_2		P_2
17	Unit 5	0		P_1		P_1		P_2		P_2
18	Unit 6	0		P_1		P_1		P_2		P_2
19	Unit 7	0		P_1		P_1		P_2		P_2
20	Unit 8	0		P_1		P_1		P_2		P_2
21	Unit 9	0		P_1		P_1		P_2		P_2
22	Unit 10	0		P_1		[2]4P_1		P_2		P_2
	Particulate (pounds):									
23	Units 1-3	50,000		P_1		P_1		P_1		P_5
24	Units 4-5	60,000		P_1		P_1		P_1		P_5
25	Units 6-8	40,000		P_1		P_1		P_1		P_5
26	Units 9-10	60,000		P_1		P_1		P_1		P_5
	Soil loss (tons):									
27	Units 1-3	32		P_1		P_1		P_1		P_4
28	Units 4-5	18		P_1		P_1		P_1		P_4
29	Units 6-8	47		P_1		P_1		P_1		P_4
30	Units 9-10	30		P_1		P_1		P_1		P_4

[1]The negative and positive deviational variables, d_k^- and d_k^+, represent the negative and positive deviations from each goal where the subscript k is the index for each goal number.

[2]Each priority has a differential weight of 1 associated with it except as shown here.

The optimal prescription of treatments for trial run 1 is reported in table 8. The corresponding values of the deviational variables are shown in table 9. Observe in table 8 that no single residue or regeneration treatment is prescribed for all cutting units. One apparently surprising result is that, although broadcast burning is only used sparingly, machine piling and burning is prescribed for each of the six cutting units where it is a feasible alternative. However, an examination of the goals for this trial run indicates that this is exactly what should occur.

Let's consider each goal separately to see why this is true. Goal number 1 is to meet as closely as possible the residue budget goal which would be specified by a land manager as a realistic target. Since "no treatment" has no associated costs, treatment selection should only be from those alternatives which do have costs. Broadcast burning all 316 acres at a cost of $80 per acre would utilize only $25, 280 of the $50, 000 residue budget. Therefore, it is reasonable that more costly residue treatments likely would have been prescribed on some of the cutting units. A reexamination of table 2 shows that the regeneration success ratios for machine piling and burning dominate those for broadcast burning as well as hand piling and burning. Similarly, machine piling and burning results in the lowest potential rates of spread (table 4).

Table 8--*Optimal treatments for trial run 1. Equal priorities and weights*

Cutting unit number	Treatment combination number	Treatment description	Proportion of unit
1	5	Broadcast burn, hand plant	1.000
2	8	Machine pile and burn, hand plant	.500
	9	Machine pile and burn, aerial seed	,500
3	8	Machine pile and burn, hand plant	.500
	9	Machine pile and burn, aerial seed	,500
4	8	Machine pile and burn, hand plant	.500
	9	Machine pile and burn, aerial seed	.500
5	5	Broadcast burn, hand plant	,566
	11	Hand pile and burn, hand plant	.434
6	8	Machine pile and burn, hand plant	1.000
7	9	Machine pile and burn, aerial seed	1.000
8	11	Hand pile and burn, hand plant	1.000
9	8	Machine pile and burn, hand plant	1.000
10	5	Broadcast burn, hand plant	.631
	6	Broadcast burn, aerial seed	.324
	11	Hand pile and burn, hand plant	.045

Table 9--*Goal achievement results*

Goal number	Goal description	Underachievement (d_k^-)[1]				Overachievement (d_k^+)[1]			
		Trial run number				Trial run number			
		1	2	3	4	1	2	3	4
1	Residue budget (dollars)	0	0	0	10,560.00	0	0	5,541.43	0
2	Regeneration budget (dollars)	0	0	0	0	0	0	17,312.57	5,407.50
	Regeneration success (percent):								
3	Unit 1	0	0	0	0	0	0	0	0
4	Unit 2	0	0	0	0	0	0	0	0
5	Unit 3	0	0	5.95	0	0	0	0	0
6	Uint 4	0	5.00	10.00	0	0	0	0	0
7	Unit 5	2.17	2.17	6.43	0	0	0	0	0
8	Unit 6	11.00	11.00	11.00	11.00	0	0	0	0
9	Unit 7	5.00	5.61	5.49	0	0	0	0	0
10	Unit 8	5.00	5.00	5.00	0	0	0	0	0
11	Unit 9	11.00	11.00	23.00	11.00	0	0	0	0
12	Unit 10	3.47	1.84	6.24	0	0	0	0	0
	Rate of spread (chains):								
13	Unit 1	0	0	0	0	8.00	8.00	8.00	8.00
14	Unit 2	0	0	0	0	1.00	1.00	2.00	1.00
15	Unit 3	0	0	0	0	1.00	1.00	6.71	1.00
16	Unit 4	0	0	0	0	1.00	1.00	22.50	1.00
17	Unit 5	0	0	0	0	9.74	9.74	25.74	8.00
18	Unit 6	0	0	0	0	1.00	1.00	1.00	1.00
19	Unit 7	0	0	0	0	1.00	1.12	4.91	1.00
20	Unit 8	0	0	0	0	6.00	6.00	6.00	4.00
21	Unit 9	0	0	0	0	1.00	1.00	15.00	1.00
22	Unit 10	0	0	0	0	8.18	8.00	31.41	8.00
	Particulate (pounds):								
23	Units 1-3	78.8	78.8	42.9	78.8	0	0	0	0
24	Units 4-5	0	0	296.6	0	0	0	0	76.0
25	Units 6-8	91.2	91.2	113.1	52.0	0	0	0	0
26	Units 9-10	23.6	20.0	479.8	20.0	0	0	0	0
	Soil loss (tons):								
27	Units 1-3	0	0	0	0	3.40	3.40	0	3.40
28	Units 4-5	0	0	0	0	2.30	2.30	0	2.59
29	Units 6-8	0	0	0	0	3.67	3.46	0	4.85
30	Units 9-10	0	0	0	0	3.53	3.59	0	3.59

[1]The negative and positive deviational variables, d_k^- and d_k^+, represent the negative and positive deviations from each goal where the subscript k is the index for each goal number.

The particulate matter resulting from both machine piling and burning and hand piling and burning is identical, and both produce less particulate matter than does broadcast burning (table 5). The only case where machine piling and burning is not the preferred treatment is when soil loss is considered (table 6). In this instance, hand piling and burning and broadcast burning are the preferred treatments. However, the difference between treatments is not enough to offset the overall superiority of machine piling and burning when measured in terms of the other goals.

Another result revealed in table 8 is the prescription of multiple treatments on a particular cutting unit. Fractionalization is not desirable but is unavoidable if goal programing is used to solve the stated problem. While this may detract somewhat from the practical usefulness of goal programing, it still permits the use of the technique as a planning tool to evaluate the impacts of various residue treatments.

Table 9 displays the results of trial run 1 in terms of goal attainment. The results show that all goals cannot be achieved if a single priority is specified and all differential weights are equal to 1. In particular, the regeneration success goals for cutting units 5-10 are underachieved. Also, as expected, none of the rate-of-spread goals are achieved. However, the minimum possible rates of spread are achieved for all but cutting units 5, 8, and 10. The particulate emission goals, set at hypothetical maximum-permissible levels, were met or exceeded in all cases (i.e., there was underachievement of each of the goal levels). However, none of the soil loss goals were held within their hypothetical maximum permissible levels. Lastly, the residue and regeneration budgets are achieved exactly, thus resulting in completely utilizing both budgets.

Whether the goal achievements and the prescribed treatments are acceptable is a matter of conjecture. To examine this question further, it was decided to evaluate the sensitivity of the optimal solution to changes in differential weights associated with selected deviational variables in the objective function. Accordingly, a second trial run was formulated. In this run, it was assumed that, if possible, the rate of spread on cutting unit 10 should be reduced to 8 chains per hour--the minimum for the unit. In an effort to achieve this rate-of-spread goal, a differential weight of 4 was assigned to the positive deviational variable associated with goal number 22. Further, a differential weight of 0. 25 was assigned to the negative deviational variable associated with the regeneration success ratio goal for the fourth cutting unit. Thus, attainment of the 75-percent regeneration success ratio on the fourth cutting unit was only one-quarter as important as was the attainment on the other nine units. All other differential weights were set to unity, and all goals were given equal priority.

The goal structure for trial run 2 is summarized in table 7, and the optimal treatment prescriptions are shown in table 10. The results in table 10 are very similar to those of the first trial run. The goal attainment for run 2 is shown in table 9. Of particular interest are the goal achievement levels of the two goals whose corresponding differential weights were modified. As seen in table 9, the regeneration success on cutting unit 4 was underachieved by 5 percent after the 0. 25 differential weight was assigned.

Table 10--*Optimal treatments for trial run 2. Equal priorities and differential weights with two exceptions: (1) the differential weight for the negative deviational variable of goal 6 is 0.25; and (2) the differential weight for the positive deviational variable for goal 22 is 4*

Cutting unit number	Treatment combination number	Treatment description	Proportion of unit
1	5	Broadcast burn, hand plant	1.000
2	8	Machine pile and burn, hand plant	.500
	9	Machine pile and burn, aerial seed	.500
3	8	Machine pile and burn, hand plant	.500
	9	Machine pile and burn, aerial seed	.500
4	9	Machine pile and burn, aerial seed	1.000
5	5	Broadcast burn, hand plant	.566
	11	Hand pile and burn, hand plant	.434
6	8	Machine pile and burn, hand plant	1.000
7	9	Machine pile and burn, aerial seed	.939
	12	Hand pile and burn, aerial seed	.061
8	11	Hand pile and burn, hand plant	1.000
9	8	Machine pile and burn, hand plant	1.000
10	5	Broadcast burn, hand plant	.816
	6	Broadcast burn, aerial seed	.184

However, unexpectedly, the regeneration success on cutting unit 7 was also slightly worse than in trial run 1. Also, the rate of spread on cutting unit 10 was reduced to a minimum of 8 chains per hour after the new differential weight of 4 was assigned. However, the rate of spread on cutting unit 7 was slightly higher than in run 1. Note that the new differential weights also slightly affected the attainment of goals 12, 26, 29, and 30.

It is clear that, in this problem formulation, the use of the two differential weights does not significantly affect either the prescribed treatments or the goal attainment levels. This does not come as a surprise because a sensitivity analysis of the optimal solution to run 1 revealed the insensitivity of the problem to perturbations in these two differential weights, as well as the others. However, the second trial run was formulated to demonstrate this property.

In addition to allowing the inclusion of differential weights within a given priority level, goal programing is also capable of solving problems involving more than one priority. To demonstrate this powerful feature, two additional trial runs are presented.

For trial run 3, highest priority was assigned to the two environmental goals (i.e., soil loss and particulate emission). Second highest priority was assigned to goals for rate of spread and regeneration success, and lowest priority was assigned to the two budget goals. The optimal treatment prescriptions for trial run 3 are presented in table 11. As expected, in an effort to achieve the two environmental goals, no residue treatment was prescribed for a portion of six of the cutting units, Also, machine piling and burning was prescribed for only one unit. Another difference between runs 1 and 2 and run 3 was that hand planting was prescribed for all cutting units.

Table 11--*Optimal treatments for trial run 3. Three priorities*

Cutting unit number	Treatment combination number	Treatment description	Proportion of unit
1	5	Broadcast burn, hand plant	1.000
2	5	Broadcast burn, hand plant	1.000
3	2	No treatment, hand plant	.190
	11	Hand pile and burn, hand plant	.810
4	2	No treatment, hand plant	1.000
5	2	No treatment, hand plant	.286
	11	Hand pile and burn, hand plant	.714
6	8	Machine pile and burn, hand plant	1.000
7	2	No treatment, hand plant	.098
	11	Hand pile and burn, hand plant	.902
8	11	Hand pile and burn, hand plant	1.000
9	2	No treatment, hand plant	1.000
10	2	No treatment, hand plant	.249
	11	Hand pile and burn, hand plant	.751

The most interesting difference between this run and the previous two is seen in table 9. Recalling that highest priority was assigned to goals 23-30, we see that the soil loss goals were achieved and that a substantial improvement over the hypothetical maximum tolerable particulate emission was realized. These environmental goals were achieved at the expense of the lower priority goals. For instance, the goal attainment levels for priority-two goals were worse for a majority of the goals, with only one goal showing any improvement. Last, the two priority-three, budget goals for residue and regeneration were both overachieved. This implies that the prescribed optimal treatments cannot be undertaken unless additional funds are secured.

Trial run 3 demonstrates the importance of goal priority specification and its effect on the recommended course of action. To further illustrate this point, a fourth trial run was made.

Trial run 4 involved five priority levels. The goals and their associated goal levels are shown in table 7. The goals for trial run 4 by priority were: (1) regeneration success, (2) rate of spread, (3) budget, (4) soil loss, and (5) particulate emissions. As in trial run 3, all differential weights within a given priority were set equal to 1.

The optimal treatment prescriptions for trial run 4 are displayed in table 12. As expected, machine piling and burning and broadcast burning are the preferred treatments.

.The goal attainment results shown in table 9 reveal that all regeneration success goals except those associated with cutting units 6 and 9 are achieved. Note, however, that the maximum possible regeneration success for both units is 64 percent. Thus, it is impossible to achieve the 75-percent success being sought. In effect, then, all priority-one goals are achieved. The second-priority goals (i.e., rate of spread) are also achieved as fully as possible. The residue budget goal is underachieved, resulting in a surplus of funds, while the regeneration budget is overachieved, resulting in an over-commitment of funds. However, there is a net surplus of unallocated funds. The four soil loss goals are overachieved; resulting in more than the theoretical permissible amount of soil loss. Last, three of the particulate emission goals are underachieved, while one is over-achieved. Thus, in three of four cases, the prescribed treatments will produce less than the theoretical maximum tolerable level of emissions.

Table 12--*Optimal* treatments for *trial run 4. Five* priorities

Cutting unit number	Treatment combination number	Treatment description	Proportion of unit
1	5	Broadcast burn, hand pile	1.000
2	8	Machine pile and burn, hand plant	.500
	9	Machine pile and burn, aerial seed	.500
3	8	Machine pile and burn, hand plant	.500
	9	Machine pile and burn, aerial seed	.500
4	8	Machine pile and burn, hand plant	.500
	9	Machine pile and burn, aerial seed	.500
5	5	Broadcast burn, hand plant	1.000
6	8	Machine pile and burn, hand plant	1.000
7	8	Machine pile and burn, hand plant	.500
	9	Machine pile and burn, aerial seed	.500
8	5	Broadcast burn, hand plant	1.000
9	8	Machine pile and burn, hand plant	1.000
10	5	Broadcast burn, hand plant	1.000

CONCLUSIONS AND RECOMMENDATIONS

The principal objective of this paper was to explore the potential of goal programing for evaluating forest residue treatment alternatives. An example was presented to highlight selected aspects of this evaluation.

It is clear that, while goal programing offers considerable promise as an operational decisionmaking tool, it is by no means a panacea for residue treatment selection. Furthermore, the drawbacks discussed below are in no way unique to the evaluation of residue treatment alternatives. In fact, these same drawbacks are common to similar forest management applications of goal programing.

The implications of the divisibility and additivity assumptions of goal programing were demonstrated by the illustrative sample problem. The former assumption permits a cutting unit to be treated by multiple residue and/or regeneration treatments. For instance, in run number 1, two residue and two regeneration treatments were prescribed for cutting unit 10 (table 8). This fractionalization might cause serious problems if an attempt was made to implement the goal programing solution in a real-world environment. Additional study along these lines is warranted.

A possible solution would be to use an integer linear programing algorithm to solve the problem, However, since no integer goal programing algorithm utilizing an ordinal ranking of goals currently is available, this would necessitate assigning a set of numerical preemptive priority factors.[8] As already discussed, this defeats the very purpose of goal programing.

The implications of the additivity assumption were also highlighted in the illustrative sample problem by the introduction of the particulate matter and soil loss goals. Although it is true that simultaneously burning residue on several units results in a cumulative particulate emission effect, it is probably incorrect to assume that such effects are additive. This also applies to the soil loss goals.

Further, if the cutting units are burned under reasonable atmospheric conditions at different times, there probably would not be any significant cumulative effect. Under these conditions, it may be more appropriate to establish individual emission goals for each cutting unit rather than one cumulative goal for all units. These two drawbacks are also common to linear programs.

A second difficulty encountered in using goal programing lies in goal specification. A decisionmaker or analyst planning to use goal programing must be very precise in specifying goal attainment levels and priorities. Optimal solutions under certain combinations often produce surprising results which at first may seem incorrect. However, it is usually discovered that the goals were either misformulated or inappropriately weighted or ranked. Although the precise quantification of goal attainment levels and priorities is listed here as a drawback, it should also be pointed out that because goal programing can accept this type of information, it is also one of the strong points of the technique.

At the present state of development, it is difficult or impossible to adequately quantify goals, goal attainment levels, or goal preferences. This is especially true if they are interpreted within a multiple use planning context. For example, in his discussion of goals and decisionmaking in the U. S. Forest Service, Alston (1972) states that ". . . priority determination must become an explicit as well as an integral part of the planning activity." Alston also discusses the importance of assigning weights to the various goals. As previously presented, goal programing can accommodate both the ordinal ranking of goals and the cardinal weighting of goals as specified by a decisionmaker, The fact that most managers currently do not explicitly rank or weight goals is not very surpirsing. However, to make maximum use of goal programing, it is clear that this is precisely what must be done.

[8] According to Lee, an integer goal programing algorithm utilizing ordinal ranking procedure has recently been developed.

Another problem associated with using goal programing concerns the dearth of information needed to adequately estimate coefficients. While this difficulty is common to most programing analyses, it is one which seriously limits operational usefulness. Conversely, however, the use of programing techniques graphically points out existing data gaps. Not only does this provide management with an assessment of its current level of knowledge and understanding, it also accommodates an evaluation of the degree of reliability to be associated with the results of the analysis.

Last, concern over computational matters encountered in using goal programing for residue treatment evaluation deserves additional comment. Because goal programing permits the inclusion of a variety of functionals, it is sometimes difficult to decide on the most appropriate form for any given problem. This was illustrated in the sample problem presented earlier. Both the analyst and the decisionmaker must be very careful in exploring the implications of alternative functionals before committing themselves.

A second computational limitation is that Lee's computer program can accommodate only relatively small problems. For example, in the sample formulation only 15 to 20 cutting units could be included in an analysis of residue treatment alternatives. Of course, Lee's algorithm could be reprogramed to handle larger problems or use could be made of regular linear programing computer packages which easily accommodate much larger problems. However, in this latter case, an ordinal ranking of goals can not be accommodated.

The principal recommendation of this paper is that goal programing be further evaluated in a real-life decisionmaking environment. Only in this way can a more realistic decision be made concerning the usefulness of the technique for evaluating forest residue reduction treatments. Specifically, it is recommended that the next step be to work with the staff of a National Forest to structure a real-life test of the model illustrated in this paper. A necessary prerequisite of such an application will be a modification of Lee's computer program to accommodate larger problems or the use of a standard linear programing package. Additional investigation is required before a choice between these two can be recommended.

Goal programing is one of the few mathematical programing techniques which offer considerable promise as an aid for making operational decisions in a multiple goal context. By its very nature, it appears compatible with the explicit or implicit decisionmaking procedure utilized by forest managers. Thus, continued research into the applicability of the technique is recommended at this time.

LITERATURE CITED

Alston, Richard M.
1972. FOREST -- Goals and decisionmaking in the Forest Service. U. S. Dep. Agric. For, Serv., Res, Pap. INT-128, 84 p. U.S. Dep. Agric. For. Serv., Intermt. For, & Range Exp. Stn., Ogden, Utah.

Bare, Bruce, and Benjamin A. Jayne.
1973. Evaluating logging residue production systems through simulation. *In* Proc. Nonpoint Pollut. Environ. Qual. Control Conf., p. 56-63. Univ. Wash., Seattle.

Charnes, A., and W. W. Cooper.
1961. Management models and industrial applications of linear programming. Vol. 1, 471 p. John Wiley, New York.

Cramer, Owen P., ed.
1974. Environmental effects of forest residues management in the the Pacific Northwest. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. PNW-24, 556 p. U. S. Dep. Agric. For. Serv., Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Field, David B.
1973. Goal programming for forest management. For. Sci. 19(2):125-235.

Grantham, John B., Eldon M. Estep, John M. Pierovich, and others.
1974. Energy and raw material potentials of wood residue in the Pacific Coast States: A summary of a preliminary feasibility investigation. U. S. Dep. Agric. For. Serv., Gen. Tech. Rep. PNW-18, 37 p. U.S. Dep. Agric. For. Serv., Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Howard, James O.
1973. Logging residue--volume and characteristics. U. S. Dep. Agric. For. Serv., Resour. Bull. PNW-44, 26 p. U.S. Dep. Agric. For. Serv., Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Ijiri, Y.
1965. Management goals and accounting for control. 191 p. North Holland Publ. Co., Amsterdam.

Lee, Sang M.
1972. Goal programming for decision analysis. 387 p. Auerbach Publishers, Philadelphia.

Pierovich, John M., and Richard C. Smith.
1973. Choosing forest residues management alternatives. U. S. Dep. Agric. For. Serv., Gen. Tech. Rep. PNW-7, 11 p. U.S. Dep. Agric. For. Serv., Pac. Northwest For. & Range Exp. Stn., Portland, Oreg:

Porterfield, Richard L.
1973. Predicted and potential gains from tree improvement programs: A goal programming analysis of program efficiency. Ph. D. thesis. Yale Univ. , New Haven, Conn. 240 p.

Porterfield, R.
1974. The goal programming model, in quality control in the forest and mill. CA Rep. No. 54, p. 61-91. Tech. Assoc. Pulp & Pap. Ind.

Romesburg, H. C.
1974. Scheduling models for wilderness recreation, J. Environ. Manage. 2: 159-177.

Rustagi, Krishna P.
1973. Forest management planning for timber production: a goal programming approach. Ph. D. thesis. Yale Univ. , New Haven, Conn. 166 p.

U. S. Department of Agriculture, Forest Service.
1974. Goal programming user's manual. 45 p. [D. Monteith, ed.] U.S. Dep. Agric. For. Serv., East. Reg., Milwaukee.

CONVERSION FACTORS

1 foot = 0. 3048 meter

1 surveyor's chain (66 feet) = 20. 1168 meters

1 acre = 0.4046856 hectare

1 pound = 0.453592 kilogram

1 short **ton** (2,000 pounds) = 0. 907184 metric ton

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