Timber Management Planning with Timber RAM and Goal Programming

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Abstract: By using goal programming to enhance the linear programming of Timber RAM, multiple decision criteria were incorporated in the timber management planning of a National Forest in the southeastern United States. Combining linear and goal programming capitalizes on the advantages of the two techniques and produces operationally feasible solutions. This enhancement may also be applicable to linear programming packages other than Timber RAM.

INTRODUCTION

In its timber management planning, the Forest Service, U. S. Department of Agriculture, often uses a linear programming (LP) package called Timber RAM (Resources Allocation Method) to calculate the potential yield under forest regulation. Regulation is defined as that future arrangement of forest treatments in space and time which achieves specified long-term objectives. The other part of timber management planning, harvest scheduling, is the treatment of existing forest conditions to achieve short-term goals and make some move towards the regulated condition. This planning phase is generally being carried out in some subjective, nonoptimal manner. I show here how goal programming (GP) might be used to improve the utility of Timber RAM for both forest regulation and harvest scheduling.

Timber RAM

To understand this paper, the reader must be somewhat familiar with the LP-based Timber RAM. Space does not permit a complete description here; for details on the Timber RAM package, see Navon (1971). Timber RAM is a set of computer programs which (1) generate input for any of several standard LP solution packages, and (2) produce final reports based on the input and the LP solutions. The latest versions of these programs are written for Univac 1100-series computers using the EXEC 8 operating system. However, the LP matrix generated for Univac's Functional Mathematical Programming System (FMPS) can also be solved using IBM's Mathematical Programming System (MPS). Timber RAM can also produce a matrix for solution by Univac's linear programming package ILONA. Earlier versions of Timber RAM are available for CDC and IBM computers.

Input data for Timber RAM include current stand conditions, projected yields of alternative treatments, regulation methods, harvest flow and budgetary constraints, regeneration possibilities and limitations, stand accessibility, and associated economic data and constraints. Different decision criteria can be entered by specifying indices of performance, such as volume, net revenue, and cost, with associated discount rates and periods of optimization. The user selects a single objective function for each desired solution of the LP problem.

In the United States, Timber RAM has been used primarily to maximize the short-run potential yields of western National Forests where there is a preponderance of overmature timber. Previously, these forests were regulated through use of volume control formulae. The linear programming with Timber RAM provided an improved approach (Hennes and others 1971). However, most of these applications of RAM were formulated as harvest scheduling problems, as is evident from the objective function, which is to maximize first decade harvest, and from the lack of constraints on the harvest flows after the forest is assumed to be regulated. Yet, budgetary constraints, such as are necessary for an operational harvest schedule, were also lacking. Hence, the solutions merely indicated the maximum yield that would be biologically and technologically possible during the short-term planning period, and did not provide a solution to the regulation problem.

In the southeastern United States, where the National Forests are generally understocked, area control has been used instead of volume control as the regulation method. Due to the relatively small contribution of the National Forests to southeastern timber supplies, Timber RAM has not been used in this region even though it can model the area control approach.

The Timber RAM system is adequately documented and fully supported by the Forest Service. For many National Forest planners, availability and convenience outweigh the inflexibilities of the system, enumerated by Chappelle and others (1976). Some of the technical drawbacks of RAM can be reduced by the procedures outlined in this paper.

New legislation regarding the National Forests implies, however, that managers must seek to achieve future conditions which are optimal and which insure regulation. These conditions will then limit all harvests, including those prior to the achievement of the regulated state. Strict area control cannot in general satisfy the constraints on harvest levels during conversion to the regulated state, and the other procedures currently in use do not adequately constrain to assure regulated conditions. This paper describes how Timber RAM, enhanced by GP, can be used to determine the required solutions to the timber management program.

Goal Programming

GP is a special form of LP suggested by Charnes and others (1955). It permits the simultaneous treatment of multiple objectives which may be incommensurate. Typical LP objective function rows are added to the constraint matrix as equalities. Right-hand sides that reflect the desired level of each objective are included, as are slack and surplus variables for each row. Then a new objective function composed of the slack and surplus variables of the former objective functions (the positive and negative deviations from the desired goals) is constructed and minimized by a standard LP algorithm. Differential weights greater than or equal to zero may be attached to the deviations to reflect the decisionmaker's value system.

Applications of GP to natural resources problems have generally used ordinally weighted deviations to effect a preemptive ranking of the goals, as described by Field (1973). In this study, however, cardinal weights were used to indicate relative values among goals rather than goal preferences. Rustagi (1976) used a similar approach in applying GP to forest regulation. This idea is extended here to include harvest scheduling by using GP to develop compromises between the several solutions available from Timber RAM.

METHODS

Timber RAM Input

Forest Data

The test area for this study was Oconee National Forest in the middle Piedmont of Georgia. In this forest of approximately 40,000-ha, about 80% of the area is in stands of loblolly pine (Pinus taeda L.) and short pine (P. echinata Mill.), and the remainder is in various mixtures of pine and several species of hardwoods. The pine stands are categorized by three classes of site productivity and nine classes of stand age or condition. The other stands (hereafter referred to as hardwoods) are categorized by only two productivity classes.

For each stand class and a variety of treatments, yields were estimated from published models, forest inventory data, and local timber sale data. Local forest policies dictated the type and range of activities that had to be evaluated. Generally, clearcuts at several ages, with or without prior thinning, were used for the pine whereas uneven-aged management with cutting cycles of two different lengths were used for the hardwoods. Local estimates of costs and revenues associated with harvest and regeneration were obtained. These forest data were then coded for use in Timber RAM.

Problem Constraints and Decision Criteria

The National Forest Management Act of 1976 and current Forest Service policy may be interpreted as prohibiting any harvest greater than the long-term sustainable average, and any harvest less than the level of any previous harvest. Indeed, the law seems to imply that a perpetually even flow of timber yield from the present cut henceforth is required. The law permits these constraints to be based on 10-year averages. Under these assumptions, the current cut is the lower bound for the initial harvest whereas long-term sustained yield is the upper bound on the initial and all subsequent harvests; and the intervening flows must be uniform or at least nondeclining. The law states that flow constraints may be relaxed only for consideration of other multiple use objectives. The requirement for even flows during the conversion to the regulated condition, it may be argued, may then be relaxed as necessary to achieve a high level of sustained yield, a possible multiple use objective.

Nondeclining and even flow constraints are easily incorporated in the Timber RAM model by using the option called "volume control and regulation" with "sequential lower bounds only." The lower bound must be set at zero for each control period during the time allowed for conversion to the regulated condition. The maximum yield permitted in the last control period of conversion must equal the postconversion average (long-term sustained yield). Fluctuation in 10-year yields cannot be permitted after conversion. For the Oconee forest application, limits were also placed on the expenditures and on the area harvested and regenerated in each decade by using Timber RAM's "interval constraints." Thus, harvest scheduling as well as forest regulation constraints were included in the same model.

The three decision criteria used for the Oconee application were the maximization of total volume and of present net revenue, and the minimization of total cost. These criteria covered the entire planning horizon of 150 years; economic values were discounted to the present at a 6% rate of interest.

Matrix Alternatives

The single LP matrix normally generated by Timber RAM from the input defining the problem is usually inadequate for planning. The planner may want to obtain solutions under different sets of constraints as well as different decision criteria. Also, certain modifications can improve efficiency of computation and others are required to implement the GP formulation. The following methods were used to create the necessary models for the Oconee National Forest.

Alterations during Matrix Generation

Two intermediate optimization problems were generated. The first was designed primarily to test the model. Here, all but one productivity class of pine was removed from the model and only clearcuts were permitted as management activities. The objective was to produce a small and generally predictable matrix. Solutions to this problem were obtained under the full range of constraint and objective variations discussed below. In addition, some matrix coefficients were systematically changed and postoptimality analyses were performed.

The second intermediate problem contained all the stand classes and constraints that were in the full problem, but the number of activities was reduced from 2229 to 228. For each basic variation of the full problem, a solution was first obtained with this abbreviated model. The solution was then used as an advanced basis to start the optimization phase of the full problem. This proved to be an efficient way to test solution procedures, and it shortened computation times for solutions to the full problem. Such an approach is useful when applying LP to any large problem.

Alterations after Matrix Generation

There are two ways to change a matrix already generated by Timber RAM. Simplest, but not necessarily most efficient, is to physically change, replace, add, or delete certain entries by editing. This procedure is useful for correcting a few errors in a small matrix. For a large matrix (the full problem in this application had 77442 elements) it is usually cheaper, but not necessarily quicker, to correct the raw input and generate a new matrix. Some form of editing or a programmed rewrite may be necessary for a large number of systematic changes which cannot be handled by these methods or others discussed below. Here, one FORTRAN program was used to generate test problem matrices with reduced yield coefficients, and another was used to create rows in the large matrix for certain GP models.

The best way to make temporary changes in an error-free matrix is with the standard "revise" and "modify" options in the LP package. Typical changes include relaxing certain constraints, changing right-hand sides, and adding or modifying rows for GP. Relaxing certain flow constraint rows not only provides useful information on trade-offs, but because the solution times are relatively short, is also another good way to test solution procedures. Other modifications successfully tested in this study are (1) creating objective functions not available from the Timber RAM matrix generator; (2) deleting redundant rows that occur with certain options; and (3) creating nonconstraining rows to facilitate reading the solution.

Goal Programming Formulations

In this application, two basic GP models were constructed. In the first, the three single-criteria optima (volume, net revenue and cost) from the LP models were the goals, and the sum of the underachievement of the volume and revenue goals and the overachievement of the cost goal was minimized. In separate variations of this model the deviations were equally weighted, weighted in favor of volume, and "relatively" weighted. In the last case each goal row was divided by the right-hand side (the goal) before the deviations were added. Thus, the sum of the relative or proportionate deviations from the goals as opposed to absolute deviations was minimized.

The second GP formulation minimized the sum of the deviation from the total volume goal and the deviations from each periodic volume flow goal. The original right-hand side of the constraint equation was used as the goal for each periodic flow. Thus, the objective function included the underachievement of the current cut by the harvest in the first period, the underachievement of the previous harvest by each subsequent harvest during conversion, the overachievement of the long-term average by the last harvest in conversion, and the over- and under- achievements of the long-term average by each post-conversion harvest. Variations in flow goals and economic goals, with a variety of weights, were tested only on the small problem.

Many other combinations of weighted goals and constraints can be formulated to best meet the planning needs of the decisionmaker. For goals that would normally be objectives in an LP model, simply add a right-hand side that is at least as large (or small) as can be attained with single objective optimization. Otherwise, the row should be a constraint. For goals that would be constraints in an LP model, the existing right-hand side or constraint is typically used. However, solutions to such problems should be carefully studied and compared to fully constrained, single objective solutions, especially if many or all the goals are achieved. There may be more acceptable solutions that are easily obtainable but go unrecognized in such goal formulations.

RESULTS

The results involve LP solutions, GP solutions, and postoptimality analysis of the small test problem. The LP set were obtained from Timber RAM using the procedures outlined above. The GP set is based on the reformulations of the Timber RAM matrix as GP models. The postoptimality results are based on LP and GP solutions for the single site, single rotation, and uniformly managed test problem.

Linear Programming Solutions

The first solution of interest used the standard Timber RAM criteria of volume maximization. Typically, if the solution was feasible and if the decisionmaker was happy with the harvest provided for the first decade (the short-term planning period), the analysis stopped there. In this case, however, the solution contained alternative optima which indicated that there are other strategies which meet the constraints and still give the same optimal objecttive value. This result implies that the analysis may not be complete because the procedure does not rank the strategies which can produce the optimum.

The solutions based on economic criteria also revealed some interesting conditions. The net revenue optimum was achieved by only one strategy, but the total harvest and long-term average were less than those provided by the maximum volume solution. A long-term yield less than the maximum, combined with the Forest Service's reluctance to use "profit" as a decision criterion, makes this solution less acceptable, even though it met all constraints. From a policy standpoint, cost minimization might be more acceptable, except that with this criterion only enough acres would be harvested to meet the current cut constraint. In the other two solutions the first period harvest was more than double the current cut. Consequently, none of these three solutions provided a completely acceptable basis for a timber management plan.

Goal Programming Solutions

Standard LP variations and postoptimality analysis might be able to improve single criterion solutions or show the "cost" of certain constraints. But, without reformulation or considerable external analysis, such procedures cannot effect the compromise between the alternative solutions that planning procedures usually require. GP provides for such a compromise. The solution using the optima from the three LP solutions as equally weighted absolute goals achieved the same long-term sustained yield as the volume maximization solution, as well as 96% of the maximum net revenue and 96% of the maximum volume for the planning period. There were no alternative optima in this solution.

Other goal formulations with differential weights would give different, but still feasible and conveniently determined solutions. When the deviation from the volume goal was given a weight of 10, while the others remained at one, the solution nearly achieved the volume goal. But the net revenue was higher than in the LP solution that maximized volume.

A formulation with equal weights on all goals carries implied weights in favor of the goals of larger numerical value. Relative weighting reverses this bias. Such effects were demonstrated in this application by the levels of achievement for the largest and smallest goals, revenue and cost, respecttively. A solution using relative weights favored the cost goal. In this solution the current cost was just matched, as it was in the cost minimization solution, but many more acres were treated because of the influence of the volume goal.

Postoptimal Solutions

Sensitivity analyses to test the stability of certain solutions, given specified changes in inputs, were limited to the small problem. These iterative techniques are quite expensive when applied to large problems. However, the following results would seem to apply equally well to the large problem.

In the first set of tests, the sensitivity of the solution to changes in yield estimate was determined under the LP volume maximization criteria. A uniform change in current and future yields produced no change in the strategy that gives the optimum value of the objective function. Naturally, levels of periodic flows and total yields varied directly with changes in input.

It was next assumed that yield estimates for existing stands were correct and that the only changes that must be considered were for the yields of regenerated stands. New solutions then arose, but the activities selected for the first few periods were still unchanged. Similar results were obtained with the GP formulations. The stability of the preferred strategy reflects the dependence of early treatments and results on the conditions in existing stands. Recall that this analysis supports a short-term planning effort and that replanning and analysis will be required at relatively short intervals. Thus, considerable variation in long-term yield projections may not be detrimental to a typical timber management plan.

Postoptimality analysis was also used in the GP formulation to systematically change the weights on certain goal deviations. A wide range of solutions resulted, and indicated just how heavily a particular goal must be favored before it will dominate all others. For example, the volume goal required a weight 31 times those for harvest flow goals in order to approximate the LP optimum for volume without flow constraints.

CONCLUSIONS

Timber RAM may be attractive for the beginning forest planner, if the necessary computer facilities are available. It provides the basis for several approaches to forest regulation and scheduling of harvests on public lands. A land manager can employ some of the techniques presented here to enhance the application of Timber RAM. Simple reformulation as a goal model is within the capability of many users of RAM and helps to synthesize several satisfactory or nearly satisfactory solutions. The combination of LP and GP can also be useful with mathematical programming packages other than Timber RAM, including those used on privately owned lands. Finally, using GP in timber management planning sets the stage for multiple use planning because it provides the framework for the subsequent inclusion of other forest resources and products as additional objectives.

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