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Timber RAM... a long-range planning method for commercial timber lands under multiple-use management

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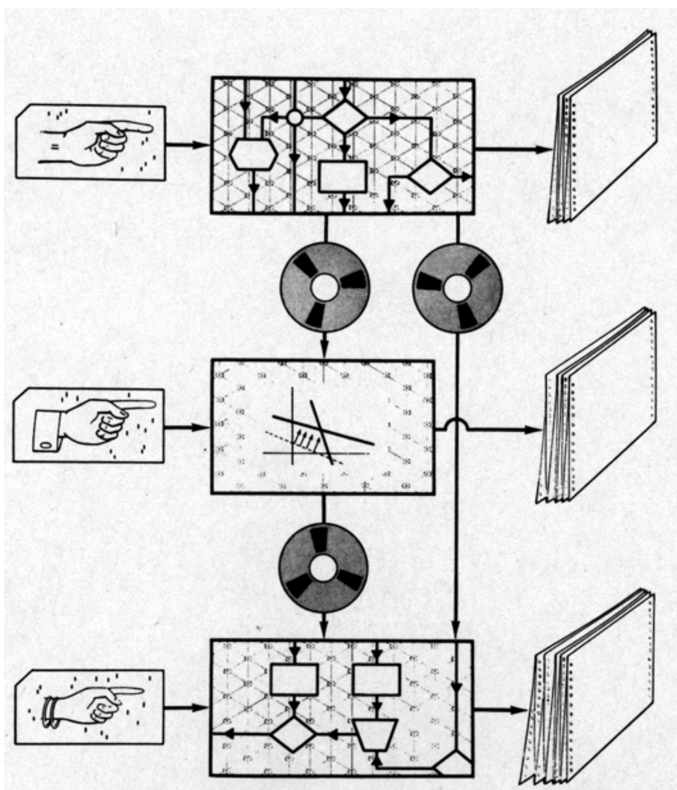

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FOREWORD

A major aim of the Multiple-Use Economics research unit of the Pacific Southwest Forest and Range Experiment Station is the development of a Resources Allocation Method (RAM). This method is designed to provide an analytical framework for drawing long-range forest management plans and for evaluating wildland multiple-use management policies.

Timber RAM is a subsystem of RAM, designed to generate cutting and reforestation schedules for commercial forest lands under multiple-use management. These Timber RAM plans can be used to evaluate current management policies and goals and to evolve new ones. Timber RAM was developed by the following members of the research unit staff:

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Michael J. Irving, *Mathematician and Programer* (part-time)
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Steven Chen, *Computer Scientist* (part-time)

Special credit is due Michael Irving and Steven Chen for writing the Timbram-Matrix program and Michael Irving for writing the Timbram-Report program.

Valuable assistance in the testing of Timber RAM was provided by the Branch of Management Plans and Timber Inventories, California Region of the Forest Service, U.S. Department of Agriculture, San Francisco, California.

GLOSSARY

Many terms familiar to foresters—and mathematical programers—are given particular meaning in Timber RAM.

Activity: a scheduled sequence of silvicultural treatments defined for a particular timber class by periodic inputs and outputs per acre treated.

Arbitrary Control Constraint: one of the three types of control constraints which can be imposed on periodic harvests.

Constraint: restriction on the quantity of an input used or output produced during a particular period.

Control Constraint: restriction on the volume (or area) harvested during each period of a sequence of periods—beginning with the first period. The periods for which control constraints are specified are referred to collectively as the conversion period.

Conventional Control Constraint: one of the three types of control constraints which can be imposed on periodic harvests.

Conversion Period: the sequence of periods—starting with the first period for which harvest control constraints have been specified by the user. Since a harvest control constraint must be specified for the first period the conversion period consists of at least the first period. When no harvest regulation constraints are specified, the conversion period can be extended to the planning horizon.

Economic Report: a table produced by the computer program Timbram-Report displaying total periodic costs and revenues for each period from the present up to the planning horizon.

Harvest Graph: a graph produced by the computer program Timbram-Report displaying the total periodic harvest for each decade from the present to the planning horizon.

Harvest Report: a table produced by Timbram-Report displaying the total periodic harvest from the present up to the planning horizon.

Harvest Schedule: a cutting and reforestation schedule produced by Timbram-Report displaying by decade, the acres and volume harvested with each activity, selected from the present up to the planning horizon.

Linear Programing: a mathematical technique for solving resources allocation problems.

Management Alternative: a scheduled sequence of silvicultural treatments for a specific timber class.

Objective: any one of the inputs or outputs summed over a sequence of decades extending from the present up to the planning horizon. Costs and revenue objectives can be discounted to the present.

Planning Alternative: the objective, constraints and activities from which a Timber RAM plan will be calculated.

Period: a decade or the first and second half of the first decade when the "five-year" option is selected.

Planning Horizon: the last period for which inputs and outputs are to be estimated or constrained.

Post-Conversion Period: the sequence of decades from the end of the conversion period to the planning horizon.

Problem Schedule: a schedule produced by Timbram-Report displaying by decade all the inputs and outputs and the contribution to the objective of each activity selected for the Timber RAM plan.

RAM: Resources Allocation Method, a system for long-range multiple-use planning of wildlands being developed at the Pacific Southwest Forest and Range Experiment Station.

Regulated Cycle: a sequence of post conversion periodic harvests spanning a rotation.

Regulation Constraint: restriction on the volume (or area) harvested during any decade of the post-conversion period.

Sequential Control Constraint: one of the three types of control constraints which can be imposed on periodic harvests.

Timber Class: a collection of stands of sufficiently similar character to be treated as if they were identical.

Timber RAM Plan: a cutting and reforestation schedule—and the corresponding revenues and costs—developed with Timber RAM for a particular planning alternative.

Timber RAM Problem: a forest management linear program generated with the computer program Timbram-Matrix. Several planning alternatives—and therefore several Timber RAM plans—can be generated from a single Timber RANI problem.

Timbram-Matrix: a computer program used to set up forest management problems as Timber RAM problems.

Timbram-Report: a computer program used to translate a combination of activities into a Timber RANI plan.

CONTENTS

The Timber Resources Allocation Method (Timber RAM) is a computerized method for developing long-range forest management plans. Each Timber RAM plan consists of a cutting and reforestation schedule and of reports tabulating the corresponding stumpage volumes, revenues, and costs. Schedules and reports can span a sequence of decades extending from the present to a "planning horizon" up to 35 decades in the future. With Timber RAM plans, the stumpage and economic potential of large forested areas can be estimated for alternative management policies. Timber RAM plans can also provide aggregate input and output goals and management guidelines for sequences of annual plans. The schedule and corresponding stumpage volumes, revenues, and costs of Timber RAM plans are calculated for 10-year periods. They can also be calculated separately for the first half and for the second half of the first decade to provide schedules and reports for 5-year plans.

Given an inventory of forest resources and alternative ways of managing each type of stand, Timber RAM can be used to calculate a schedule which meets a specified objective, such as: maximize revenues, maximize stumpage volume harvested, or minimize expenditures. Besides meeting the objective, the Timber RAM schedule can be required to meet constraints on the periodic level of revenues, and expenditures, and on the periodic volume of stumpage harvested. The levels at which revenues, expenditures and stumpage are constrained can be varied from period to period. Finally, the Timber RAM schedule can be required to meet constraints specifying what percentage of each type of stand will become accessible for cutting in successive periods.

Timber RAM can be used to develop long-range plans for both privately and publicly owned forests. Private owners, for example, may choose for the objective: maximize the present value of net revenue. They may also choose to constrain cash flows and stumpage harvested above minimum levels for two or three decades. Private owners with an interest in conservation may want to assure a minimum supply of stumpage for additional decades. Private owners with heirs, and public agencies, may well feel obliged to assure a perpetual and stable supply of stumpage. With Timber RAM, they can develop such plans by constraining harvest levels for as long as 35 decades—ample time to stabilize the periodic yield of any forest. Some public agencies may prefer to specify the objective: minimize expenditures; and constrain timber harvest above minimum levels for one or two rotations to insure a sustained yield of stumpage. Public agencies may also want to constrain revenues above a minimum level for several decades to meet the needs of local government.

The opportunity costs of imposing such constraints can be estimated by calculating a second plan in which the constraints have been deleted or modified. An opportunity cost is defined as the difference in the value of the objective in the two plans. The opportunity costs of a policy requiring a stable and perpetual supply of stumpage can be estimated by calculating two Timber RAM plans; the first in which periodic stumpage harvests are constrained for, say two rotations, and the second in which periodic stumpage harvests are not constrained, or constrained for only two or three decades. The opportunity cost of other multiple-use management policies can be estimated in the same way; for example, the opportunity cost of establishing stream bank protection zone of various widths, or of extending endangered species habitats.

Maximizing revenues—or minimizing expenditures—is only one of the goals of forest management. By specifying constraints it is possible to introduce explicitly into the planning process many of the other goals pursued by private owners and public agencies.

This paper describes the Timber RAM approach to long-range forest management planning. It outlines the procedures for using Timber RAM on computers, and explains the options of the computer programs.

Timber RAM plans are calculated by the linear programing method. This method has been completely automated and linear programing codes are available commercially for every large and medium size computer. The current version of Timber RAM requires the use of the linear programing code ILONA on the UNIVAC 1108 computer. The Timber RAM programs can be easily adapted to other combinations of linear programing code and computer. The California Region, U.S. Forest Service, for example, is adapting the Timber RAM programs to the code REX and the CDC 3100 computer.

The Timber RAM computer programs and a four-part Users' Manual are available on request to the Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701. Each program listing and each part of the Users' Manual must be requested by title. To obtain a copy of the programs on magnetic tape, send a 7-track, 800 BPI, one-half-inch tape at least 1,200 feet long to the Director, Attention: Computer Sciences Library. This tape will be written in UNIVAC 1108 EXEC II Symbolic CUR format unless card image format is requested.

Part I of the Users' Manual is the *Smokey Forest Case Study*. It illustrates the use of Timber RAM to draw long-range plans for the Smokey Forest, a hypothetical publicly owned forest. The data forms and listings of the control decks necessary to make the computer runs discussed in the case study are available on specific request to the Director.

Part II of the Users' Manual is the *Forester's Guide*. With this Guide, professional foresters without training in linear programing can use all the standard Timber RAM options. But if they are completely unfamiliar with the care and feeding of computers, they will require some help to process Timber RAM computer runs.

Part III is the *Mathematical Programer's Guide*. It describes the mathematical relations used in Timber RAM. If Timber RAM is used extensively, some savings in data processing can be realized with procedures discussed in this guide. Familiarity with the theory of linear programing and experience in using computers are prerequisites to using these procedures.

Part IV is the *Computer Programer's Guide*. It includes a description and a flow chart of every subroutine used in the Timber RAM programs. The Computer Programer's Guide is primarily designed to facilitate the adaptation of the Timber RAM programs to any large or medium size computer, and to their linear programing codes.

A wide spectrum of silvicultural treatments and management policies can be analyzed with the standard options of Timber RAM. This spectrum can be further broadened by minor modifications in the Timber RAM programs. The necessary information for modifying these programs is presented in the Computer Programer's and the Mathematical Programer's Guides.

TIMBER RAM APPROACH

Timber RAM Activities

The Timber RAM approach involves the selection of a combination of "activities" maximizing—or minimizing—an objective and satisfying constraints. Each activity is a complete sequence of silvicultural treatments extending from the present to the planning horizon. To minimize data processing, all timber stands with similar silvicultural and economic characteristics are grouped into a "timber class." Several activities are then defined for each timber class. A typical activity for a timber class consisting of overaged stands on highly productive land might consist of the following sequence: (1) clearcut the standing timber and plant in the first decade; (2) partial cut the regenerated timber on a 10-year cycle from the sixth decade until the harvest cut in the ninth decade; (3) repeat the treatments on the regenerated timber up to the planning horizon. The Timber RAM activities are expressed by the total inputs per acre required and the total outputs per acre produced in each decade. The concept of an activity can be easily grasped from illustrations for a simplified problem with a 10-decade planning horizon in which stumpage and net revenue are the outputs and land the only input *(fig. 1)*. Activity 1 is the Timber RAM activity for the sequence of treatments described above. Stumpage is expressed here in thousands of board feet (MBF) and net revenue in dollars. Outputs and inputs are listed for each decade—with one exception: land. Since this input is the same for every decade (1 acre) it is listed only once. Activity 2 and activity 3 represent the same sequence of treatments as activity 1 but with the standing timber harvest scheduled in decade 2 and 3. Additional activities must be specified if this overaged stand is to be carried beyond the third decade. Activities 1, 2, and 3 assume an 8-decade rotation age for the regenerated timber. To evaluate alternative rotation ages, additional activities must be specified. Activities 4, 5, and 6 represent the same sequence of treatments as the first three activities but with a 7-decade rotation age for the regenerated timber *(fig. 1)*. Any sequence of treatments can be described by a Timber RAM activity. Precommercial thinning of

Decade	Inputs and Outputs	ACTIVITIES (80-year rotation)			ACTIVITIES (70-year rotation)			ACTIVITIES (70-year rotation)		
		1	2	3	4	5	6	7	8	9
1st	Vol.	35			35				12	12
	Net Rev.	700			700				240	240
	(disc.)	(523)			(523)				(179)	(179)
2nd	Vol.		36			36				5
	Net Rev.		720			720				100
	(disc.)		(300)			(300)				(42)
3rd	Vol.			34			34	34	28	26
	Net Rev.			680			680	680	560	520
	(disc.)			(158)			(158)	(158)	(130)	(121)
4th	Vol.									
	Net Rev.									
	(disc.)									
5th	Vol.							0		
	Net Rev.							-55		
	(disc.)							(-4)		
6th	Vol.	5			5					
	Net Rev.	75			75					
	(disc.)	(3)			(3)					
7th	Vol.	8	5		6	5				
	Net Rev.	120	75		90	75				
	(disc.)	(3)	(2)		(2)	(2)				
8th	Vol.	6	8	5	30	6	5	7	5	5
	Net Rev.	90	120	75	750	90	75	105	75	75
	(disc.)	(1)	(2)	(1)	(10)	(1)	(1)	(1.4)	(1)	(1)
9th	Vol.	30	6	8		30	6	8	6	6
	Net Rev.	750	90	120		750	90	120	90	90
	(disc.)	(5)	(1)	(1)		(5)	(1)	(1.3)	(1)	(1)
10th	Vol.		30	6			30	33	30	30
	Net Rev.		750	90			750	825	750	750
	(disc.)		(3)	(.4)			(3)	(3.3)	(3)	(3)
	Land	1	1	1	1	1	1	1	1	1
OBJECTIVE		530	304	159	538	303	159	155	310	301

Volume in MBF--Net Revenue in $ (discounted at 6%)--Land in acres

Figure 1—*Timber RAM activities corresponding to sequences of forest treatments defined by periodic outputs (volume harvested and discounted net revenues) and one input (land). The bottom row shows the contribution of each activity to the objective "maximize discounted net revenue over the first eight decades."*

regenerated timber in the fifth decade is illustrated with activity 7; overstory removal in the first decade with activity 8; partial cutting the standing timber in the second decade after an overstory removal in the first decade is illustrated with activity 9. Note that activities specified for a given timber class can represent different sequences of treatments and also different schedulings of the same sequence of treatments.

With the Timber RAM computer program Timbram-Matrix a large number of activities can be specified easily and cheaply, for each timber class, once timber yield, cost and revenue tables have been prepared.

Linear Programing

The combination of activities making up a Timber RAM plan, is found by the linear programing method. If no constraints were specified the combination of activities maximizing revenues, maximizing stumpage harvested, or minimizing expenditures could be found by inspection.

To illustrate this point, consider a forest consisting of a single 1,000-acre timber class of over-mature even-aged timber. Let the objective be: to maximize total net revenue from stumpage harvested in the first 8 decades; and let us consider only the sequences of treatment represented by the first six activities defined above *(fig. 1).* For each activity, let us calculate the total discounted net revenue over the first 8 decades and enter it in the row labeled: objective *(fig. 1).* Since activity 4 will yield the highest discounted net revenue per acre over the first 8 decades, all 1,000 acres must be managed with activity 4 to maximize the objective.

If because of contractual commitments, a minimum stumpage volume of 10 MMBF must be harvested in each of the first 3 decades, the entire forest cannot be managed with activity 4 since there would be no timber left to harvest in the second and third decade. Now, the combination of activities maximizing the objective and meeting the constraints on stumpage harvested cannot be found by inspecttion. Although in this example the combination of activities is quickly found with simple arithmetic, more realistic problems involving several timber classes and additional constraints require the use of the linear programing method.

The solution to our simplified problem is: Objective = \$361,522 = (428) (\$538) + (278) (\$304) + (294) (\$159).

Activity No.	*Acres managed*	*Stumpage harvested in decade* 1st	2nd	3rd
			MMBF	
4	428	15	0	0
2	278	0	10	0
6	294	0	0	10
Total	1,000	15	10	10

The solution to this problem shows two characteristics typical of Timber RAM plans:

First, the total inputs and outputs contributed by each activity is directly proportional to the number of acres managed with this activity. Mathematicians call this type of proportionality "linearity;" hence, linear programing. For example, the total contribution of activity 4 to the volume harvested in the first decade (15 MMBF), is the yield per acre (35 MBF) multiplied by 428, the number of acres to be managed with this activity. The objective is calculated by the same method.

Second, a given timber class is managed with several activities. In this example 42.8 percent of the timber class area must be managed with activity 4; 27.8 percent with activity 2 and 29.4 percent with activity 6. In real situations there will be many timber classes, nevertheless several activities will typically be required to manage each timber class. These activities may represent different sequences of treatments as well as different schedulings of the same sequence of treatments. Note that, the regenerated timber on the timber class in our problem is managed partly on one rotation (8 decades for activity 2) and partly on another (7 decades for activities 4 and 6).

PLANNING WITH TIMBER RAM

Defining Planning Alternatives

With Timber RAM a combination of activities maximizing—or minimizing—an objective is found given a set of activities for each timber class, and constraints on the inputs and outputs. Changing the objective, constraints, or activities defines a new planning alternative for which a different combination of activities will normally be found. For example, given a set of activities and constraints, a combination of activities will be obtained by selecting as objective: the total discounted net revenue collected over 8 decades; a different combination of activities will be obtained in most situations if instead, total discounted net revenue collected over 4 decades is selected as the objective. Each new combination of activities is also a new Timber RAM plan.

Several Timber RAM plans will normally be required to plan each management unit. The first Timber RAM plan can reflect current or tentative policies and goals. For example: maximize discounted net revenues for the first 8 decades; clearcut the standing timber and manage the regenerated timber on a 7- or 8-decade rotation; and harvest at least 10 million board feet in each of the first three decades. This first Timber RAM plan will establish whether the harvest goals for the first 3 decades is feasible, and if it is, what the maximum total discounted net revenue for the first 8 decades can be. A great deal more information is provided by the Timber RAM plan. This information is presented in cutting and reforestation schedules and reports and a Harvest Graph. The schedules display for each activity selected the inputs per acre and outputs per acre; the number of acres to be managed; and the total periodic inputs and outputs. The reports summarize this information for each period over all the activities selected. The Harvest Graph displays the total periodic stumpage harvested for each decade from the present to the planning horizon.

Additional planning alternatives can be defined and the corresponding Timber RAM plans obtained by making one or a combination of changes in the specification of: the objective, the constraints, and the activities. For example: Changes in the objective can be specified:

- by varying the number of decades over which the objective is defined (maximize discounted net revenues over 4 decades instead of over 8 decades)
- by changing the index of performance (maximize stumpage volume harvested, instead of maximize discounted net revenues)
- by varying the discount rate of the index of performance (discount net revenues at 10 instead of 6 percent).

Changes in constraints can be specified by varying the level of constraints in the first Timber RAM plan or by adding or deleting constraints. With such changes it becomes possible:

- to explore changes in current or tentative goals
- to evaluate alternative multiple-use management policies on: even flow, sustained yield, and the size of stream side zones, and of scenic areas and protected wildlife habitats
- to evaluate accelerated road construction or tree improvement programs.

Changes in activities can be specified by adding or deleting activities to evaluate:

- special treatments for sensitive areas
- different rotation ages
- new types of logging
- various levels of management intensity including fertilization and the introduction of genetically improved stock.

Professional training, experience, and intuition must be exercised in selecting the specifications of each additional planning alternative.

Generating Timber RAM Plans

To generate Timber RAM plans three steps are required *(fig. 2).* Each step consists of preparing an input deck and making a computer run.

Step I: setting up a Timber RAM problem with the program Timbram-Matrix. Objectives, constraints, and all the data necessary to define activities for every timber class are entered on specially designed data forms. The Data Input deck for step I is punched directly from these forms. The program Timbram-Matrix is then run to produce the Linear Program (LP) Data Input Tape used in step II and the Report Input Tape used, in step III. The information printed on these tapes can be checked by inspecting the Timbram-Matrix Input computer printout. Errors are eliminated by correcting the data input deck and re-running Timbram-Matrix.

Step II: Finding a combination of activities with the linear programing computer code ILONA *(fig. 2).* The LP Control deck consists of only a few cards used to select particular options of the computer program ILONA and to specify which objective of the Timber RAM problem will be maximized—or minimized. Changes in the level of periodic harvest, revenue and cost constraints can also be made with the LP Control deck. Except for experienced mathematical programers, changes in the other constraints or in the activities require repeating step I to set up another Timber RAM problem. (Procedures for changing, adding, or deleting every constraint and activity with the LP Controls are described in the *Mathematical Programer's Guide.)* With a single Timber RAM problem it is therefore possible to define many planning alternatives and to generate the corresponding Timber RAM plans.

The computer run with the program ILONA has two possible outcomes, depending on whether there exists a combination of activities which satisfies the constraints specified. If a combination exists, ILONA will find it and prepare the Linear Program Solution Tape used in step III. If no combination of activities can satisfy all the constraints, ILONA will abort with the comment: "infeasible." In either case, the LP Iteration Log and Solution computer printout provides detailed information on the calculations performed by ILONA. In case of infeasibility, the constraint or constraints causing the infeasibility can be detected and modified or removed by trial and error methods.

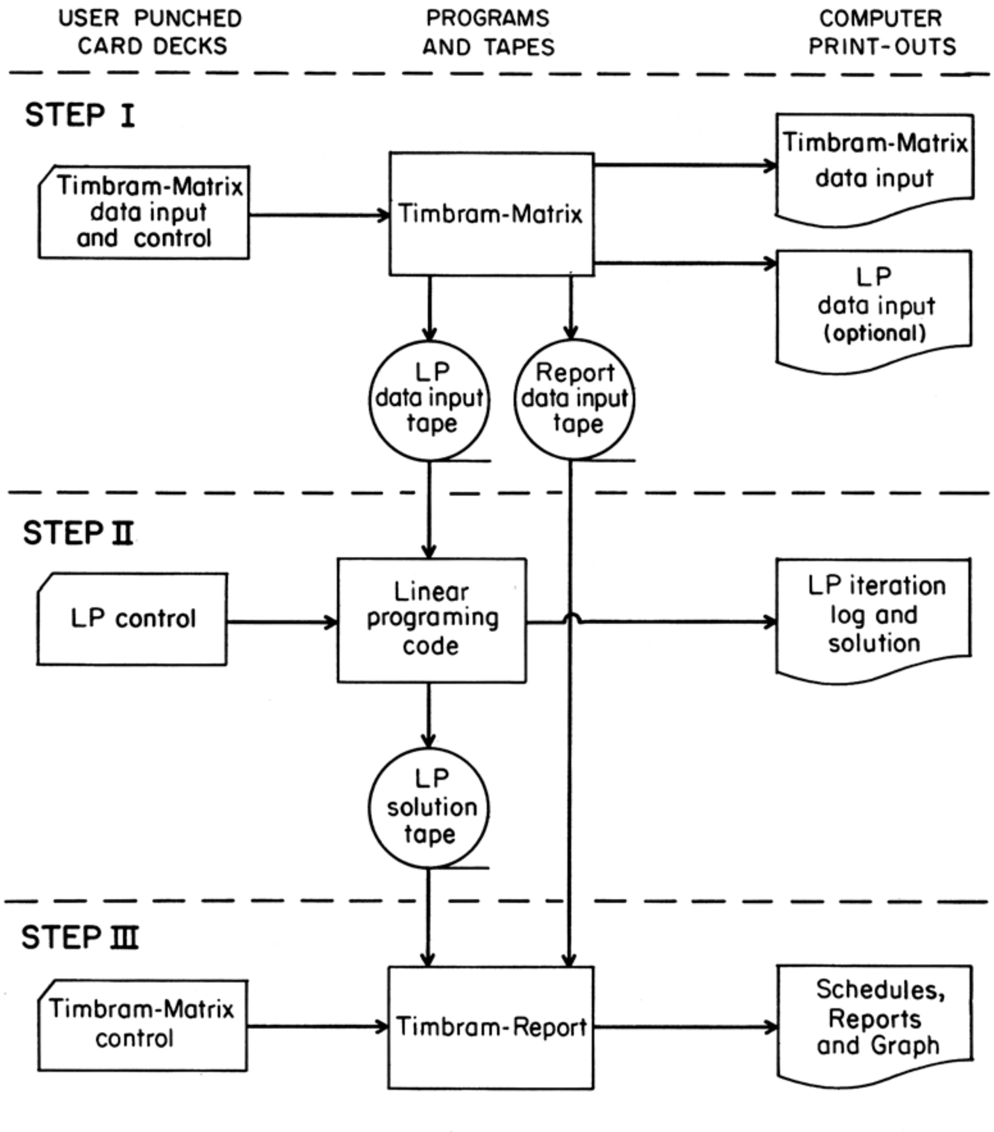

Figure 2—*Three steps are required to generate a Timber RAM plan. Step I: set up a Timber RAM problem with the program Timbram-Matrix. Step II: find a combination of activities with the linear programing computer code ILONA. Step III: translate the combination of activities into Schedules, Reports, and a Graph with the computer program Timbram-Report.*

Step III: translating the combination of activities into schedules and reports and a harvest graph with the Timber RAM program Timbram-Report *(fig. 2).* The Timbram-Re port Control deck consists of only a few cards specifying which documents are desired, the number of periods to be covered by each document, and the rates to be used in discounting revenues and costs.

The three Timber RAM steps can be performed in a single integrated computer run. However, this should not be attempted until the data have been meticulously checked and the user has acquired some experience in running these programs.

The cost of generating Timber RAM plans vary greatly with the specifications of the Timber RAM problem, the LP code, and the computer used. Generally, costs can be expected to rise steeply as the number of timber classes and decades is increased;

but the cost of each subsequent Timber RAM plan will often be only a fraction of the cost of the initial plan.

Selecting a Timber RAM Plan

If all the inputs and outputs defining the activities can be expressed in some common unit, a single value for each Timber RAM plan can be calculated. Then Timber RAM plans can be ranked rationally. If no common unit can be defined, the alternative solutions must be ranked intuitively. Even if a purely rational ranking of plans is possible, the final selection of a plan must be made intuitively to give proper consideration to social needs and political realities.

In the process of selecting a plan, management policies represented by alternative Timber RAM plans are implicitly evaluated. An explicit evaluation can be made once a plan has been selected, by changing the specifications of the constraints or of the activities to simulate the change in policy to be evaluated. The coordination of resource management planning with road construction planning can also be carried out by changing the specification of constraints. For example, the management of stands in unroaded areas might be planned as follows:

A Timber RAM plan is generated on the assumptions all stands are currently accessible. This plan is submitted to the transportation planners who determine whether an economical roading plan can be developed to meet the requirements of this initial Timber RAM plan. Transportation planners may find it economical to defer road access to certain stands. Accessibility constraints would be specified and a new Timber RAM plan generated. This plan would again be submitted to the transportation planners for review. This procedure can be extended to include review of Timber RAM plans or revisions of Timber RAM problems by fire, recreation, range and wildlife management planners.

When linear programing is used to find a combination of activities, the assumption is made that for each activity, average timber yield, costs, and revenues per acre are constant regardless of the number of acres managed with this activity. When timber classes are reasonably homogeneous, the average stumpage harvested with any activity is indeed constant—regardless of the number of acres cut; average revenues and costs, however, ususally are not. If large areas are cut, the average revenue per acre may fall as the price is driven down; so will the average cost per acre as economies of scale are realized.

This proportionality—or linearity—assumption introduces a possible bias in the estimation of total periodic inputs and outputs and in the selection of the combination of activities. The economic data used in long range planning are necessarily crude: expected prices and costs 10, 20, 30 years hence, often for treatments never yet attempted. The additional error induced by the "linearity" assumption will be relatively small if for each activity, average costs and revenues per acre are estimated for an "expected number of acres managed," equal to, say, one-half the acreage of the timber class. The activity level for each Timber RAM plan must then be inspected to establish by how much they differ from the "expected number of acres managed," and to determine whether the inputs and outputs per acre defining the activities are still acceptable estimates.

To obtain a more rigorous measure of the possible bias introduced by the "linearity" assumption, the objective and total periodic inputs and outputs of the Timber RAM plan can be recalculated with adjusted inputs and outputs for the activities selected by the linear program. This step requires making only two computer runs: one with Timbram-Matrix and one with Timbram-Report. (Detailed procedures are explained in the *Forester's Guide*—Part II of the Users' Manual.) The schedules and reports obtained without making a linear programing computer run are only a pseudo Timber RAM plan because by definition a Timber RAM plan is a solution to a linear programing run.

If the differences between the Timber RAM plan and the pseudo Timber RAM plan are unacceptably large, a new Timber RAM plan can be generated with the adjusted coefficients, and the activity levels once more inspected. By comparing the schedule of the initial Timber RAM plan with that of the Timber RAM plan generated with adjusted costs and revenues the bias induced by the linearity assumptions in the selection of the combination of activities can be assessed.

The stability of the combination of activities, objectives, and total periodic inputs and outputs with respect to adjustments in the data, must in any case be explored before making operational decisions based on Timber RAM plans. If a 10 percent change in costs, revenues, or stumpage data results in a combination of activities requiring completely different treatments or schedulings of treatments, then the Timber RAM plans cannot provide stable management guidelines. However, they may still provide stable estimates of the economic and silviculture potential of a forest. For example, the Timber RAM plan based on adjusted inputs and outputs may require that a completely different group of timber classes be managed intensively but show only small changes in the objective and total periodic inputs and outputs. Fortunately, the stability of Timber RAM plans can, in many cases, be improved by redefining some of the timber classes and activities.[1] Of course, only the individuals responsible for making management decisions can judge what level of instability in the Timber RAM plans is acceptable. If acceptably stable plans cannot be generated with Timber RAM, more sophisticated methods, such as, quadratic, dynamic or mixed integer linear programing must be used to develop long-range plans.

The realism with which land management and policy alternatives can be evaluated with Timber RAM plans depends on the characteristics of the Timber Resources Allocation Method and upon the imagination with which it is used. The characteristics of the method are defined by the aspects of linear programing discussed above and the imagination with which it can be used is restricted by the options of the two Timber RAM programs: Timbram-Matrix and Timbram-Report.

TIMBRAM-MATRIX OPTIONS

Activities

Timber RAM activities can be defined by two inputs: Land and Cost; and four outputs: Volume Harvested, Gross Revenue 1, Gross Revenue 2, and Net Revenue. Every activity in a Timber RAM problem must be defined by the same inputs and outputs. Any combination of inputs and outputs is admissible as long as it includes land.

The precise definitions of Cost, Gross Revenue 1 and Gross Revenue 2 are left to the discretion of the user. Net Revenue is calculated automatically by Timbram-Matrix as the difference between Gross Revenue 2 and Cost.

Definitions may reflect business or social accounting categories. For example, a public agency might define Cost as operating expenses, Gross Revenue 1 as gross national product, and Gross Revenue 2 as gross stumpage fees collected. Net Revenue which is automatically calculated by Timbram-Matrix as the difference between Gross Revenue 2 (stumpage collected) and Cost (operating expenses) would then represent net revenues.

The units for land, stumpage volume and revenues and costs are respectively acres, thousand board feet and dollars. These can be changed to any unit desired with trivially simple changes in a few subroutines of Timbram-Matrix and Timbram-Report.

The unit of time or period in Timber RAM is a decade. Hence, the inputs and outputs defining the activities are totals over each decade. To provide targets and management guidelines for 5-year plans, inputs and outputs can also be totalled for the first and second half of the first decade. Changing the unit of time requires major modification of several subroutines.

Each input and output can be defined for up to 35 decades. All inputs and outputs need not be defined for the same number of decades, but any one input or output must be defined for the same number of decades in all the activities. To illustrate, for every activity, Volume Harvested can be defined for 30 decades while Revenues and Costs are defined only for 5 decades.

The number of activities which can be defined for each timber class is unlimited. Several hundred activities are likely to be defined for a Timber RAM problem. The data preparation and processing task is greatly reduced with the management alternative options. For each timber class, sequences of treatments are specified and Timbram-Matrix generates the activities corresponding to specified alternative schedulings. For example, activities 1, 2, and 3 discussed above *(fig. 1)* can be generated by defining the management alternative:

- clearcut the standing timber
- reforest the same decade
- partial cut the regenerated timber on a 10-year cycle from age 50 until harvest cut at age 80
- schedule the standing timber cut for the first 3 decades

and by providing Timbram-Matrix with tables of yields, costs, and revenues. To define a management alternative both a sequence of treatments and its scheduling must be specified. This is done by completing a single line on one of the specially designed Timbram-Matrix data forms. Many different types and sequences of treatments can be specified with the

[1]The clues necessary to carry out this delicate task are obtained by making a "sensitivity analysis." See Dantzig, George B., *Linear programming and extensions.* Princeton: Princeton University Press, p. 265-275. 1963.

standard management alternative options. If some activities cannot be specified with these options the user has two alternatives: generate each of these activities himself and enter the data on another of the Timbram-Matrix data forms, or modify the program Timbram-Matrix. The management alternative options and the technique used by Timbram-Matrix to generate activities are discussed in detail in the *Appendix.*

Objectives

In Timber RAM, each of these inputs and outputs can be used as an index of performance, or objective: Volume Harvested, Gross Revenue 1, Gross Revenue 2, Cost, and Net Revenue. The precise definition of the first four is entirely at the discretion of the user; the last, Net Revenue, is calculated by Timber RAM as the difference between "Gross Revenue 2" and "Cost."

These objectives can be defined for any sequence of decades desired up to the planning horizon of the Timber RAM problem. For example, decisions to "maximize total Net Revenues for the first 3, 5, or 12 decades" represent three possible objectives for a Timber RAM problem with a planning horizon of at least 12 decades. The economic objectives—Gross Revenue 1 and 2, Net Revenue, and Cost—can be discounted at any interest rate desired. In addition, Gross Revenue 1 or 2 and Cost can be discounted at different interest rates—a practice strongly recommended by some economists.[2] But when this is done, no discount rate can be attributed to Net Revenue. All discounting is calculated on the assumption that costs and revenues occur in the middle of each period.

For a given Timber RAM problem six alternative horizons can be specified for each objective. In addition, the cost and revenue objectives can be discounted at seven different interest rates. Up to 174 alternative objectives can be specified in a single Timber RAM problem.

Constraints

A forest manager's freedom of action is limited by many considerations. Some of these limitations can be expressed in Timber RAM by specifying "Constraints." Thus, the manager can allow for limitations on the area and accessibility of the timber classes; on the availability of genetically improved planting stock; on the periodic level of harvests, costs, and revenues. Constraints can also be specified to regulate the forest and to insure a controlled flow of timber during the conversion period. All these constraints are imposed by specifying upper or lower bounds on the periodic level of the inputs and outputs defining the activities.

Area and Accessibility Constraints

These constraints are specified individually for each timber class. They can be modified only by making a computer run with Timbram-Matrix to define a new Timber RAM problem.

Area constraints can be specified as the *maximum* number of acres to be managed with the Timber RAM activities; this specification allows the possibility that none, or only a few of the acres of a timber class will be managed. Area constraints can alternatively be specified as the *total* number of acres to be managed with the activities; thus insuring that every acre of this timber class will be managed.

Timber-class area constraints can provide a partial basis for evaluating land classification policies. For example, the impact of establishing scenic corridors or vistas on costs, revenues, and volume harvested can be estimated by reducing the area of the timber classes affected and preparing a new Timber RAM plan. Or the acreage of each timber class falling in the scenic zone can be defined as one or several separate timber classes and special silvicultural treatments specified to preserve the esthetic qualities of this area. The policy to establish scenic zones can then be evaluated by analyzing the schedules and reports for the "scenic" and "nonscenic" Timber RAM plans. This procedure can be extended to evaluate policies on streamside zones, or high-erosion zones.

Accessibility constraints specify the percent of the acreage of each timber class which is expected to be accessible in each of the first five planning periods. These constraints are omitted when every timber class is fully accessible at the beginning of the first period. Note that if the first decade is split into two planning periods, the first five planning periods will span only 4 decades. By manipulating these accessibility constraints, an accelerated road construction plan can be evaluated in terms of the input or output selected as the objective. To do this a second Timber RAM problem is defined—identical to the first except for the percentage of the acres of each timber class

[2]Mobasheri, F, *Optimization techniques in the planning, design, and operation of water resources systems.* (Unpubl. rep. on file, Eng. & Physical Sci. Ext., Univ. Calif., Los Angeles, Calif. 1968.)

accessible in the first five periods, which now must reflect the accelerated roading plan. A first approximation to the value of the accelerated roading plan can be obtained by weighing the change in the objective against the difference in cost of the two roading programs.

Periodic Constraints

In Timber RAM every constraint is in fact a periodic constraint, but it is convenient to reserve this term for constraints which can be modified without rerunning Timbram-Matrix.

Periodic constraints can be specified on the area planted with genetically improved stock and on the level of each of the five inputs and outputs which can be used as indices of performance (Volume, Gross Revenue 1, Gross Revenue 2, Net Revenue, and Costs). These constraints are specified either by an "upper" or by a "lower" bound on the periodic level. Gross Revenues, Net Revenues, and Volume Harvested can only be constrained above minimum periodic levels by "lower bounds." Costs and the area planted with genetically improved stock, can only be constrained below maximum periodic levels by "upper" bounds. Periodic constraints can be specified for every decade up to the planning horizon. These constraints must be specified with great care since it is quite easy to specify a maximum cost level inconsistent with a minimum harvest or revenue level. In such a case, the linear program computer run will abort and the computer printout will state that there is no feasible solution. Fortunately, these levels can be changed without rerunning the Timbram-Matrix program.

In the first decades of a tree improvement program, the number of acres which can be reforested with the improved stock may be limited by the availability of planting stock. In such a situation, the maximum number of acres on which improved stock can be planted can be specified for every decade up to the planning horizon. In each decade, the improved stock will be allocated to the area offering the highest return—in terms of the objective specified—and normal stock will be planted on the remainder of the acres reforested in that decade. Hence no matter how little genetically improved stock is available, the linear program computer run will never abort because of the constraints.

Harvest Control and Regulation Constraints

Harvest control constraints are used to shape the stream of harvests, regulation constraints to stabilize it.[3] Control and regulation constraints are specified by an upper and a lower bound on the periodic harvest levels and can be changed only by rerunning Timbram-Matrix. These bounds can be set at different levels for every period. Any degree of control and regulation can be specified by varying the bounds. Harvest control constraints are mandatory. They are imposed on the first and succeeding decades which are then referred to as the "conversion period." Therefore the length of the "conversion period" in Timber RAM is determined by the number of decades for which the user specifies harvest control constraints. The compulsory specification of a "conversion period" greatly simplified the structure of the computer program. Users not interested in harvest control can specify very wide bounds for a single decade. This one decade "conversion period" will have no impact on the selection of combination of activities. Regulation constraints are optional. When they are specified they must be imposed on the remaining decades of the Timber RAM plan which are then referred to as the post-conversion period. Hence in Timber RAM, the post-conversion period always spans the decades from the end of the conversion period to the planning horizon.

Harvest control and regulation constraints can be imposed either on the total stumpage volume or on the total number of acres harvested in each period. In a given Timber RAM problem all the harvests constraints—including the Periodic Harvest constraints—must be expressed in the same units. The constraints being very similar for the "volume" and "area" options, the discussion will assume that periodic harvests are expressed in thousand board feet, and only differences will be pointed out.

Three types of control can be imposed on the conversion-period harvests: arbitrary, sequential and conventional.

In *arbitrary control,* the harvest level of each period is restricted to a range of values specified by a fixed upper and lower bound; for example: 125 and 90 million board feet—or 3,000 and 2,500 acres *(fig. 3A).* When the arbitrary control and the volume options are selected, Periodic Harvest constraints are redundant and should not be specified. Arbitrary control can be used to generate Timber RAM plans with any sequence of periodic harvests consistent with the resources available and treatments specified.

[3]For a detailed discussion of the Timber RAM approach to forest regulation see Hennes, LeRoy C., Daniel I. Navon, and Michael J. Irving, *Harvest control and regulation in Timber RAM.* USDA Forest Serv. Res. Note PSW-231, 10 p., illus., Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif. 1971.

In *sequential control,* each periodic harvest level is restricted to a range of values around the preceding periodic harvest level *(fig. 3B).* The upper and lower bounds of this range are expressed as a percentage of the preceding periodic harvest level; for example: given a harvest level of 100 million board feet, 0.25 and 0.10 specify the range 125 to 90 million board feet for the next periodic harvest. The first periodic harvest level is restricted to a range around a specified "current level," to provide a means of insuring a smooth transition into the Timber RAM plan. With sequential control constraints, large jumps or drops in stumpage harvested can be bridged by gradual changes in periodic harvest levels.

In *conventional control,* each periodic harvest level is restricted to a range of values around their average *(fig. 3C).* The upper and lower bounds of the range are specified as percentages of the average. The first periodic harvest can in addition be restricted to a range around a specified "current level" to insure a smooth transition into the Timber RAM plan. The upper and lower bounds of this range are also specified as percentages—but of the "current level." (If the two ranges constraining the first periodic harvest are inconsistent, the linear program computer run will abort with the comment "infeasible.")

Regulation constraints are specified to stabilize the periodic stumpage harvest level by redistributing acres among age classes. This is accomplished indirectly by controlling the periodic harvest level after all over-aged or poorly stocked timber classes have been liquidated during the decades of the conversion period. This control is exercized by restricting each of the post conversion periodic harvest levels to a range around their average. The width of this range will reflect the degree of regulation desired.

To illustrate, consider a forest consisting of a dozen timber classes varying with respect to age stocking and area, but of uniform potential productivity or "site class." Let us further assume that all the standing timber is cut during an 8-decade conversion period. If all the regenerated timber is to be managed on the same rotation age, say 80 years, the periodic harvests after the eighth decade will re-occur on an 8-decade "regulated cycle." Therefore by restricting the post-conversion periodic harvest levels to a range around their average for only 8 decades the forest will be regulated for an indefinitely long period—in theory. The conversion period need not be as long as the post-conversion period. To illustrate, in the above example, if sufficient acreages of 10-, 20- and 30-year-old saplings and poles are already standing, the conversion period can be cut to 5 decades.

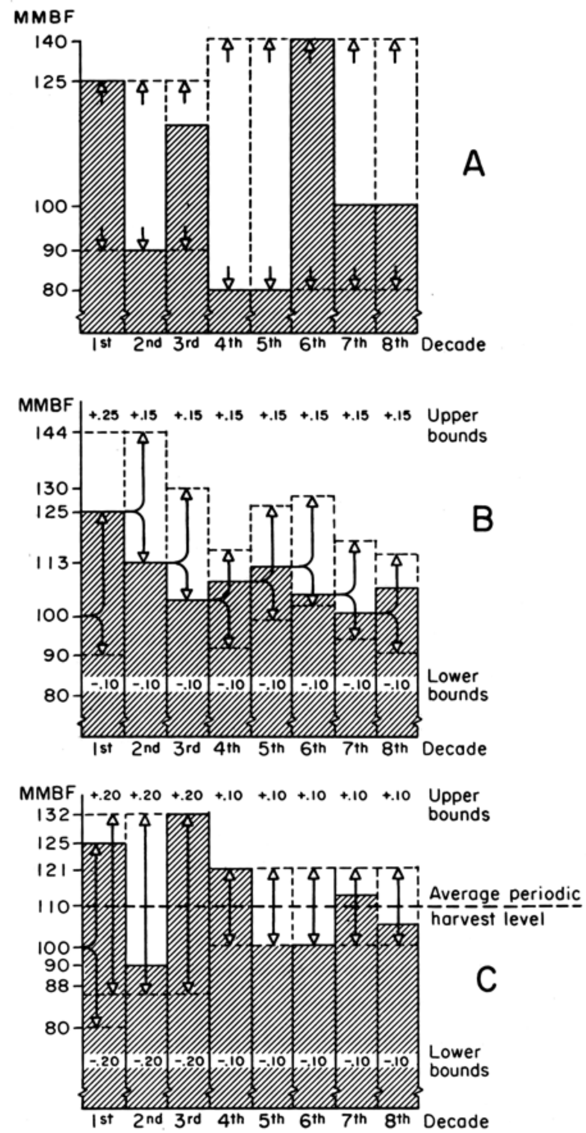

Figure 3— *Timber RAM permits three types of harvest control: A, arbitrary; B, sequential; and C, conventional. Each shaded bar represents the periodic harvest level. The tip of each arrow shows a bound. In sequential and conventional controls, the base of each arrow indicates the harvest level from which the bound was calculated. Upper and lower bounds are expressed as percentages. Except for the "current level" (100 MMBF), the harvest levels are unknown when the bounds are specified.*

But to stabilize periodic harvests, it is essential that by the end of the conversion period all overaged and poorly stocked acres be liquidated, since otherwise the second "regulated cycle" of periodic harvests will be different from the first.

If several rotation ages are contemplated, the "regulated cycle" has a much longer period. For example, for 7- and 8-decade rotations the cycle is 56 decades (the smallest common multiple of seven and eight). In these cases the post-conversion period can be limited to the longest rotation age—here 8 decades—and the forest will be for practical planning purposes adequately regulated. If total periodic stumpage is stabilized but partial cuts account for too large a percentage of the stumpage harvested in some of the post-conversion decades, the regulation constraints can be specified on the stumpage clearcut only. When the standing timber consists largely of overaged stands, a large drop in volume harvested may occur between the last decade of the conversion period and the first decade of the post-conversion period. This drop can be controlled with the "conversion link" constraint. With this constraint, the last periodic harvest level of the conversion period is restricted to a range of values around the average harvest level of the post conversion period.

When harvests are defined in terms of the number of acres harvested, and the potential productivity of the timber classes does not vary widely, stumpage harvested can be stabilized by imposing control constraints only. A conversion period extending over a number of decades equal to the longest rotation on which the regenerated timber will be managed will usually provide an adequately regulated forest. But unless the forest is already approximately regulated, wide fluctuations in periodic stumpage are likely to occur during the conversion period. Defining the harvest constraints in terms of the number of acres harvested is likely to prove useful only in peculiar situations. This option is provided in Timber RAM as a tribute to traditional forest management methods; and because its marginal cost was low.

TIMBRAM-REPORT OPTIONS

The Timbram-Report program can translate the linear program solution into any combination of the following five documents:

- Timber Harvest Schedule *(fig. 4)*
- Problem Schedule or Objective Report *(fig. 5)*
- Harvest Report *(fig. 6)*
- Economic Report (fig. *7)*
- Harvest Graph *(fig. 8)*

These documents are illustrated with computer printout of the Smokey Forest Case Study.

The Timber Harvest Schedule gives—for each activity selected by Timber RAM—the number of acres to be managed, the cut per acre, and the total cut for each period *(fig. 4).* The Schedule also gives the total volume harvested in each period and a breakdown by overstory removals, clearcuts, and all other cuts.

The problem schedule is similar to the harvest schedule but gives economic data as well as harvest volume *(fig. 5).* In addition, it shows the contribution of each activity (per acre and total) to the objective. The total objective value appears at the top of the report. Periodic totals for every input and output are given at the bottom. All revenues and costs are discounted at rates set by the user. The discount rate(s) of the objective or a zero discount rate should be included among the rates set by the user. Because this section of the program supplies large quantities of information the user should not request more periods of output than is absolutely necessary. When the Problem Schedule is not requested, an Objective Report is output automatically. This report gives only the activity name, acres managed, and the total contribution of each activity selected by Timber RAM to the objective.

The Harvest Report is an abstract of the Timber Harvest Schedule giving the total periodic and cumulative volumes harvested in each period *(fig. 6).* Subtotals for periodic overstory removal and partial cuts are also given. The true post-conversion average harvest level is also given at the top of the report. This average will differ from the average of the post-conversion harvests calculated by Timber RAM if the Regenerated Timber is managed on two or more rotations.

The Economic Report is an abstract of the Problem Schedule giving the periodic and cumulative values for Cost, Gross Revenue 1, Gross Revenue 2, and Net Revenue *(fig. 7).* Each can be discounted with up to five different discount rates.

The Harvest Graph displays the harvest level for every period up to the planning horizon *(fig. 8).*

Multiple copies of the Timbram-Report output can be requested and an additional copy can be placed on magnetic tape as a permanent record if desired.

SMOKEY FOREST PROBLEM II RUN 1
NET REVENUE POTENTIAL

OBJECTIVE: TNR34 - NET REVENUE   OPTIMIZED THROUGH PERIOD 16 : DISCOUNT RATES = .060 (REVENUES) AND .060 (COSTS)

TIMBER HARVEST SCHEDULE
PERIODS 1 - 10

ACTIVITY NAME / ACRES CUT — TOTAL VOLUME CUT - MMBF (VOLUME CUT / ACRE - MBF/AC)

ACTIVITY NAME / ACRES CUT	1	2	3	4	5	6	7	8	9	10
E13.I, 2, 2 / 1621.521		56.75* (35.00)					10.22 (6.30)	4.38 (2.70)	4.54 (2.80)	53.19* (32.80)
E13.S, 2, 2 / 1000.000		35.00* (35.00)					8.00 (8.00)	3.50 (3.50)	35.00* (35.00)	
E13.M, 2, 2 / 7378.483		258.25* (35.00)					46.48 (6.30)	19.92 (2.70)	221.35* (30.00)	
E11.G, 1, 1 / 939.310	32.88* (35.00)					5.92 (6.30)	2.54 (2.70)	2.63 (2.80)	30.81* (32.80)	
E11.N, 3, 3 / 3200.034			112.00* (35.00)					20.16 (6.30)	8.64 (2.70)	8.96 (2.80)
E11.S, 1, 1 / 11560.690	404.62* (35.00)					72.83 (6.30)	31.21 (2.70)	346.82* (30.00)		
E11.S, 3, 3 / 2000.000			70.00* (35.00)					16.00 (8.00)	7.00 (3.50)	70.00* (35.00)
E11.C, 2, 2 / 2500.000		87.50* (35.00)					15.75 (6.30)	6.75 (2.70)	75.00* (30.00)	
E11.C, 3, 3 / 4799.965			168.00* (35.00)					30.24 (6.30)	12.96 (2.70)	144.00* (30.00)
OS1.G, 3, 6 / 3077.039			41.54+ (13.50)	8.31 (2.70)	8.62 (2.80)	62.46* (20.30)				
OS1.I, 1, 4 / 6015.048	80.00+ (13.30)	12.03 (2.00)	14.44 (2.40)	93.23* (15.50)					37.89 (6.30)	16.24 (2.70)
OS1.I, 2, 5 / 6484.952		86.90+ (13.40)	15.56 (2.40)	17.51 (2.70)	116.73* (18.00)					40.86 (6.30)
OS1.S, 4, 4 / 4000.000				112.00* (28.00)					32.00 (8.00)	14.00 (3.50)
OS1.S, 4, 6 / 2942.240				40.01+ (13.60)	8.24 (2.80)	59.73* (20.30)				
OS1.M, 4, 4 / 2480.722				69.46* (28.00)					15.63 (6.30)	6.70 (2.70)
E02.G, 3, 6 / 1112.694			5.79 (5.20)	2.23 (2.00)	2.67 (2.40)	18.36* (16.50)				
E02.G, 4, 7 / 1544.466				8.80 (5.70)	3.71 (2.40)	4.17 (2.70)	28.57* (18.50)			
E02.I, 3, 5 / 2117.378			11.01 (5.20)	4.23 (2.00)	31.76* (15.00)					13.34 (6.30)
E02.S, 3, 6 / 5688.831			29.58 (5.20)	11.38 (2.00)	13.65 (2.40)	93.87* (16.50)				
E02.S, 4, 7 / 12384.836				70.59 (5.70)	29.72 (2.40)	33.44 (2.70)	229.12* (18.50)			
E02.M, 3, 5 / 12151.794			63.19 (5.20)	24.30 (2.00)	182.28* (15.00)					76.56 (6.30)
E00.I, 2,10 / 5000.000							31.50 (6.30)	13.50 (2.70)	14.00 (2.80)	164.00* (32.80)
OVERSTORY REMOVAL CUTS										
ACRES	6015.05	6484.95	3077.04	2942.24	.00	.00	.00	.00	.00	.00
MMBF	80.00	86.90	41.54	40.01	.00	.00	.00	.00	.00	.00
INTERMEDIATE CUTS										
ACRES	.00	6015.05	33570.70	44561.99	26750.11	26429.30	30000.00	28439.31	29117.29	36449.93
MMBF	.00	12.03	139.57	147.36	66.61	116.36	145.70	117.08	132.66	176.65
HARVEST CUTS										
ACRES	12500.00	12500.00	10000.00	12495.77	20754.12	12820.80	13929.30	11560.69	11817.79	13421.49
MMBF	437.50	437.50	350.00	274.69	330.77	234.42	257.69	346.82	362.16	431.18
TOTAL CUTS										
ACRES	18515.05	25000.00	46647.73	60000.00	47504.23	39250.11	43929.31	40000.00	40935.08	49871.41
MMBF	517.50	536.43	531.11	462.06	397.37	350.78	403.39	463.90	494.83	607.83

+ = OVERSTORY REMOVAL CUT; * = HARVEST CUT

Figure 4—*The Timber Harvest Schedule lists for each activity selected by the linear program total volume and number of acres harvested in each period. The volume per acre is given in parentheses. The volume and acres harvested in each period from all activities is totaled at the bottom, by type of cut: overstory removal, intermediate, and harvest cuts.*

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                              SMOKEY FOREST PROBLEM II  RUN 1
                                  NET REVENUE POTENTIAL

OBJECTIVE: TNR34  -  NET REVENUE          OPTIMIZED THROUGH PERIOD 16 :  DISCOUNT RATES = .060 (REVENUES) AND .060 (COSTS)
                TOTAL OBJECTIVE VALUE =     31370.99  (UNITS =  $1000  )

                                   **************************
                                   *                        *
                                   *    PROBLEM SCHEDULE    *
                                   *    PERIODS   1 - 5     *
                                   *                        *
                                   **************************

DISCOUNT RATES:  REVENUES =  .06,   COSTS =  .06

ACTIVITY NAME    INDEX  OF      UNITS    OBJECTIVE                              TOTAL  VALUE
  ACRES CUT     PERFORMANCE                                                     VALUE/ACRE

                                                           1          2          3          4          5

E13,I, 2, 2   GROSS REVENUE 1  $1000                               2249.71*
   1621.521                    $/ACRE                            ( 1387.41)

              GROSS REVENUE 2  $1000                               1184.06*
                               $/ACRE                            (  730.21)

              COSTS            $1000                                172.53*
                               $/ACRE                            (  106.40)

              NET REVENUE      $1000       1037.53                 1011.52*
                               $/ACRE    (  639.85)              (  623.81)

              HARVEST VOLUME    MMBF                                 56.75*
                               MBF/ACRE                          (   35.00)


E13,S, 2, 2   GROSS REVENUE 1  $1000                               1387.41*
   1000.000                    $/ACRE                            ( 1387.41)

              GROSS REVENUE 2  $1000                                730.21*
                               $/ACRE                            (  730.21)

              COSTS            $1000                                106.40*
                               $/ACRE                            (  106.40)

              NET REVENUE      $1000        648.65                  623.81*
                               $/ACRE    (  648.65)              (  623.81)

                      VOLUME    MMBF
                               MBF/ACRE
              HARVEST
                                                                                 (    5.70) (    2.40)


E02,M, 3, 5   GROSS REVENUE 1  $1000                                          883.38     221.34    1191.82*
  12151.794                    $/ACRE                                       (   72.70) (   18.21) (   98.08)

              GROSS REVENUE 2  $1000                                          441.69     142.29     728.33*
                               $/ACRE                                       (   36.35) (   11.71) (   59.94)

              COSTS            $1000                                          147.23      15.81     154.50*
                               $/ACRE                                       (   12.12) (    1.30) (   12.71)

              NET REVENUE      $1000       1033.31                            294.46     126.48     573.84*
                               $/ACRE    (   85.03)                         (   24.23) (   10.41) (   47.22)

              HARVEST VOLUME    MMBF                                           63.19      24.30     182.28*
                               MBF/ACRE                                     (    5.20) (    2.00) (   15.00)


E00,I, 2,10   GROSS REVENUE 1  $1000
   5000.000                    $/ACRE

              GROSS REVENUE 2  $1000
                               $/ACRE

              COSTS            $1000                                229.50
                               $/ACRE                            (   45.90)

              NET REVENUE      $1000       -149.31                 -229.50
                               $/ACRE    (  -29.86)              (  -45.90)

              HARVEST VOLUME    MMBF
                               MBF/ACRE


OVERSTORY REMOVAL CUTS
              AREA              ACRES                  6015.05    6484.95    3077.04    2942.24        .00
              GROSS REVENUE 1  $1000                   3586.85    2175.58     580.73     312.37        .00
              GROSS REVENUE 2  $1000                   1793.42    1087.79     290.36     156.18        .00
              COSTS            $1000                    597.81     362.60      96.79      52.06        .00
              NET REVENUE      $1000                   1195.62     725.19     193.58     104.12        .00
              HARVEST VOLUME    MMBF                     80.00      86.90      41.54      40.01        .00

INTERMEDIATE CUTS
              AREA              ACRES                      .00    6015.05   33570.70   44561.99   26750.11
              GROSS REVENUE 1  $1000                       .00     351.38    2021.04    1238.72     350.98
              GROSS REVENUE 2  $1000                       .00     225.89    1080.42     707.78     230.00
              COSTS            $1000                       .00     254.59     290.24     147.51      24.20
              NET REVENUE      $1000                       .00     -28.71     790.18     560.27     205.81
              HARVEST VOLUME    MMBF                       .00      12.03     139.57     147.36      66.61

HARVEST CUTS
              AREA              ACRES                 12500.00   12500.00   10000.00   12495.77   20754.12
              GROSS REVENUE 1  $1000                  29423.29   17160.04    7747.21    2980.43    2247.53
              GROSS REVENUE 2  $1000                  14711.65    8945.12    4077.48    1611.51    1364.07
              COSTS            $1000                   2381.89    1330.03     594.15     324.41     270.93
              NET REVENUE      $1000                  12329.76    7615.09    3483.33    1287.11    1093.14
              HARVEST VOLUME    MMBF                    437.50     437.50     350.00     274.69     330.77

TOTAL CUTS
              AREA              ACRES                 18515.05   25000.00   46647.73   60000.00   47504.23
              GROSS REVENUE 1  $1000                  33010.14   19687.00   10348.98    4531.52    2598.51
              GROSS REVENUE 2  $1000                  16505.07   10258.80    5448.26    2475.48    1594.07
              COSTS            $1000                   2979.69    1947.22     981.18     523.98     295.13
              NET REVENUE      $1000                  13525.38    8311.58    4467.09    1951.50    1298.94
              HARVEST VOLUME    MMBF                    517.50     536.43     531.11     462.06     397.37
```

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*                        *
*    OBJECTIVE REPORT    *
*                        *
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ACTIVITY NAME	ACRES CUT	OBJECTIVE VALUE (UNITS = $1000)	OBJECTIVE VALUE/ACRE (UNITS = $/ACRE)
E13,I, 2, 2	1621.52	1037.53	639.85
E13,S, 2, 2	1000.00	648.65	648.65
E13,M, 2, 2	7378.48	4740.18	642.43
E11,G, 1, 1	939.31	953.53	1015.13
E11,N, 3, 3	3200.03	1143.29	357.28
E11,S, 1, 1	11560.69	11788.78	1019.73
F11,S, 3, 3	2000.00	724.11	362.05
E11,C, 2, 2	2500.00	1423.53	569.41
E11,C, 3, 3	4799.96	1721.19	358.58
OS1,G, 3, 6	3077.04	401.64	130.53
OS1,I, 1, 4	6015.05	2089.12	347.32
OS1,I, 2, 5	6484.95	1398.69	215.68
OS1,S, 4, 4	4000.00	498.97	124.74
OS1,S, 4, 6	2942.24	262.36	89.17
OS1,M, 4, 4	2480.72	304.65	122.81
E02,G, 3, 6	1112.69	81.43	73.19
E02,G, 4, 7	1544.47	74.41	48.18
F02,I, 3, 5	2117.38	179.22	84.64
E02,S, 3, 6	5688.83	417.56	73.40
E02,S, 4, 7	12384.84	598.16	48.30
F02,M, 3, 5	12151.79	1033.31	85.03
F00,I, 2,10	5000.00	-149.31	-29.86

Figure 5—*The Problem Schedule lists for each activity selected by the linear program the total inputs required and outputs produced in each period. Inputs and outputs per acre are given in parentheses. Periodic volume totals are given at the bottom. The total contribution of each activity to the objective is also listed. The Objective Report, an abstract of the Problem Schedule, lists for each activity the total contribution to the objective and the number of acres managed. It is automatically printed by Timbram-Report when the Problem Schedule is not requested.*

SMOKEY FOREST PROBLEM II RUN 1
NET REVENUE POTENTIAL

OBJECTIVE: TNR34 - NET REVENUE   OPTIMIZED THROUGH PERIOD 16 ; DISCOUNT RATES = .060 (REVENUES) AND .060 (COSTS)
TOTAL OBJECTIVE VALUE = 31370.99 (UNITS = $1000)

LONG RANGE SUSTAINED YIELD AVERAGE = 673.45 MMBF/DECADE

HARVEST REPORT

	OVERSTORY REMOVAL CUTS			INTERMEDIATE CUTS			HARVEST CUTS			TOTAL CUTS		
PERIOD	ACRES	MMBF PERIODIC	MMBF TOTAL	ACRES	MMBF PERIODIC	MMBF TOTAL	ACRES	MMBF PERIODIC	MMBF TOTAL	ACRES	MMBF PERIODIC	MMBF TOTAL
1	6015.	80.00	80.00	0.	.00	.00	12500.	437.50	437.50	18515.	517.50	517.50
2	6485.	86.90	166.90	6015.	12.03	12.03	12500.	437.50	875.00	25000.	536.43	1053.93
3	3077.	41.54	208.44	33571.	139.57	151.60	10000.	350.00	1225.00	46648.	531.11	1585.04
4	2942.	40.01	248.45	44562.	147.36	298.95	12496.	274.69	1499.69	60000.	462.06	2047.10
5	0.	.00	248.45	26750.	66.61	365.56	20754.	330.77	1830.46	47504.	397.37	2444.47
6	0.	.00	248.45	26429.	116.36	481.92	12821.	234.42	2064.88	39250.	350.78	2795.25
7	0.	.00	248.45	30000.	145.70	627.62	13929.	257.69	2322.57	43929.	403.39	3198.64
8	0.	.00	248.45	28439.	117.08	744.70	11561.	346.82	2669.39	40000.	463.90	3662.54
9	0.	.00	248.45	29117.	132.66	877.36	11818.	362.16	3031.55	40935.	494.83	4157.37
10	0.	.00	248.45	36450.	176.65	1054.01	13421.	431.18	3462.74	49871.	607.83	4765.21
11	0.	.00	248.45	39590.	175.44	1229.46	9681.	319.38	3782.12	49271.	494.83	5260.03
12	0.	.00	248.45	35352.	180.39	1409.85	18167.	561.85	4343.97	53519.	742.24	6002.27
13	0.	.00	248.45	29680.	158.00	1567.85	17233.	584.24	4928.21	46913.	742.24	6744.51
14	0.	.00	248.45	24923.	141.18	1709.03	16575.	601.06	5529.27	41498.	742.24	7486.76
15	0.	.00	248.45	25239.	148.73	1857.77	13105.	466.40	5995.67	38344.	615.14	8101.89
16	0.	.00	248.45	24042.	128.18	1985.94	10878.	380.75	6376.42	34920.	508.93	8610.82
17	0.	.00	248.45	34469.	205.70	2191.65	7739.	275.57	6651.99	42208.	481.27	9092.09
18	0.	.00	248.45	38600.	214.25	2405.90	13102.	491.69	7143.68	51703.	705.94	9798.03
19	0.	.00	248.45	39823.	216.97	2622.87	15352.	553.31	7696.99	55175.	770.29	10568.32
20	0.	.00	248.45	38282.	197.26	2820.13	14646.	542.69	8239.68	52928.	739.95	11308.27

Figure 6—*The Harvest Report lists by type of cuts the total volume and acres harvested in each period.*

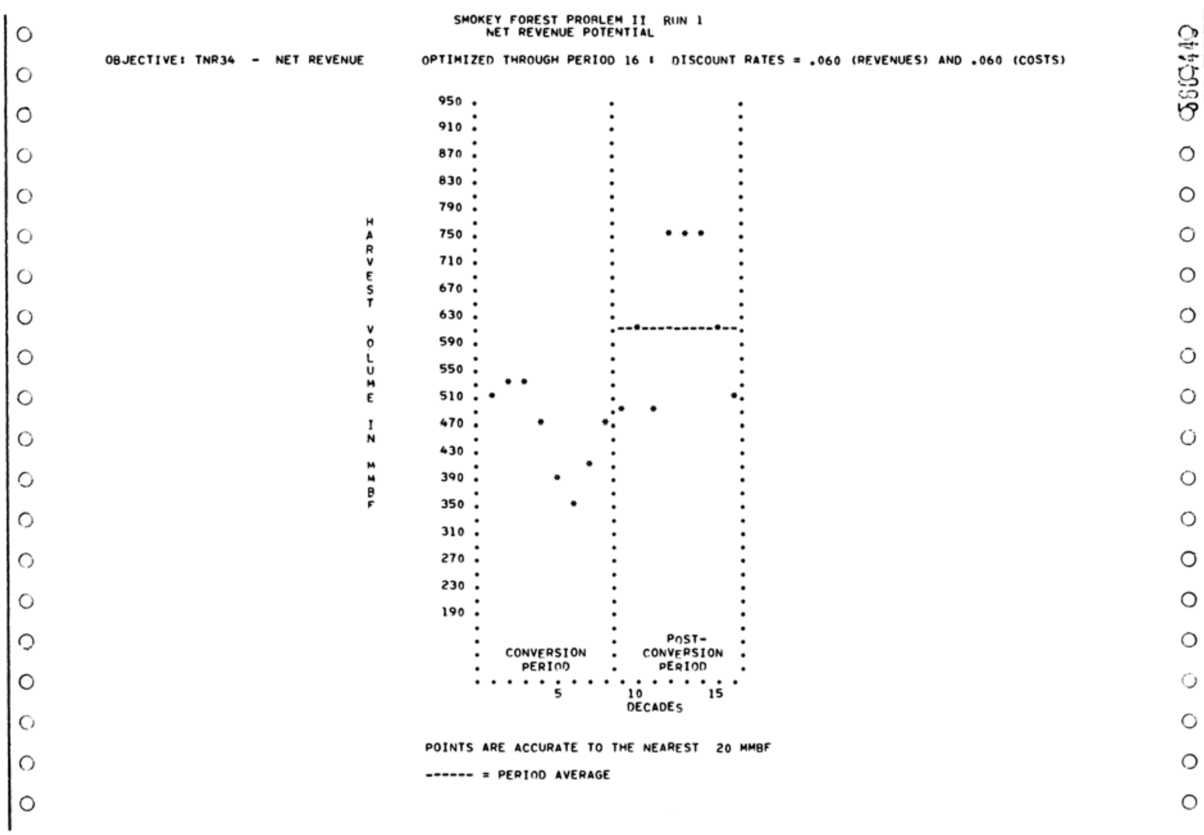

Figure 8—*The Harvest Graph displays the total volume harvested in each period up to the "planning horizon."*

(See page 16 for Figure 7)

SMOKEY FOREST PROBLEM II RUN 1
NET REVENUE POTENTIAL

OBJECTIVE: TNR34 - NET REVENUE OPTIMIZED THROUGH PERIOD 16 : DISCOUNT RATES = .060 (REVENUES) AND .060 (COSTS)
TOTAL OBJECTIVE VALUE = 31370.99 (UNITS = $1000)

ECONOMIC REPORT

(UNITS = $1000)

	DISCOUNT RATES		GROSS REVENUE 1		GROSS REVENUE 2		COSTS		NET REVENUE	
PERIOD	REVENUES	COSTS	PERIODIC	TOTAL	PERIODIC	TOTAL	PERIODIC	TOTAL	PERIODIC	TOTAL
1	.000	.000	44175.01	44175.01	22087.50	22087.50	3987.50	3987.50	18100.00	18100.00
	.100	.100	27429.21	27429.21	13714.60	13714.60	2475.92	2475.92	11238.68	11238.68
	.060	.060	33010.14	33010.14	16505.07	16505.07	2979.69	2979.69	13525.38	13525.38
2	.000	.000	47181.02	91356.03	24585.81	46673.32	4666.64	8654.14	19919.18	38019.18
	.100	.100	11294.76	38723.97	5885.65	19600.25	1117.16	3593.08	4768.49	16007.17
	.060	.060	19687.00	52697.13	10258.80	26763.87	1947.22	4926.92	8311.58	21836.95
3	.000	.000	44416.45	135772.48	23383.23	70056.54	4211.08	12865.21	19172.15	57191.33
	.100	.100	4099.46	42823.43	2158.18	21758.43	388.67	3981.75	1769.51	17776.68
	.060	.060	10348.98	63046.11	5448.26	32212.13	981.18	5908.09	4467.09	26304.04
4	.000	.000	34829.61	170602.09	19026.73	89083.27	4027.34	16892.55	14999.39	72190.72
	.100	.100	1239.38	44062.81	677.05	22435.48	143.31	4125.05	533.74	18310.42
	.060	.060	4531.52	67577.63	2475.48	34687.61	523.98	6432.07	1951.50	28255.54
5	.000	.000	35767.39	206369.49	21941.71	111024.98	4062.29	20954.84	17879.43	90070.14
	.100	.100	490.70	44553.51	301.02	22736.50	55.73	4180.79	245.29	18555.72
	.060	.060	2598.51	70176.13	1594.07	36281.68	295.13	6727.20	1298.94	29554.48
6	.000	.000	30464.54	236834.02	18346.28	129371.26	3429.71	24384.55	14916.57	104986.71
	.100	.100	161.14	44714.65	97.04	22833.54	18.14	4198.93	78.90	18634.61
	.060	.060	1235.87	71412.00	744.26	37025.94	139.13	6866.33	605.13	30159.61
7	.000	.000	36361.71	273195.73	21835.78	151207.03	3969.64	28354.19	17866.14	122852.84
	.100	.100	74.15	44788.80	44.53	22878.07	8.10	4207.02	36.43	18671.05
	.060	.060	823.69	72235.69	494.64	37520.58	89.92	6956.25	404.72	30564.33
8	.000	.000	40082.57	313278.30	28110.55	179317.58	3460.75	31814.94	24649.80	147502.64
	.100	.100	31.51	44820.31	22.10	22900.17	2.72	4209.74	19.38	18690.43
	.060	.060	507.01	72742.70	355.57	37876.15	43.78	7000.03	311.80	30876.12
9	.000	.000	43441.10	356719.39	30417.79	209735.37	3719.00	35533.94	26698.80	174201.44
	.100	.100	13.17	44833.48	9.22	22909.39	1.13	4210.87	8.09	18698.52
	.060	.060	306.83	73049.53	214.85	38091.00	26.27	7026.30	188.58	31064.70
10	.000	.000	54634.56	411353.95	38462.94	248198.31	4612.43	40146.37	33850.51	208051.95
	.100	.100	6.39	44839.87	4.50	22913.89	.54	4211.41	3.96	18702.48
	.060	.060	215.48	73265.01	151.70	38242.70	18.19	7044.49	133.51	31198.21
11	.000	.000	44950.36	456304.30	31301.71	279500.02	3624.62	43770.99	27677.08	235729.03
	.100	.100	2.03	44841.89	1.41	22915.30	.16	4211.57	1.25	18703.72
	.060	.060	99.00	73364.01	68.94	38311.64	7.98	7052.47	60.95	31259.17
12	.000	.000	67236.25	523540.55	47765.56	327265.57	5540.06	49311.05	42225.50	277954.53
	.100	.100	1.17	44843.06	.83	22916.13	.10	4211.67	.73	18704.46
	.060	.060	82.69	73446.69	58.74	38370.38	6.81	7059.28	51.93	31311.09
13	.000	.000	71193.05	594733.59	50567.98	377833.55	5293.66	54604.71	45274.32	323228.85
	.100	.100	.48	44843.53	.34	22916.47	.04	4211.70	.30	18704.76
	.060	.060	48.89	73495.58	34.73	38405.10	3.64	7062.92	31.09	31342.18
14	.000	.000	72800.34	667533.93	50864.59	428698.14	5178.39	59783.10	45686.20	368915.05
	.100	.100	.19	44843.72	.13	22916.60	.01	4211.72	.12	18704.88
	.060	.060	27.92	73523.50	19.50	38424.61	1.99	7064.91	17.52	31359.70
15	.000	.000	58760.96	726294.88	40579.45	469277.59	4398.85	64181.95	36180.60	405095.64
	.100	.100	.06	44843.78	.04	22916.64	.00	4211.72	.04	18704.92
	.060	.060	12.58	73536.08	8.69	38433.29	.94	7065.85	7.75	31367.45
16	.000	.000	48163.07	774457.95	33218.87	502496.46	3584.57	67766.52	29634.31	434729.95
	.100	.100	.02	44843.80	.01	22916.65	.00	4211.72	.01	18704.93
	.060	.060	5.76	73541.84	3.97	38437.27	.43	7066.28	3.54	31370.99
17	.000	.000	44489.41	818947.36	30092.75	532589.21	3597.40	71363.92	26495.35	461225.30
	.100	.100	.01	44843.80	.00	22916.65	.00	4211.72	.00	18704.93
	.060	.060	2.97	73544.81	2.01	38439.27	.24	7066.52	1.77	31372.76
18	.000	.000	69068.77	888016.12	47981.71	580570.91	5005.16	76369.08	42976.55	504201.84
	.100	.100	.00	44843.81	.00	22916.66	.00	4211.72	.00	18704.93
	.060	.060	2.57	73547.38	1.79	38441.06	.19	7066.70	1.60	31374.36
19	.000	.000	74085.90	962102.02	51282.08	631852.98	5435.53	81804.61	45846.54	550048.38
	.100	.100	.00	44843.81	.00	22916.66	.00	4211.72	.00	18704.93
	.060	.060	1.54	73548.92	1.07	38442.13	.11	7066.82	.95	31375.32
20	.000	.000	72957.14	1035059.15	51001.44	682854.42	5102.73	86907.34	45898.72	595947.09
	.100	.100	.00	44843.81	.00	22916.66	.00	4211.72	.00	18704.93
	.060	.060	.85	73549.77	.59	38442.72	.06	7066.87	.53	31375.85

Figure 7—*The Economic Report lists by period the total discounted revenues and costs. Revenues and costs can be discounted at different rates. Up to five different pairs of discount rates can be specified.*

CONCLUSIONS

The solution to a Timber RAM problem is not necessarily the best combination of activities. It is only a combination which is consistent with specified constraints and which maximizes—or minimizes—a particular index of performance. Managers and planners must then evaluate alternative combinations of activities by determining the extent to which each combination meets social, economic, and ecological needs and political realities. This evaluation is too complex and too subtle to be programed for computers; in our society, it lies largely outside the domain of economic analysis.

Timber RAM simplifies the planning task by shifting to computers the burden of calculating alternative, plans with which planners and managers can determine whether policies governing the multiple-use management of forest land are mutually consistent. And when policies are consistent, Timber RAM makes it possible to estimate the inputs required and the outputs produced should these policies be carried out efficiently. The complexity of natural, social, and economic phenomena dictates that these estimates will be at best crude. Hence, Timber RAM estimates must be considered only first approximations to the actual inputs and outputs. Nevertheless a tool such as Timber RAM places a high premium on the improvement of data gathering and processing, for this in turn will lead to improvement of the estimates.

Timber RAM not only permits evaluation of current policies, it also can be used to develop new policies. It will indicate whether with current and expected technology a policy can be carried out and at what cost; whether it can be carried out only by modifying related policies; and how much these policies must be changed.

The inputs and outputs estimated by Timber RAM are limited to timber, land area, and related costs and revenues. The interaction of range, watershed, recreation, wildlife, and timber management policies can be partially evaluated in terms of the Timber RAM inputs and outputs. The impact of extending recreation use, or stream and wildlife protection, can be introduced in the Timber RAM analysis by defining appropriate activities and manipulating timber class acreages. Extension—or contraction—of range areas can be handled in a similar manner. And the analysis of these policies can be integrated with policies defining the desired timber production profile.

Timber RAM is thus the first step toward a quantitative evaluation of multiple-use interactions. Work on the Resources Allocation Method seeks to extend the list of estimates to include as many inputs and outputs of multiple-use forest management as the current state of the arts reasonably permits. In the measure in which this attempt succeeds, RAM schedules and reports will permit a still more rational evaluation of the interaction of multiple-use management policies.

APPENDIX

Generating Activities with the Management Alternative Options of Timbram-Matrix

Even if all the stands of a forest are combined into 20 or fewer timber classes, several hundred activities are likely to be generated for each Timber RAM problem. The data preparation and processing are greatly reduced and simplified if these activities are defined with the management alternative options of the Timbram-Matrix program. A management alternative is defined by specifying a sequence of treatments for a particular timber class, and also specifying one or more schedulings for these treatments.

Specifying Sequences of Treatments

To simplify the exposition, let us call any timber already established at the beginning of the first planning period "Standing Timber," and use the term "Regenerated Timber" for stands regenerated from the first planning period onward. Regenerated Timber includes the timber planted on land which was unstocked at the beginning of the first period as well as the timber planted to replace Standing Timber.

In general, the Standing Timber and Regenerated Timber of a given timber class will be managed with very different silvicultural treatments. The Standing Timber may be poorly stocked, or overage, in which case it will normally be liquidated, by clearcutting. The Regenerated Timber of this same timber class will presumably be well stocked, and it may be managed intensively by partial cutting. In addition, the Standing Timber may be clearcut over many decades—hence at a wide range of ages—to redistribute the acreage among age classes. The Regenerated Timber, on the other hand, will generally be harvested at one given rotation age—or at most at two or three different rotation ages. These differences in silvicultural treatments for Standing and Regenerated Timber can be specified with the Timbram-Matrix management alternative options.

For a given management alternative, the Regenerated Timber treatments are specified by a rotation age and by the estimated stumpage volume per acre which the treatments will yield for every decade of the rotation. This sequence of cuts and yields is assumed to repeat itself cyclically. For example, clearcutting Regenerated Timber on an 8-decade rotation would be specified as zero volume for the first 7 decades and a clearcut volume for the eighth decade. Any sequence of partial cuts can be easily specified simply by estimating the partial cuts and final cut yields, and assigning them to the appropriate decade. For example, partial cuts in the 3 decades preceding the harvest cut would be specified by assigning the estimated yield from these cuts to the fifth, sixth and seventh decade.

The Standing Timber treatments are specified by a "type of management" (clearcut only, clearcut preceded by partial cuts on a 10- or 20-year cycle, etc.,...) and yields for entry, re-entry and harvest cuts for every age at which these cuts might occur. The Standing Timber yields and the Regenerated yields are consolidated into a Volume Data Class and entered on the Timbram-Matrix data input forms. Similar forms must be prepared for the corresponding costs and revenues data.

With the Timbram-Matrix options, management alternatives can be defined for treatments involving:

- variations in the rotation age of the Regenerated Timber
- the introduction of genetically improved stock
- different logging practices or utilization standards
- the introduction of partial cuts in the Standing Timber on a 10- or 20-year cycle
- various techniques of reforestation
- the removal of the overstory in two-story timber classes—after which the understory can be managed as any other type of Standing Timber
- variations in the level of partial cuts and harvest cuts representing alternative cutting regimes, precommercial thinning, fertilizing, etc.

Specifying Schedulings of Treatment Sequences

In general, a given sequence of treatments can be executed on several time tables; clearcutting mature old growth, for example, can be stretched over several decades to redistribute the acreage among age classes. To schedule a sequence of treatments requiring no partial cutting in the Standing Timber, the first and last periods in which the clearcutting can occur must be specified. When partial cuts are also planned in the Standing Timber, the first and last periods in which the stands can be entered for partial cutting must also be specified.

Consider for example a forest that has 20,000 acres in stands with these characteristics:

- a well-stocked understory which will average 40 years of age in the first planning decade
- a mature overstory.

To reduce data processing costs, let us combine these stands into a single timber class—called 0S1.[4] After the removal of the overstory, let us schedule partial cuts on a 10-year cycle until the Standing Timber is harvest cut and let us manage the Regenerated Timber "intensively" on an 80-year rotation up to the planning horizon in the 16th decade *(fig. 9).* This sequence of treatments partially defines a management alternative which we name 0S1 X.[5] To complete the definition of this management alternative we must specify the decade of first and last entry as well as the decade of first and last harvest since the type of harvesting calls for partial cuts in the standing timber. The overstory being mature, let us specify the first entry—which will be an overstory removal—for the first decade. Let us delay the first harvest cut until the understory which is 40 years old in the first

[4]Timber classes are identified in Timber RAM by any three "alphanumeric" characters. The alphanumeric characters consist of the set of 26 letters and 10 digits.

[5]The name of a management alternative OS1 X consists of three characters identifying the timber class (OS1) followed by a single alphanumeric character identifying the sequence of silvicultural treatments (X).

Sequence of treatments
Standing Timber: overstory removal, partial cuts on a 10-year cycle until the final harvest cut, then plant.
Regenerated Timber: partial cut at age 50, 60, and 70; final harvest cut at age 80, then plant.

Scheduling of treatments
First Entry: Period 1 First Harvest: Period 4
Last Entry: Period 5 Last Harvest: Period 6

PERIOD (decade)	ACTIVITIES OS1 X														
	14	24	34	44	15	25	35	45	55	16	26	36	46	56	
1	13.3 (E)				13.3 (E)					13.3 (E)					
2	2.0 (RE)	13.4 (E)			2.0 (RE)	13.4 (E)				2.0 (RE)	13.4 (E)				STANDING
3	2.4 (RE)	2.4 (RE)	13.5 (E)		2.4 (RE)	2.4 (RE)	13.5 (E)			2.4 (RE)	2.4 (RE)	13.5 (E)			TIMBER
4	15.5 (IHC)	15.5 (IHC)	15.5 (IHC)	28.0 (HC)	2.7 (RE)	2.7 (RE)	2.7 (RE)	13.6 (E)		2.7 (RE)	2.7 (RE)	2.7 (RE)	13.6 (E)		
5					18.0 (IHC)	18.0 (IHC)	18.0 (IHC)	18.0 (IHC)	29.0 (HC)	2.8 (RE)	2.8 (RE)	2.8 (RE)	2.8 (RE)	13.5 (E)	YIELDS
6										20.3 (IHC)	20.3 (IHC)	20.3 (IHC)	20.3 (IHC)	20.3 (IHC)	
7															
8															
9	6.3 (E)	6.3 (E)	6.3 (E)	6.3 (E)											
10	2.7 (RE)	2.7 (RE)	2.7 (RE)	2.7 (RE)	6.3 (E)	6.3 (E)	6.3 (E)	6.3 (E)	6.3 (E)						REGENERATED
11	2.8 (RE)	2.8 (RE)	2.8 (RE)	2.8 (RE)	2.7 (RE)	2.7 (RE)	2.7 (RE)	2.7 (RE)	2.7 (RE)	6.3 (E)	6.3 (E)	6.3 (E)	6.3 (E)	6.3 (E)	TIMBER
12	32.8 (IHC)	32.8 (IHC)	32.8 (IHC)	32.8 (IHC)	2.8 (RE)	2.8 (RE)	2.8 (RE)	2.8 (RE)	2.8 (RE)	2.7 (RE)	2.7 (RE)	2.7 (RE)	2.7 (RE)	2.7 (RE)	YIELDS
13					32.8 (IHC)	32.8 (IHC)	32.8 (IHC)	32.8 (IHC)	32.8 (IHC)	2.8 (RE)	2.8 (RE)	2.8 (RE)	2.8 (RE)	2.8 (RE)	
14										32.8 (IHC)	32.8 (IHC)	32.8 (IHC)	32.8 (IHC)	32.8 (IHC)	
15															
16															

Volumes are in MBF/ACRE
E: entry cut
RE: re-entry cut
IHC: intensive harvest cut (last of a series of cuts)
HC: harvest cut (clear cut)

Figure 9—*Management alternative OS1 and corresponding activities generated with Timbram-Matrix.*

decade reaches 70 years, by specifying the first harvest in the fourth decade. The last entry and the last harvest can be set at any decade which is consistent with the first entry and harvest selected. For example, the last entry cannot be specified before the first entry, or after the last harvest. Let us set the last entry in the fifth decade and the last harvest in the sixth decade. For management alternative OS1 X, Timbram-Matrix will generate 14 activities, some with many intermediate cuts before the harvest cut *(fig. 9).* For example, activity 0S1 X 26:[6] remove the overstory in the second decade, partial cut in the third, fourth and fifth decades, and harvest cut in the sixth decade when the timber class averages 90 years.

The total number of Standing Timber cuts in every activity generated for a particular management alternative can be specified with the maximum number of cuts option. For management alternative OS1 X setting the maximum number of cuts at 3 would eliminate activities 14, 15, 25, 16, 26, and 36 since these six activities all have more than three cuts in the Standing Timber *(fig. 10).* If spectacular growth were expected after the removal of the overstory, activities which schedule clearcutting of both the overstory and the understory in the same period should be eliminated. This could easily be done by setting "minimum number of cuts" at 2. Then Timbram-Matrix would not generate activities 44 and 55 *(fig. 10).*

The management alternative options of Timbram-Matrix, make practical the consideration of many different sequences and schedulings of silvicultural treatments for each timber class.

[6]The name of an activity consists of the management alternative name followed by two characters indicating the period of entry and the period of harvest of the Standing Timber; period 10 is indicated by "A," period 11 by "B."

PERIOD (decade)	ACTIVITIES OS1 X													
	14	24	34	44	15	25	35	45	55	16	26	36	46	56
1	13.3 (E)				13.3 (E)					13.3 (E)				
2	2.0 (RE)	13.4 (E)			2.0 (RE)	13.4 (E)				2.0 (RE)	13.4 (E)			
3	2.4 (RE)	2.4 (RE)	13.5 (E)		2.4 (RE)	2.4 (RE)	13.5 (E)			2.4 (RE)	2.4 (RE)	13.5 (E)		
4	15.5 (IHC)	15.5 (IHC)	15.5 (IHC)	28.0 (HC)	2.7 (RE)	2.7 (RE)	2.7 (RE)	13.6 (E)		2.7 (RE)	2.7 (RE)	2.7 (RE)	13.6 (E)	
5					18.0 (IHC)	18.0 (IHC)	18.0 (IHC)	18.0 (IHC)	29.0 (HC)	2.8 (RE)	2.8 (RE)	2.8 (RE)	2.8 (RE)	13.5 (E)
6										20.3 (IHC)	20.3 (IHC)	20.3 (IHC)	20.3 (IHC)	20.3 (IHC)
7														
8														

Activities eliminated if maximum number of cuts were set = 3

Activities eliminated if minimum number of cuts were set = 2

Figure 10—*Activities deleted with the "maximum" and "minimum number of cuts" option. Only the volume outputs for the Standing Timber are shown here.*

SUMMARY

Navon, Daniel I.

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Oxford: 624:U681.3.

Retrieval Terms: Timber RAM; timber management planning; multiple-use management; linear programing; simulation; computer programs.

Timber RAM (Resource Allocation Method) is a computerized method for generating long-range plans for forest lands under multiple-use management. To generate such plans, three computer programs must be used: (a) Timbram-Matrix, (b) a linear programing (LP) code, and (c) Timbram-Report. LP codes for every medium and large computer are available and can be obtained commercially. The Timbram-Matrix and Timbram-Report programs and a four-part User's Manual are available on request to the Director, Pacific Southwest Forest and Range Experiment Station, P. O. Box 245, Berkeley, California 94701. Timbram-Matrix and Report can be used only on the UNIVAC 1108 (Exec II) computer with the ILONA LP code. These two programs were designed to facilitate their adaptation to other computers and LP codes.

Part I of the User's Manual— *The Smokey Forest Case Study*—illustrates how Timber RAM could be used to plan the management of a hypothetical publicly owned forest. Part II is *The Foresters' Guide* with which a professionally trained forester familiar with electronic data processing procedures can generate Timber RAM plans. Part III—the *Mathematical Programers Guide*—describes the mathematical relations used in Timber RAM. Part IV— *The Computer Programers Guide*—includes all subroutines used in Timbram-Matrix and Timbram-Report, and instructtions for adapting these programs to various computers and LP codes.

Each Timber RAM plan consists of cutting and reforestation schedules and related reports for a sequence of decades extending up to 350 years from the present. The schedules establish for each decade how many acres of each timber class will be harvested, the type of cut—and implicitly the type of reforestation—how much stumpage will be removed, and what the corresponding discounted costs and revenues will be. In the Reports, the stumpage harvested in every timber class and the corresponding discounted costs and revenues are totalled by period.

For each timber class, alternative sequences of silvicultural treatments referred to as "activities" are defined. These activities may differ with respect to the type and timing of the treatments. Linear programing is used to find a combination of these activities which maximizes stumpage or discounted revenues, or minimizes discounted costs; stumpage, revenues and costs can be summed for any sequence of decades beginning with the first decade. In addition, the combination of activities can be required to satisfy "constraints" on the periodic level of stumpage harvested, revenues and costs. "Harvest control and regulation constraints" can also be specified to control the flow of stumpage and to regulate the forest. The combination of activities is then translated into a Timber RAM plan. Alternative combinations of activities can be obtained by changing the objective, the constraints, or the activities.

The corresponding alternative Timber RAM plans can be used to establish whether current management policies are consistent with each other, with the available natural resources, and with expected financial resources. Changes in multiple-use management policies on scenic areas, erodible soils, roading, snow management, and cutting practices can be evaluated in terms of their impact on stumpage harvested, costs and revenues.

Once a plan has been selected, the schedules and reports provide management guidelines and targets for annual plans. To facilitate this shortrun planning task, schedules and reports can be prepared for the first and second half of the first decade.

The use of linear programing greatly simplifies the problem of finding a combination of activities, but it requires making a "linearity" assumption: that for any timber class, the stumpage, revenues and costs are proportional to the number of acres treated. Because average costs and revenues are not constant with respect to the number of acres treated, Timber RAM plans may be biased. This bias can be estimated and

must be corrected before operational decisions are made. If the bias cannot be reduced to an acceptable level, more sophisticated programing methods than linear programing must be used to develop long-range plans.

Timber RAM can be used to generate plans which are efficient with respect to stumpage harvested, costs or revenues, and which are consistent with specific management policies and available resources. Because social values and political realities cannot be reduced to mathematical relations, the final selection of a Timber RAM plan must remain intuitive.

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The Forest Service of the U.S. Department of Agriculture

. . . Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.

. . . Participates with all State forestry agencies in cooperative programs to protect and improve the Nation's 395 million acres of State, local, and private forest lands.

. . . Manages and protects the 187-million-acre National Forest System for sustained yield of its many products and services.

The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

TIMBER MANAGEMENT PLANNING

Selected Glossary of Terms

I Land Classification

Non-Forest Land - land that has never supported forests and lands formerly forested which are now devoted to other uses.

Non-Commercial Forest Land - forest land that is unproductive and is incapable of yielding crops of industrial wood.

Productive Reserved Forest Land - forest land that is otherwise commercial but is reserved from timber harvest through statute or administrative regulation. These are the lands such as Wilderness included in the Special Category in the Forest Multiple Use plans.

Commercial Forest Land - forest land which is producing or is capable of producing crops of industrial wood and not otherwise withdrawn from timber utilization by statute or administrative regulation.

II Components of Commercial Forest Land

Standard - This is the component of commercial forest land where the key use is for timber production.

Modified - Some aspects of timber management are modified to comply with direction from the Multiple Use Plans of the Forest. Water and Travel Influence Zones are included here, as are National Recreation Areas.

Marginal - These areas include and reflect decisions that standard timber utilization, logging, or cutting practices are not compatible with other resource values and that timber sales with needed requirements are likely unmarketable. Examples of the marginal component are critical soil areas and unmarketable products such as hardwoods.

Deferred - These are areas where formal decisions have been made to postpone regular timber harvest pending classification action. This is a specialized category and would be used, for example, if a specific area within the Forest is being considered by the Forest Service, as a new Wilderness Area.

Unregulated - This component includes areas of present and planned developments for recreation, administrative sites, etc. Also included are experimental forests and certain remote forest situations.

III Harvest Terms

Harvest Potential - (To be re-christened Potential Yield) The harvest potential is the maximum regulated sustained yield cutting level attainable with intensive forestry. Excluded in estimates of harvest potential are effects of intense activities that at this time remain unproven or speculative such as genetics, fertilization, and irrigation.

Programmed Allowable Cut - (Comparable to our Present Use of "Allowable Cut") The programmed allowable cut is that part of the harvest potential that is scheduled for a specific year. The Forest Supervisor decides on the level of cut based on current demand, funding, silvicultural practices and multiple use consideration.

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Timber RAM (Resource Allocation Method) is a long-range planning method for commercial timber lands under multiple-use management. Timber RAM can produce cutting and reforestation schedules and related harvest and economic reports. Each schedule optimizes an index of performance, subject to periodic constraints on revenues, costs, and, harvest levels. Periodic constraints can also be used to regulate forest stands and to even out the flow of timber during conversion. Schedules are calculated on computers by using linear programing techniques.

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