

Forest Management Planning for Timber Production: A Sequential Approach

Krishna P. Rustagi

Abstract: Explicit forest management planning for timber production beyond the first few years at any time necessitates use of information which can best be described as suspect. The two-step approach outlined here concentrates on the planning strategy over the next few years without losing sight of the long-run productivity. Frequent updating of the long-range and short-range plan makes it possible to keep a dynamic posture. Instead of one single objective of maximization of discounted present net worth, there are two objectives. The short-run objective implicitly maximizes the volume or the discounted present net worth of timber harvested during the first rotation, subject to equal area constraint; the long-run objective explicitly maximizes the rate of return to the land either as timber volume (MA1) or annualized land rent. The reduced size of the two problems makes this approach extremely practical.

INTRODUCTION

Timber management planning essentially involves decisions on two basic issues: temporal and spatial scheduling of harvest during a planning period and the reforestation strategy that is to follow each harvest. The former provides the amount of timber and income flow during the planning period. The latter does much more. It indicates the flow of timber and income one rotation in the future, the needed reforestation investment during the planning period, and the rate of return to the land under the proposed alternative(s). These short and long-run flows are shaped by the management objectives, spatial distribution of growing stock, and restrictions, if any, on the level of harvest and/or reforestation activities.

Combining harvest scheduling with reforestation planning in one model puts heavy demand on the information needs. Not only are yield, stumpage price, and reforestation and other costs needed for each stand, but the same information must be projected for several decades and perhaps centuries. The net result is an excessively large model and less than reliable input.

If the forest schedule can be separated from the reforestation plan, the resulting two models would be relatively small and need far less data. The net result: operatively practical models with better control on the quality of input at far less effort. The two-stage sequential approach is an attempt in this direction.

UNCONSTRAINED OPTIMIZATION

The economic management objective is usually taken as a maximization of discounted present net worth over a number of rotations. If there are no restrictions on the level of activities, the same result could be accomplished by setting up a performance standard for each stand and evaluating its performance against this standard. Stands which are performing poorly should be harvested and reforested with the alternative(s) which maximize soil expectation value (SEV). Mathematically, a stand should be harvested if:

$$MR - iR < i(SEV)$$

Where

MR = marginal value growth in a stand if its harvest is postponed for one year

R = current value upon harvest

i = interest rate

SEV = maximum soil expectation value possible on that site under the given reforestation alternatives.

Although this criterion for harvest scheduling looks innocently simple, it is extremely difficult to apply in practice. The value growth MR is affected by volume growth, timber quality improvement (better diameter, height and tree form), and appreciation (or depreciation) in stumpage prices due to inflation and cycling in economy. In addition, both R and MR are influenced by the price elasticity of stumpage demand.

Adoption of this criterion would maximize the long-run discounted present net worth for the entire forest without actual use of a sophisticated model. It may be pointed out, however, that if the forest is unbalanced to start with, the uneven or interrupted yearly (or periodic) flow of timber will be perpetuated.

CONSTRAINED OPTIMIZATION

In public and industrial ownerships, certain restrictions are imposed on the level of activities in order to ensure long-run sustained flow of timber. These restrictions usually result in regulation of harvest by equal volume or area over time. Though restrictions of any kind would reduce the total discounted net present worth, volume regulation tends to be more restrictive and gives rise to the spectacular but controversial allowable cut effect

(Schweitzer and others 1912). Further, it is impossible to obtain strict even flow due to a variety of reasons, including unbalanced initial forest structure, impreciseness in the estimation of growth and yield over time, changes in utilization standards and technology, and changes in the management intensity.

Area regulation would also produce fluctuating harvest during the conversion period (first rotation) but ensure more predictable and sustainable long-term harvest. Other advantages of area regulation include predictability and stability of reforestation investment and overall management-related activities.

Linear programming models are often used for constrained optimization (Navon 1971, Clutter and others 1968). Nautiyal and Pearse (1967) also presented a theoretical model for maximizing discounted present net worth subject to area regulation. Though theoretically correct, these models are not very practical because of huge data needs and immense problem size. Past experience has indicated that precise estimation of yield and growth, operations costs, stumpage prices and interest rates are not possible beyond a few years and yet these models require this information for at least one rotation and often for more than a century!

In view of this, some real questions may be raised. How sophisticated should a model be, when the data cannot be obtained with any degree of reliability? how intensively should such data be used by the model? How far into the future should the planning horizon extend? Obviously, the sophistication of the model should match the sophistication of the data input; if the data needs can be reduced both with respect to time and space, it may be possible to direct more attention to the data collection effort, thus improving the overall planning.

THE SEQUENTIAL APPROACH

If the management planning problem is partitioned into two components, these would be (a) harvest and: thinning scheduling and (b) reforestation planning. In the sequential approach these two components are handled one at a time.

Harvest scheduling is a disinvestment process, and focuses primarily on timber and cash flow during the planning period. The entire existing volume in a forest, together with its growth, is to be harvested before the first planned reforestations mature. Any harvest scheduling strategy may be used between the performance standard approach at the one extreme and equal annual (or periodic) volume at the other extreme. Because of its focus on output and income in the near future, harvest scheduling may be termed short-range planning.

Reforestation implies deliberate investment of capital with land. The focus here is on productivity and profitability of investment which will be realized one rotation in the future. The level of investment in reforestation coupled with the productive potential of the forest lands essentially determine future productivity and profitability. Because of its long-range (beyond first rotation) implications, reforestation planning may be termed long-range planning.

The objectives and data needs for the two components are entirely different. In harvest scheduling, information is needed by individual stands which may be characterized by species, site, age, stocking, and accessibility. Both quantitative and qualitative data on yield and the expected stumpage prices are needed for each stand and each year of the conversion period. It will be shown, however, that the yield and stumpage price information may be needed only for a subset of all stands and only for a fraction of the conversion period.

The data needs for reforestation planning involve only operations after harvest. These include reforestation cost, expected total yield and stumpage prices for likely species, management regimes and rotation lengths. Only classification of the forest area needed here is by site, accessibility, and perhaps conversion costs.

Two assumptions are the basis for this sequential approach: (1) the future rotation determination is not influenced by the existing growing stock, and (2) the proposed reforestation planning must be optimal independently of the harvest strategy used. These two assumptions enable us to partition one immense single constrained optimization problem into two relatively very small optimization problems.

Rotation of the future crop--determined by the reforestation plan--indicates the time span in which the existing growing stock and growth thereupon has to be harvested. Therefore, if continuous timber flow is required, the harvest scheduling should be preceded by the long-range plan. In the sequential approach, the long-range plan is developed first. The long-range plan is best summarized as follows:

Long-Range Plan (Reforestation)

<u>Objective:</u>	Maximization of long-run timber output or rate of return to the land
<u>Constraints:</u>	I. Reforestation of equal annual (or periodic) areas by site II. Equal annual (or periodic) reforestation budget
<u>Input:</u>	I. Area distribution by site, accessibility, etc. II. For each site and species, method of regeneration, initial stocking level, management regime, and rotation: - Total reforestation and subsequent management costs - Expected product output at rotation age - Expected annual rate of return to the land
<u>Output:</u>	I. Area to be reforested annually II. The reforestation schedule together with rotation lengths by site III. The long run annual total timber output IV. The long run annual total income from the use of forest land

The long-range planning problem could be handled by linear programming (LP) if the management objective is either long-run timber yield maximization or the maximization of rate of return to the land. If a combination of both is desired, the problem could be handled by goal programming (Rustagi 1976). As the problem size would be small--only a few hundred variables at most--there would be scope for refining site classification, and including a large number of regeneration methods, and management regimes, and several rotations. The small size of the problem would also enable in-depth sensitivity analysis.

The long-range plan gives an annual reforestation program which will maximize long-run income from the use of forest land subject to area and reforestation budget constraint. If there is no constraint on reforestation budget, the plan would indicate annual budget needs to implement the reforestation program. This program may be implemented as long as the input or the constraints do not change. If any change does take place, the problem can be easily reformulated and solved.

Once the areas to be reforested by site and accessibility classes have been determined by the long-range plan, their geographic location must be determined. In the second stage of the sequential planning, a harvest schedule is developed which tells where, when, and how much to harvest in different years of the conversion period. This harvest scheduling problem may be summarized as follows:

Short-Range Plan (Harvest Schedule)

<u>Objective:</u>	Maximization of discounted harvest income from existing stands or maximization of total timber yield during the conversion period
<u>Constraint:</u>	Area to be harvested in each year by site and accessibility class as given by the long-range plan
<u>Input:</u>	Estimate of yield and expected stumpage prices for each stand and for each year of the conversion period
<u>Output:</u>	For each year of the conversion period I. Geographical location of stands to be harvested II. Expected harvest volume III. Expected income from harvest

Though theoretically this harvest schedule should be prepared for the entire conversion period, it is not really necessary to do so. Those stands which are putting on the least volume or value growth in each site will be the first to be scheduled for harvest. Likely candidates for this category include stands past maturity, grossly understocked stands, or stands currently under less economic species. Immature stands which are growing vigorously are unlikely to be taken up for harvest for some time. Thus, if a harvest schedule is prepared for 10 years at a time using only a proportionate area comprising the least vigorously growing stands, and the plan is implemented for the first 5 years and revised, the planning outcome will be as optimal as if the schedule is prepared for the entire conversion period.

There are two significant advantages in harvest scheduling for a shorter period. First, only a fraction of the total forest area need be considered by the harvest schedule: thus, more precise estimates of volume and value are possible for a given amount of effort. Second, as the harvest schedule is to be for only 10 years (maybe less), relatively reliable estimates of stumpage values and harvest costs are possible. In short, the amount of information to be collected may be as small as 10 percent of what would be needed to prepare a harvest schedule for the entire conversion period.

The harvest scheduling problem may be handled by linear programming. However, with an area constraint, different management objectives or different scheduling strategies, such as oldest stand first, should not produce significantly different impacts on the objective function value. An arbitrarily determined harvest schedule based on roading condition and proximity of stands to be harvested--which may not be built into an LP model--may outperform the schedule drawn by using LP.

DISCUSSION

Suppose one million hectares of forest land is to be managed for sustained production with the long-run objective of maximization of income to the land. Also suppose that there is a constraint on the reforestation of income to the land. Also suppose that there is a constraint on the reforestation budget. Further, suppose that based on productivity, accessibility, administrative considerations, and conversion possibilities, this forest land can be divided into 10 site classes, and for each site class, 5 reforestation alternatives are available, with information on reforestation cost, rotation lengths, total timber output, and income from harvest at rotation age.

The long-range problem, if the sequential approach is used, will have only 50 decision variables, 10 area constraints and one budget constraint. The solution will include the number of hectares to be harvested and reforested and the rotation to be adopted in each site class. Also, total long-run timber output and income from the use of forest land can be computed.

Suppose that this million hectares can be divided into 10,000 homogeneous stands. If the short-range plan is to be prepared for 10 years, with an average rotation length of 50 years, yield and stumpage information will be needed for approximately 2,000 stands covering 200,000 hectares. If formulated as an LP problem, it will have about 20,000 decision variables and 2,050 constraints. The problem size may be substantially smaller if the rotation is longer than 50 years or the planning period is shorter than 10 years. For example, a 5-year planning period may result in only 5,000 decision variables and 1,025 constraints.

If, however, the two components are merged into one model such as Timber-RAM (Navon 1971), and a plan is prepared for the next 50 years with the same degree of spatial and temporal resolution, the number of decision variables will increase to one million with number of constraints in excess of 10,000. Whereas this large problem size will force aggregation, further resolution is possible under the sequential approach.

The advantages of the sequential approach to timber management planning may be summarized as follows:

1. The size of both the long and short-range problems are small. This makes it possible to examine a much larger number of investment alternatives and exercise better control on the quality of input.
2. The long-range plan provides long-run predictions of timber output without actually developing a management plan for a rotation or longer period.
3. The investment analysis of planned reforestations is very explicit and separate from current harvest income.
4. As the regulation of harvest is not by volume, allowable cut effect (Schweitzer and others 1972) cannot be used for distorting investment analysis.
5. Because of small problem sizes, as frequent as annual updating of both long-range and short-range plans is practical.

It may be argued that the long-range plan described here also uses estimates of costs and stumpage process up to the end of a rotation. Unfortunately, there is no way to avoid use of these numbers if the reforestation investments are to be evaluated according to some economic criterion. These numbers will not be needed, however, if a biological criterion is used in establishing maturity. If it is assumed that the stumpage price will maintain the historical rising trend in the foreseeable future, and that thinning and fertilization will be used increasingly, the financial rotation using Faustmann's formula may not be significantly different from the rotation of maximum volume production, which can be predicted with greater accuracy and is unaffected by economic factors such as costs, stumpage prices, and interest rates.

Though the long-range plan has equal area constraint, this may be relaxed to take advantage of the timber market so long as these variations even out in the long run. This flexibility of scaling harvest up and down is available only so long as some kind of long-run sustained harvest is followed.

Thinnings were excluded purposely from harvest scheduling. Though commercial thinning is income producing, it is essentially a silvicultural operation carried out to increase the value growth of the residual stand and to prevent mortality loss. When and where to thin may be best decided after a harvest schedule has been prepared. Coordination of thinnings with harvest cut in nearby areas may provide better return than may be possible otherwise.

An application of the sequential two-step approach outlined here has been presented by Rustagi (1976) where the long-range reforestation planning has been handled by goal programming and the short-range harvest scheduling by linear programming. This application reveals that with equal area constraint, total discounted present value of harvest during a planning period is not significantly different whether the objective is biologic or economic. The actual harvest schedule, however, may vary with the short-run objective.

LITERATURE CITED

- Nautiyal, J.C., and P.H. Pearse. 1967. Optimizing the conversion to sustained yield - a programming solution. *Forest Sci.* 13(2):131-139.
- Navon, Daniel I. 1971. Timber RAM.... a long-range planning method for commercial timber lands under multiple-use management. USDA Forest Serv. Res. Paper PSW-70, 22 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
- Rustagi, Krishna P. 1976. Forest management planning for timber production: a goal programming approach. *Yale Univ. Sch. For. Environ. Stud. Bull.* 89, 80 p.
- Schweitzer, D.L., R.W. Sassaman, and C.H. Schallau. 1972. Allowable cut effect - some physical and economic implications. *J. For.* 70(7):415-418.
- University of Georgia, School of Forest Resources. 1968. Max-million: a computerized forest management system. Athens, Ga. 61 p.