

OPERATIONAL FOREST MANAGEMENT PLANNING METHODS:

proceedings, meeting of Steering Systems
Project Group, International Union of
Forestry Research Organizations

Bucharest, Romania

June 18-24, 1978

PACIFIC SOUTHWEST Forest and Range Experiment Station

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Daniel Navon, Compiler

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These 14 papers were submitted to a conference of Project Group P4.07 Division IV, International Union of Forestry Research Organizations. Topics discussed included the uses of simulations, analytical techniques, and mathematical programming techniques in land management planning, reforestation programs, intensive forestry, timber management and production, tree growth, wood transportation, and budgeting.

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PREFACE

At the XVIth World Congress held in Oslo, Norway, in 1976, the International Union of Forestry Research Organizations (IUFRO) reaffirmed its commitment to study forestry problems in the developing countries and to seek solutions. This collection of papers is the contribution to this task made by the Steering Systems Project Group, Division IV. This project was established at the Congress at the suggestion of Hans Speidel, Richard Plochman, and Robert Magin, to promote communication and collaboration among IUFRO scientists doing research in the development and application of forest management planning methods. The Project Group is conducting two major activities. First, an International Directory of Computerized Planning and Research Tools is being established under the sponsorship of the Forest Service, U.S. Department of Agriculture. Second, international meetings are held to inform members of the state of the art in forest management planning, and to promote the collaboration of all forestry researchers in addressing the challenges posed by forest management in developing nations.

The 14 papers collected here report on planning methods which have been successfully used in developed countries and which—in the judgment of the members of the Project Group—may be useful in attacking problems in less developed nations. Many of our members are deeply aware of their limited grasp of these problems. Our sincere hope is that these papers will open a dialogue which will lead to better understanding of these problems and to an effective collaboration among researchers from all nations in an attack on these problems.

The papers presented here span the spectrum of approaches used in forest management planning in recent decades. In the first paper, Bohumil Dolezal presents the classical approach to planning intensive forest management and establishes the validity of these principles for dealing with contemporary problems of developing economies.

The remaining papers deal with specific planning techniques, all of which—except two—require the use of electronic computers to conduct simulations, solve mathematical programs, or invert input-output matrices. The papers by Denie Gerold and Allen Lundgren demonstrate the usefulness, efficiency, modest cost, and versatility of electronic computers in modeling the behavior of forest stands, and in providing detailed estimates of outputs and of resources

needed for the diverse conditions typically encountered in commercial forest lands.

The paper contributed by members of the Australian Forestry Council reports on six stand-growth and yield-simulation models which rely on functions derived from graphic analysis, nonlinear estimation, and generalized least squares. This paper also reports on two linear programming (LP) methods. The first of these provides an analysis of long-term cutting strategy for intensively managed *Pinus radiata* plantations. The second combines LP with the simulation of stand yields determination of thinnings and clear felling yield for an entire plantation.

Two additional papers report on methods integrating simulation and optimization methods. The model described by Joseph Buongiorno and Dennis Teeguarden uses simulation to estimate future growth, and to help managers select promising management alternatives, and linear programming to find an optimum combination of reforestation projects. William W. Phillips and Thomas D. Corcoran present an interactive model which uses simulation to explore alternative "market transport possibilities," and linear programming for identifying optimal overall strategies.

The next five papers report on methods which rely on the use of LP and a recent extension of LP, goal programming. Ivan Kolenka presents a model for planning the logging, transport, and distribution of wood assortments in the context of a planned economy. Malcolm Kirby presents a budgeting model for large private or public forest enterprises which also provides an analytical framework for evaluation of overall management programs. The two-stage LP methods discussed in separate papers by Krishna Rustagi and Stephen Smith provide a practical strategy for dealing with one of the most vexing limitations of LP, the assumption of the availability of reliable information about future events. Richard C. Fields describes a goal programming model which provides a systematic method for dealing with a limitation of LP which has proved particularly bothersome in forestry, the impossibility of specifying an objective function which reflects adequately the incommensurable outputs of forest management.

David Betters reports on a model which integrates a computerized procedure based on factor analysis with linear programming and input-output analysis. The computerized procedure is used to develop among planners, consumers, and managers a consensus of

resource use preferences. Linear programming then provides optimal combinations of forest management alternatives and an input-output model estimates the impact on local economic activity and employment levels.

The last two papers discuss systematic procedures for evaluating well-defined forest management alternatives, without paying tribute to computers. August Henne presents an operational version of Zangemeister's Nutzwertanalyse, which retains the essential features of the original scheme for ranking a set of complementary projects. Andres Weintraub reports on a heuristic procedure for selecting a management program from among mutually exclusive alternatives.

The preparation and publication of this collection of papers was made possible through the collaboration of too many persons to permit giving them individually the acknowledgement and thanks which are due them. Goran von Malmberg, co-chairman of the Steering Systems Project Group, and all our members join me in

expressing special thanks to Professor Robert Magin for inviting us to meet with the Forest Management Planning and Managerial Economics Working Group and to Professor Adolf Priesol and Director George Bumbu for their warm hospitality. We also extend our special thanks to the Food and Agriculture Organization of the United Nations for allowing Dr. Arnoldo Contreras to share with us his clear understanding of forestry problems in developing countries, and for help FAO is giving us in reaching our colleagues in those countries.

The publication of this collection of papers was funded by the Research and National Forest System branches of the Forest Service, U.S. Department of Agriculture.

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A Method of Forest Management for the Planned Introduction of Intensive Husbandry in Virgin Forest Stands

B. Dolezal

Abstract: The method proposed is derived from long experience of intensive management in forest stands of Central Europe and from our proposal for management in virgin Iranian forests of the Caspian Region. The method establishes the need for systematic planning of stand conversion to insure both sustained yield and the harvesting of sufficient timber to sustain economic development. The method also recognises the need to integrate the planning of silvicultural activities with capital investments in roads and machinery.

INTRODUCTION

The method described in this paper is based on the realization that forest planning must be consistent with the political and economic situation of a developing country, as well as with the given natural and economic conditions, financial position, market conditions, and the technological procedures involved in the process of production, which are all traditionally taken into consideration in forest husbandry. A method of this kind is expected also to reflect the latest scientific achievements in understanding of the forest as an entity. Market conditions must be considered to insure a reasonable financial return from management. It must also be recognized that the forest is a national resource of special value in a country's watershed management and in the development of an environment beneficial to its population.

The principles discussed below and incorporated in the method for introducing an intensive system of management into virgin forest stands were obtained partly from what has been gathered during the past 250 years of intensive management in the forest stands of Central Europe, and partly from the experience gained while compiling our proposal for forest management in virgin Iranian forests of the Caspian Region. The method is based on the principles that (1) the introduction of an intensive system of management into the virgin-like forest must be planned, and (2) once converted, the commercial forest must be able to produce sustained yields adequate in quality, volume, and monetary value, and must supply the market with sufficient amounts of timber in the species and assortments needed for economic development.

The method for introducing an intensive system of management as suggested here is based on the idea of short-term credits, which are required to make the virgin stands accessible for management, for purchasing needed machinery, and if necessary, even for constructing wood-processing plants. The short-term credit needed to secure accessibility of virgin-like forests can be estimated by assuming that the stand regeneration will progress through areas that are spatially linked, so that the transport of wood from the part of the forest which has just been made accessible passes through those which have already been made accessible. The availability of short-term credit indeed appears to be an important requirement for the introduction of intensive management in the forests of developing countries.

The suggested method is based on scientific knowledge of the forest. It utilizes data on the geographical and ecological classification of forests, which serves to stratify forest land. This stratification is needed to delimit forest land planning and control units for management, to define the quantities to be estimated, and to elaborate the instructions needed to manage the forest.

METHOD

Economic Evaluation of Wood Production

Delimitation of the Forest Land Resource

It would not be reasonable to introduce intensive management into forests which, within a known period of time, are intended to serve some other type of land utilization (such as fields, meadows, grassland, dwelling estates). It is therefore urgent to determine, on the basis of consultation with competent institutions in the country, which of the forest areas will be left as permanent stands, regardless of population increases. This task appears to be urgent, especially in the territories which are characterized either by a high or by a very low forest cover percentage, compared to the targets planned for the years to come.

Survey and Analysis of Natural and Working Conditions in the Forests

The primary concerns should be the survey and analysis of soil, climate, and terrain all of which are decisive for the future productivity of the forest stands. Survey and analysis should also be concerned with the present condition of the forest stands (existing species, diameter, health condition, forest inventory data, potential production of assortments suitable for commercial and industrial uses, and the like). The remaining items to be evaluated are: conditions for management, especially the character of the topography; potential accessibility of the stands and timber transport; delimitation of gravitational areas etc.; conditions for location of timber yards and sawmills; the level of protection needed against forest fire and destructive wind.

Maps produced using photogrammetry are part of the surveys mentioned above.

Marketing

An investigation is carried out to determine the opportunities for trading timber; to assess the demand for timber assortments by local population and industries, and to estimate the export requirements as well; finally, the potential for the processing of the timber harvest by woodworking plants is assessed.

Organization of the Forest Stands

Working Circle

These are the "frames" for harvest regulation. The areas range from 15 to 50,000 ha. They are designed to insure sustained, even, and sufficient supplies of timber, in order to simplify management, and to obtain the short-term financial credits needed to make the forest accessible to transport. Working circles cover contiguous areas encompassing entire watershed or timbersheds which are homogeneous with respect to both natural and economic conditions. These working circles permit the application of a uniform method of management and a uniform type of harvesting regulation. Relatively large areas are covered by working circles. This is made possible by the introduction of the concept of "working complexes" of stands, which refer to land units homogeneous with respect to production and management. The only role left for the working circle is to insure sustained and even yields from the forest. If required, working circles can be drawn for forests managed for purposes other than timber production, e.g., protection forests, recreation forests, nature reserves, and the like.

Working Complexes of Stands

These are defined as the groupings of forest stands with ecological, productional, and management characteristics so similar that they permit the introduction of a uniform system for (1) compilation of instructions for management, (2) calculation of the index of harvest regulation, and (3) calculation of the timing of management activities for the forest, etc. The reasons for introducing the working complexes of stands into forest management are to make the goals and the decisions of management concrete, to facilitate real planning and control of managerial actions, and to simplify the managerial process. Clearly the use of working complexes is indicated when a system of intensive management is introduced into virgin-like forests.

Forest Compartments

These are defined as the permanent land management units based on the forest's biological and management typification. They range in area from 30 to 100 ha. Where possible, the forest compartments are marked off by distinct characteristics of the terrain. Their uniform morphological character should mesh with the network used for timber skidding, and with the road system. Moreover, the forest compartments are supposed to be independent units also

from the point of view of forest protection. For this reason, preventive measures of protection are worked out for each compartment. Compartments are surveyed and, as a rule, their boundaries are located using photogrammetry. The forest compartments are the basic units of the forest's spatial organization, both with respect to planning and with respect to the realization of the plan.

Subcompartments

Under diversified natural and working conditions there are occasional cases when the compartment cannot cover all ecological and stand differences; it then follows that the compartment is not a convenient unit for the planning, control, and realization of pertinent measures of management in the sectors of silviculture and forest protection. Instead, subcompartments are delimited as a lower category of the forest's spatial organization. The subcompartments are assumed to possess the same properties indicated above for the compartments--those necessary for the uniform planning of management activities related to silviculture and forest protection. In this particular case, the planning of timber transport and skidding occurs within the frame of the compartment.

HARVEST REGULATION

The principle observed is that optimum productivity be reached in the forest stands within the compartment or subcompartment; at the same time, the yields produced within the frame of the working circle must be sustained and even. In compliance with the requirement for simplicity and the conditions in developing countries, harvest regulation should be based on area. It is true that allowable cuts are derived on the basis of area and volume, as well as on assortments and value, but always so that considerations for the elements of volume are subordinated to those of area.

Calculation of the Allowable Cut

The final allowable cut is determined primarily by the "normal" felling area, according to the formula:

$$e = i_n h_u$$

where e denotes the volume of the allowable cut, i_n stands for the normal felling area, in hectares, and h_u designates the average volume per hectare of the growing stock within the working circle at the time of stand maturity.

This average stock per hectare of the working circle is obtained with the formula:

$$\bar{h}_u = \sum i h_i F_i / \sum F_i$$

where h_i denotes the per-hectare stock in stands of individual working complexes, F_i indicates the area in hectares of the i th working complex belonging to the working circle, and

$$i = F/\bar{u}$$

where F is the area of the working circle and u is the rotation of the working circle, calculated according to the formula:

$$\bar{u} = \frac{\sum u_i F_i}{\sum F_i}$$

For the volume index of harvest regulation it is possible to use the final mean annual increment in stands of the working circle. This is calculated by summing up the final mean annual increments achieved in all the individual working complexes which constitute the working circle.

The stand volumes per hectare of individual working complexes are obtained by determining the growing stock volume per hectare in sample plots distributed in individual working complexes. Principles of systematic random selection must be observed to obtain representative estimates of the characteristics of the stands of the working circle.

Concerning the realization of the allowable cut: the main object of the method proposed here is to promote the harvesting of the allowable cut in a contiguous area (French terms: quartier de regeneration, affectation unique). The method thus permits respecting the silvicultural requirements of stands in individual subcompartments or compartments within the frame of the ecological and production conditions characterizing individual working complexes. In doing so, harmony is achieved between the interests of silviculture and those of cutting regulation.

For long rotations and the use of small-area harvesting systems, the allowable cut in the quartier de regeneration is calculated from the formula:

$$e = \frac{H_0 + C_i \cdot P/2}{P}$$

where H_0 denotes the total volume of stands in the quartier de regeneration, P stands for the regeneration period (cutting cycle) expressed in years, and C_i designates the current increment. The number of regeneration treatments is determined with respect to the ecological requirements of the species represented in or introduced into the stands. Regeneration in the subsequent quartier de regeneration does not commence until completion of the stand regeneration in the quartier de regeneration immediately preceding.

The harvesting in stands, except for the quartiers de regeneration just under regeneration, is dependent on the possibility of transporting the material exploited. As a rule, the plan is to utilize the wood for charcoal burning, and only then carry it out of inaccessible stands on the backs of mules or donkeys. Sanitary fellings are largely concerned with the removal of sick, ill-shaped, overaged, and similar trees which if kept would not contribute to the value of the stand. The cycle for these treatments is usually fixed at 10 or 20 years; the volume of timber harvested per hectare in individual working complexes is estimated on the basis of a current survey of the condition of the stands.

SYSTEMS OF MANAGEMENT AND EXPLOITATION

The method for introducing intensive management into virgin-like forests assumes the use of a system of management and exploitation that is consistent with the natural and economic conditions of the country concerned. The main --and highly desirable--objective is to avoid the destruction of the forest's sources of production--the soil above all--due to erosion, waterlogging, or excessive growth of woody plants. The selection of the system of management is dependent also on the ecological requirements of the species in the specific stand environment, and on the technique of skidding to be employed. In general, it seems advantageous to prefer the small-area systems of management, the better to maintain the forest's production capability. This, however, should not exclude the use of regeneration cuttings when conditions are suitable.

CONCLUSIONS

In addition to what has been indicated above, the method of introducing intensive management into virgin forests assumes thorough planning to carry out the management practices effectively and to use expensive harvesting and transporting machinery efficiently. Another requirement is that all the complex aspects of forest management be taken into consideration. The same amount of attention given to the harvesting of timber must be paid to afforestation of harvested areas and to the tending and protection of new stands. The construction of a network of timber transport roads, adequately dense and duly distributed in space (about 15 km/ha), is also a prerequisite.

The method discussed in this paper is not only consistent with all the latest achievements in Central European forestry, it is also consistent with the natural, working, and politico-economic conditions found in developing countries.

Theoretical and Computational Foundations of Management Class Simulation

Denie Gerold

Abstract: Investigations on complicated, complex, and not well-ordered systems are possible only with the aid of mathematical methods and electronic data processing. Simulation as a method of operations research is particularly suitable for this purpose. Theoretical and computational foundations of management class simulation must be integrated into the planning systems of forest management and must provide a large number of alternatives for action. A model already in wide use is described.

INTRODUCTION

Research on complicated, complex, and not well-ordered systems is possible only with the aid of mathematical methods and electronic data processing equipment. With analytical model analysis (e.g. optimization models), the solution algorithm yields a specifically defined result, but computational experiments are more or less systematic test procedures for which there is no logically certain procedure for optimal solution. The purpose of the computational experiment is to search for the optimal solution or the best corresponding decision. Complete and partial searches are differentiated according to the scope of search processes within the framework of a given decision model. In complete searches all possible constellations of variables are calculated, and the optimum with respect to the objective concepts exists with certainty among the variants. The partial search is limited to a sample of all possible searches. It must be guaranteed that partial search procedures are directed toward the research goal. Partial searches differentiate between pure simulation and "design game plan." In simulation one specifically formulates definitions for actual decisions through decision rules at the beginning of a series of searches. In the design game plan, the strategies for a search series are not fixed at the beginning of the game, but develop in the course of the game as the result of chains of decisions.

Simulation is suitable as a method for operations research because of its adaptability for analysis of systems with numerous input and output quantities and complicated structures. It is distinguished by the following essential criteria

1. A system can be simulated if it can be subdivided into a variety of elements for which the behavioral rules can be assigned.
2. The simulation encompasses a mathematical model which "runs" but is not solved; i.e., time is very important in the simulation.
3. The process of system optimization is not directly contained in the simulation.
4. The output of the modeled system is weighted in the simulation with respect to deterministic or stochastic modifications of the input.
A number of steps must be considered in the development of a simulation model:
 - (a) Formulation of goals
 - (b) Formulation, weighting and comparison of possible alternatives
 - (c) Selection of the best alternative with respect to the objective function (decision)
 - (d) Control of the elaboration of decisions and eventual corrective measures.

The principle of the mathematical simulation is presented in figure 1.

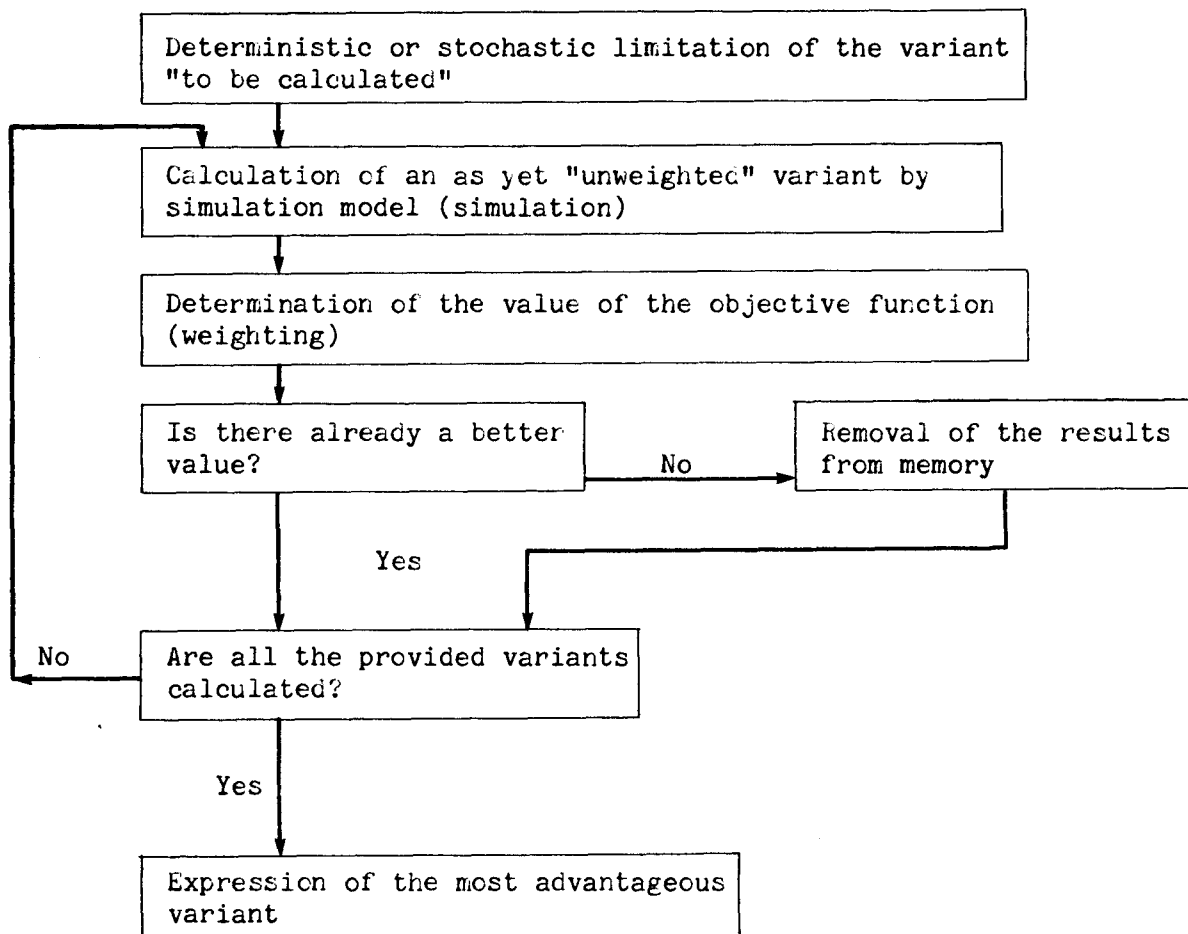


Figure 1--Principle of mathematical simulation in the form of a flow diagram.

FOUNDATIONS OF THE MANAGEMENT CLASS SIMULATION

The significance of simulation for forestry problems is conditioned primarily by the long duration of the production process. The extensive time differences between managerial measures and their effects on the forest necessitates the inclusion of future developments in present decisions. The value of a measure can be interpreted only in view of its effect on long-term goals.

The management class as a system within a sustained unit is decidedly significant for the complex planning of a forest evaluation. Its stratified structure is only ascertainable through simulation of multiple alternatives in its combined time and space-related development. A management class simulator (Gerold 1976) is a model based on the specific state of a tree species management class, which includes all stands of a tree species cultivated for similar production goals and found within a sustained unit. With this model, the effects of different variants of production and yield regulation on the development of this management class over long periods of time (the prognosis) can be analyzed. Also, the mutual correlation of the component problems of the sustained unit can be demonstrated. The formulation of this type of model has the following foundations and requirements:

- (a) The model must be integrated into the total planning system of the forest evaluation. It must have numerous alternatives and include, therefore, many component problems of sustained yield regulation. The time interval over which simulation takes place should be determined by the user.
- (b) The stand is the active element in a management class. The complex sustained yield regulation requires that the input information of the simulator refer to this conditional unit. All management class data are derived from the aggregation of stand information during simulation. The accuracy of stand information should be known, to correctly classify the results of the simulation model with respect to certainty within the framework of the decision aids.
- (c) Component models, weighted and easily integrated into the planning system of forest evaluation, are to be used for the generation of many alternatives (e.g., intermediate and final yield strategies), i.e., a large scope, in the formulation of a model. The scope of the alternatives is determined by the flexibility and quality of the management class simulator.
- (d) An efficient, updating algorithm, which guarantees certain extrapolation, is necessary for the simulation of stand information.
- (e) The model must make possible the processing of management classes of any stand, i.e., of any age, quality, and growing stand density structure. If the memory capacity of the electronic data processing unit is not sufficient for calculation of larger conditional units, because stands are numerous, then the stands are aggregates into "computation units of a higher order." In this case, the criteria must be as follows:
 - Age (e.g., 2-year intervals)
 - Quality (e.g., have quality grades)
 - Density stand volume (units of 10)

This facilitates the use of the simulator for sustained units of any given size.

- (f) On the basis of goals formulated for the stands, and of management class information, the actual conditions obtained in the individual stages of the prognostic time span, and the planning magnitude are to be weighted according to valuation criteria for the age structure and the stand density. From the weighting, the deviation from the norm is to be estimated. This weighting facilitates the selection of certain planning alternatives by the planner in the context of the overall goals.
- (g) The following prerequisites apply for the preparation of the computed information:
 - (1) An electronic data processing unit with a large memory capacity and high calculation speed must be available.
 - (2) The simulation program is based on the block principle to provide flexible subroutine exchange, thereby making possible simple consideration of new alternatives.
 - (3) The presentation of results using a high speed printer must be in the form of clear and easily visible tables. Automatic symbol equipment to represent the development of specific key numbers of the management class are to be used as much as possible.
 - (4) The preparation of stand information is rationally possible only through electronics. An additional prerequisite is a functionally efficient, permanently actualized data memory containing information which can be recalled at any time using available sorting identifiers.

Figure 2 presents the general program design of a management class simulator to calculate a planning variant. Any of the available variants (alternatives) can be simulated using this sequential scheme.

DESCRIPTION OF A MANAGEMENT CLASS SIMULATION MODEL

A management class simulator was developed on the basis of the fundamentals presented in Figure 2. It is submitted as the program flow chart and calculation program using the program language ALGOL for the electronic data processing unit BESM-6. The Soviet large-capacity computer is suitable due to its high calculation speed of an average of 10^6 operations/second for the generation of the simulation model. The memory capacity of BESM-6 permits direct processing of management classes with a maximum of 3800 stands. On the average, this corresponds to an information scope of approximately 5000 hectares. For larger conditional units, an aggregation (see figure 2) should be used. The stand data used (age, land, mature crop, quality) are available in handbooks of forest management in the data bank of the forest fund. Extensive information for various planning strategies is derived from these data during simulation for, each 10-year period of the prognostic time span. It is printed in the form of the following tables:

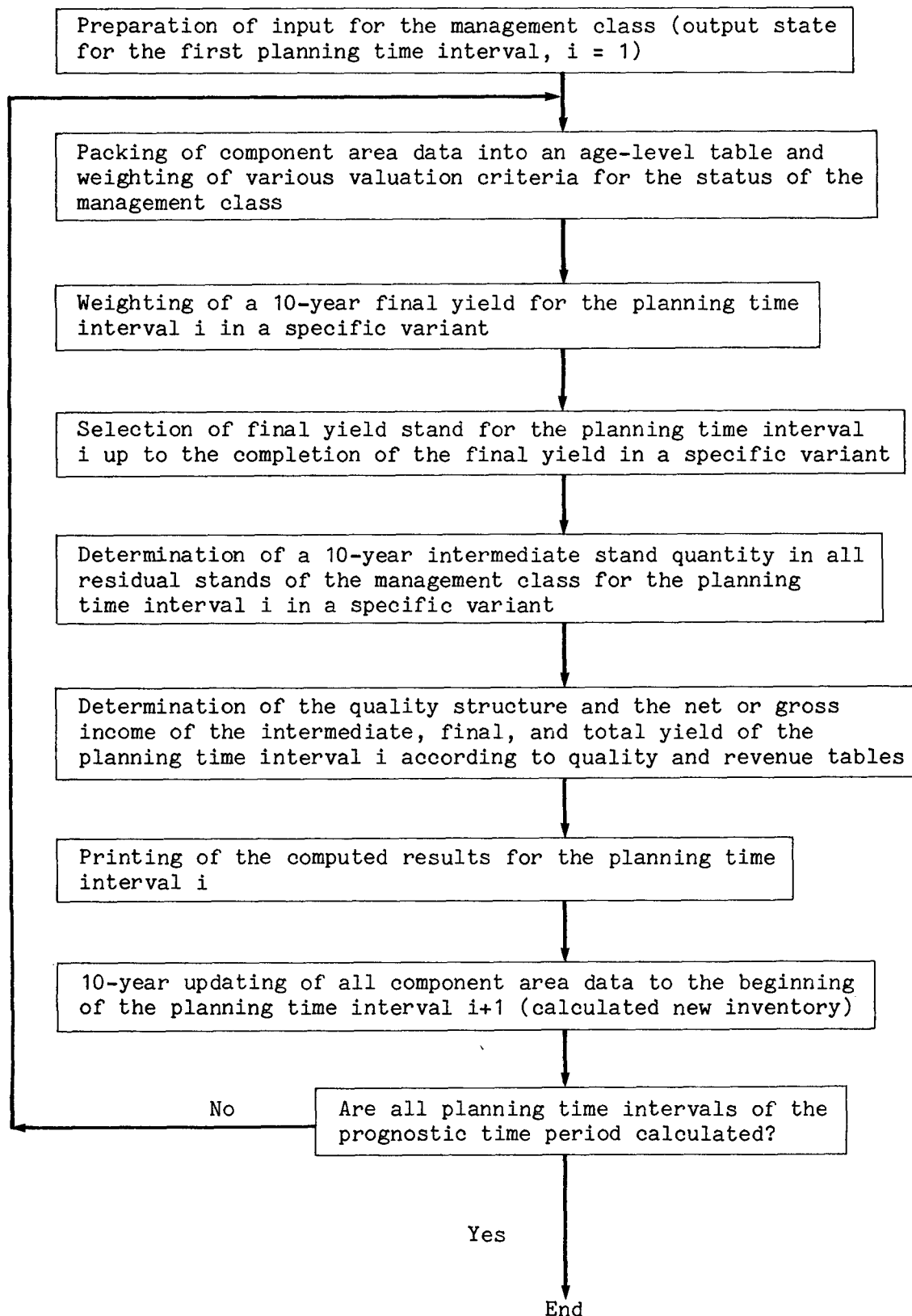


Figure 2--Representation of a general program design in the form of a program flow chart for a specific planning variant.

Age distribution table

Table for final cutting stands

Table for intermediate yields of stands

Summary of harvest and growth

Table of the range of harvest.

The simulation model is constructed in a deterministic manner; i.e., alternatives do not have any random features. Its functional efficiency was tested in a series of real management classes (Gerold 1976; Gerold and Kurth 1977; Kurth and Gerold 1977; Gerold 1978).

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A Computerized Tree Growth Projection System for Forest Resource Evaluation in the Lake States

Allen L. Lundgren

Burton L. Essex

Abstract: A computerized tree growth projection system has been developed for the Lake States Region as part of a larger Forest Resources Evaluation Program (FREP). Incorporating data from more than 1500 permanent growth plots throughout the Lake States, this system projects tree growth, mortality, regeneration, and removals in stands with any mixture of tree species and sizes, for the full range of sites encountered in the field. It incorporates the latest published timber management guides for the Lake States. It can identify silvicultural treatment opportunities now and in the future from the plot data or representative tree lists for a single stand, a management unit, an entire forest property, or an entire state or region. It can also be used to update timber inventories and to project future yields and resource conditions in response to alternative silvicultural treatment opportunities for timber resource evaluation and assessment.

INTRODUCTION

A comprehensive inventory of forest resources is essential for land management planning, but by itself is not sufficient. An inventory provides a detailed picture of the resource at one point in time. The forest is not a static entity, but a dynamic biophysical system. A full description of such a system must contain not only an estimate of its present state, but also a description of its potential future change. Without provision for continual updating, an inventory only produces a fading portrait of a resource that is changing with each passing year as regeneration, growth, death, and cutting of trees takes place. To be fully useful to the land manager and planner, a complete resource inventory system should continually update the inventory to provide current data about the condition of the resource. It also should be capable of estimating future changes in the forest resource in response to a range of possible resource management alternatives, including that of no tree cutting.

A tree growth projection system is a necessary part of a dynamic forest

resource inventory system. It must be capable of updating and projecting timber inventories in a form suitable for evaluating resource management alternatives for large areas with diverse forest conditions. To do this, it must be able to handle all species and stand conditions in a forest area, require only a minimal amount of input data such as would be available from existing resource inventories, and be computationally efficient.

Developing a tree growth projection system capable of describing the dynamic behavior of complex ecological communities such as the intricately mixed northern hardwood-conifer forests of the Lake States has long challenged inventory specialists and growth modelers. Stand growth models have been developed for several single-species forest types such as Pinus resinosa Ait. (Buckman 1962), Picea mariana (Perala 1971), and Populus tremuloides (Schlaegel 1971). Such models have been useful in developing stand management recommendations for even-aged stands with a single species. However, models have been developed for only a few Lake States species, and existing models fail to describe the behavior of the mixed-species, mixed-sized stands common to the Lake States. Stand models have been developed for some mixed-species forest types for some areas of the Lake States (for example, Dale 1972, Ek 1974, and Moser 1972), but again coverage of the resource base is far from complete. Individual tree models for more general mixed-species stands (Ek and Monserud 1974) are expensive to run and require more data than is available from most forest inventories.

Available growth models have provided valuable insights into tree and stand growth, but by themselves are not adequate for a forest-wide tree growth projection system. Efforts to assemble individual growth models and link them into a more comprehensive system have been frustrated by the lack of common input requirements and data outputs, as well as incomplete coverage of the resource.

TRAS, a computer program for projecting timber volumes, was developed and used by the U.S. Forest Service to update inventories and project future timber volumes for large forest areas (Larson and Goforth 1970). However, this program was not designed as a stand model to account for interactions among size classes of trees in response to alternative silvicultural treatments. It lacks the ability to closely model biological tree response to stand treatments in the mixed forest ecosystems common in the Lake States in the detail needed for evaluating treatment opportunities.

The need is to develop a comprehensive tree growth projection system specifically designed to project tree growth for all species in all stands for large diverse forest areas in enough detail to update forest inventories and evaluate stand treatments.

THE PROJECTION SYSTEM

After several years of work, scientists at the North Central Forest Experiment Station of the Forest Service (U.S. Dep. Agric.) have completed and tested a computerized tree growth system for the forests of the Lake States Region. Developed using data from more than 1500 permanent growth plots in

all major forest types in the Region, the projection system reliably projects stand development with or without tree cutting for several decades for all forest conditions found in Michigan, Minnesota, and Wisconsin.

This system inexpensively projects individual tree growth, mortality, and regeneration, with or without tree removals, for products in stands with any mixture of tree species and sizes, and any density, over the full range of sites encountered in the field. The latest published timber management guides for the Lake States species are incorporated into the system. These are used to identify silvicultural treatment and timber harvesting opportunities, now and in the future, from the plot data or representative tree lists used to describe a single stand, management unit, or an entire forest property, state, or region. The projection system has been linked to the U.S. Forest Service's national forest inventory system in the North Central Region. However, it can be adapted readily to other growth projection needs.

Input to the projection system is a list of individual trees that represent a forest stand. At a minimum, the list must have the tree species and diameter breast high of each tree listed, along with each tree's expansion factor to indicate the number of trees per acre each tree represents. Other information should include tree condition (alive, cut, or dead), and stand variables such as site index and age. Tree growth, mortality, and regeneration are projected for any time period (in increments of a year) or sequence of periods selected by the user.

A major advantage of this projection system is that the integrity of the individual tree list is maintained throughout the projection period, so no information about the resource is lost through aggregation. At the end of each projection period, the system produces an updated list of trees in the same format. Thus, programs available to summarize data from the initial tree list or inventory can be used to summarize data from the program output tree lists as though they were a new inventory. It will be necessary to update other data that are subject to change that are not handled by the projection system at present, such as land use or ownership change, changes in site index due to change in forest type, and special tree measurements such as merchantable bole length, log grades, or cull percent.

Silvicultural treatment prescribed for each acre each year or time period is identified by kind of treatment and forest type. A cost algorithm determines the cost of each treatment by time period for the acres indicated. Trees to be cut are designated by the appropriate silvicultural treatment. The system then projects stand development forward for the desired number of years with the trees left after cutting. If desired, the process may be repeated. Timber harvested in each time period can be produced in detail, including cubic foot volume by species and 2-inch diameter class within each type. Mortality volumes can also be summarized in detail. Inventory volumes before and after each cut can also be obtained in the same way. The difference in future stand development with and without treatment can be identified from this information and can be used for economic appraisal of stand treatment opportunities, either on an individual stand or forestwide basis.

The timber projection system has been tested extensively and has provided results well within acceptable limits of accuracy. The tests consisted of

projecting first occasion inventory plots, which had not been used to develop model coefficients, and comparing the projected value with actual values that were recorded on successive [sic] plot measurements.

The system was designed for inexpensive computing so thousands of survey plots could be updated annually to provide current Regionwide inventory data. Computing costs have been about 6 cents to project the tree list from a single plot for 10 years and develop summaries of inventory and harvest volumes.

USE OF THE SYSTEM

This Lake States system has been used to update all the survey plots in Wisconsin, from the most recent inventory (1967-69) to 1978. Removals for timber products were accounted for to provide a current inventory estimate. Similar inventory updates have been done for individual national forests in the Lake States. Plans are to periodically update each state-wide inventory as needed to provide estimates of the current status of the forest resource throughout the Region in as much detail as the original inventories.

The system also has been used to update and project inventories of individual national forests, of all state-owned land within a state survey unit, and of other forest land in response to silvicultural treatment opportunities for timber production. The output showed timber volumes harvested and timber volume inventories by decade for the next fifty years.

The development of individual stands in several National Forest Compartments in Michigan was projected for fifty years, both with and without timber cutting, to show how the system could be adapted to the Forest Service's compartment examination procedures. These illustrate only some of the ways the system can be used.

THE SYSTEM'S POTENTIAL

This timber growth projection system is designed to be the core of a larger Timber Resource Evaluation System, that will evaluate timber management opportunities on a local, state, or regional basis from an economic, social, or ecologic point of view. The evaluation system is still being developed, but the output from the projection system can be used with existing evaluation procedures and programs. The mathematical structure underlying the timber projection system was designed to allow for including other components of the ecosystem besides trees--for example, a link between trees and understory vegetation is now being developed.

The timber projection system developed for the Lake States has tremendous potential. Now, for the first time, we have a computerized system that can project forest resource development in response to timber cutting, or no timber cutting, for all forest conditions in the Region. It answers the long-felt need for a method to project future renewable resource supplies in response to treatment for evaluating management opportunities. It will be useful for timber management planning and program development for state and

regional resource assessments. Further, it can be used to update resource inventories to provide a reliable current estimate of present resource conditions.

The concepts used in developing the timber projection system are general and have potential for wide application. We plan to continue development of FREP as rapidly as possible, expanding the system to the rest of the North Central Region and to other resources. We also plan to work with others to test the applicability of the FREP tree growth projection system to other regions of the United States.

Another exciting concept will be to incorporate the tree growth projection system into the remeasurement design of forest inventories. A first step of the new inventory procedure could be to classify plots established at the time of the previous survey into disturbance classes. This might be done using LANDSAT data, conventional photography, or a combination of the two. Undisturbed plots could be grown to the date of the present survey using the tree growth projection system. These plots could then be sampled to determine what corrections, if any, need to be made in the projections to represent current inventory conditions accurately. Disturbed plots could be remeasured on the ground, together with new plots such as might be found in agricultural areas that have reverted to forest. These plots would be processed in the conventional way. The two data sets would then be combined to form the information base for the new survey.

This procedure could substantially reduce the cost of today's remeasurement surveys but still provide a detailed tree list of each plot that may be used in the projection system.

Acknowledgment: The timber growth projection system was developed jointly by a team of researchers at the North Central Station. This team included Dr. Rolfe A. Leary, Jerold T. Kahn, Roland G. Buchman, Gary Brand, Brad Smith, Margaret Holdaway, Jerrilyn LaVarre Thompson, and Linda Christensen, each of whom had responsibilities for major aspects of the study. A collection of papers outlining the system in some detail is being published as USDA Forest Service General Technical Report NC-47, North Central Forest Experiment Station, St. Paul, Minn.

APPENDIX¹

A general description is given here of the input needed, how the parts are put together, and what output is produced.

Input

The input consists of a parameter deck and a tree list. A tree list consists of tree species, d.b.h., crown ratio, and quality class for a group of individual trees. Also required are the following plot attributes: site index, stand age, and plot size.

Parameter deck

The parameter deck specifies two groups of input values: (A) user selected options and (B) numerical constants needed by each portion of the growth processor.

Numerical constants are used for

- Assigning species group codes to individual trees
- Crown ratio function coefficients
- Silvicultural treatment specifications
- Volume equation coefficients
- Mortality equation coefficients
- Potential growth function coefficients
- A species grouping priority matrix (used for combining species when more than three species occur on a plot)

These values are determined from calibrating the model on a specific data base of permanent (remeasured) plots.

Projection-related options that may be selected by the user are

- Length of projection cycle (years)
- Number of projection cycles
- Type of growth projection desired (validation, projection, or update).

The number of years the tree list is projected is determined by the number and length of the cycles. The projection is limited to a maximum, of 100 years but it may be in the form of 100 cycles of one year each or one cycle of 100 years. The length of the cycle determines how often summaries are made and the tree list examined for management opportunities.

¹ This material is abstracted from a forthcoming publication: Hahn, Jerold T., and Gary Brand, A program for implementing a generalized forest growth projection system. USDA Forest Serv. Gen. tech. Rep. NC-47, North Central Forest Exp. Stn., St. Paul, Minn.

Three different types of growth projections can be selected: validation, projection, and update. A validation run uses a tree list with measurements recorded for several different years. The tree list is projected from the initial measurement to the final measurement. Projected and actual measurements are compared to determine the accuracy of the model. A projection run begins with initial conditions and grows the trees for a specified length of time to estimate future conditions. An update run begins with initial conditions from the past and grows the trees to the present. Known product removals are used to extract the trees that produce those products from the tree list.

Tree list

The tree list can be in one of three different formats: (1) a list format, (2) a unit record format as used by the U.S. Forest Service Renewable Resources Evaluation (forest survey) projects, or (3) a computer-readable format in which the user is responsible for supplying the necessary computer code for input and output routines.

PROGRAM ORGANIZATION

Besides providing input/output capability, the program controls when the different parts of the system are used according to the options selected. The listing below gives all the subroutine and function [sic] names, their calling routines, and a brief statement of their purpose. The program has seven parts:

1. The main calling program
2. A function, VALUE, where all mathematical equations are located
3. Input subroutines
4. A subroutine for aggregating the input tree list
5. Stand treatment subroutines
6. Stand growth subroutines
7. Output subroutines.

Subsystem TRES (Timber Resource Evaluation System) of
program FREP (Forest Resources Evaluation Program)

1. Main program

Program TRES

Main calling routine, sets up and initializes arrays, performs housekeeping functions, organizes calling of subroutines.

2. Mathematical functions

Function Value

Called from RMASTR, RSURTP, GROW, ISUM, OUTPT1, and OUTPT2. Computes values for crown ratio, potential growth, modifier, mortality, and volume.

3. Input

Subroutine READ

Called from TRES
Reads user-selected options and numerical constants
and echo-prints all values.

Subroutine RMASTR

Called from TRES
Reads data from binary files in N.ASZER format into arrays
TRS and ITRS.
Initializes array parameters.

Subroutine RSURTP

Called from TRES
Reads data from files in forest survey unity record format
into arrays TRS and ITRS.
Initializes array parameters.

Subroutine OPENRD

Called from RSURTP.
Unblocks forest survey unit record file and supplies one
record at a time to RSURTP.
Has entry point READIT.

Subroutine RUSER

Called from TRES.
Supplied by user to read their data file into arrays IRS
and ITRS.

4. Aggregation of species

Subroutine FIT

Called from TRES, SCREEN, and REMOVE.
Classifies trees in arrays TRS-ITRS into projection groups.

5. Stand treatment

Subroutine SCREEN

Called from TRES.
Screens plots for possible treatment and/or sets up treatment
schedule.

Subroutine COVTYPE

Called from SCREEN.
Determines cover type using live trees in tree list.

Subroutine TREAT

Called from SCREEN.
Performs silvicultural treatments prescribed in SCREEN.

6. Stand growth

Subroutine GROW

Called from TRES.

Grows trees, selects trees for mortality, updates TRS and ITRS array.

Subroutine REMOVE

Called from CROW

Removes trees to meet specified annual removals for updates or trees recorded as having been removed by remeasurements.

Subroutine ISUM

Called from GROW, OUTPT1, TRES

Summarizes trees into classification groups and computes group totals.

7. Output

Subroutine OUTPT1

Called from TRES.

Outputs summaries for specified points in time.

Subroutine TFILE

Called from TRES.

Outputs updated forest survey unit record file.

Subroutine OPENWR

Called from TFILE.

Writes blocked unit record tape.

Has entry points WRITIT and CLOSWR.

Subroutine OUTPT2

Called from TRES.

Outputs file for validation tests.

Subroutine OUTUR

Called from TRES.

Supplied by user to output updated tree list to their specifications.

When all input (parameters and tree list) has been read, the tree list is partitioned into species groups and size classes by subroutine FIT, called from the main program, TRES.

Selecting the option to manage the stand as it is being projected, causes subroutines SCREEN, COVTYPE, and TREAT to be called. COVTYPE, which is also called at the end of a projection by OUTPT2, determines the cover type and TREAT performs the silvicultural treatments selected in SCREEN. Trees selected for removal are designated as cut and the live trees are again divided into species and diameter groups by a recall of subroutine FIT. This allows the changes in species composition caused by cutting to change the species groups thereby changing the numerical constants used to project the plot.

The tree list is projected one year at a time for the number of years in a cycle by subroutine GROW, REMOVE and ISUM. The crown ratio function, potential growth function, and modifier function are used to determine individual tree growth. Dead trees are determined using the mortality function and the pseudo-random number generator.

OUTPUT

Four different output types are possible:

- (1) "Yield table" type output containing such variables as basal area and number of dead trees, number of surviving trees, basal area and sum of diameters on a per plot and per acre basis, and cut tree volumes on a per acre basis. This output is given by subroutine OUTPT1 and is available at the end of each cycle as well as at the beginning and end of the projection period.
- (2) A new Renewable Resources Evaluation (forest survey) unit record file (subroutine TFILE and OPENRD).
- (3) A file for validating the projection system. This is produced by subroutine OUTPT2 and has meaning only if two or more measurements have been made on the plot. The file produced by OUTPT2 is ordinarily stored on disk and analyzed by a separate user-written program.
- (4) A user-designated output file (subroutine OUTUR).
- (5)

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Techniques of Australian Forest Planning

Australian Forestry Council

Research Working Group No. 2¹

Abstract: Computer modeling has been extensively adopted for Australian forest planning over the last ten years. It has been confined almost entirely to the plantations of fast-growing species for which adequate inventory, growth, and experimental data are available. Stand simulation models have replaced conventional yield tables and enabled a wide range of alternative strategies to be evaluated for each individual stand. Simulation models for entire plantations have been found invaluable for the preparation of 1- to 5-year cutting plans and for regulating the yield over 20- to 60-year periods. Many models have been constructed and found to be simple and highly cost-effective. Optimization models, using linear programming, have been constructed for yield regulation and found to give powerful insights into the interactions between the various alternatives available for all stands. However, these models are expensive and require considerable data and expertise. They are difficult to maintain, especially when staff change.

INTRODUCTION

This paper reviews Australian experience with the planning techniques used for plantations, and some even-aged natural forests, in the light of their potential usefulness to developing countries. Australia has a century of experience with industrial plantations of fast-growing exotic species, such as Pinus radiata, which have been planted extensively in developing countries in recent years. During the last 10 years, planning methods have been completely changed by the development of computer modeling techniques and it is to experience gained in this change that the paper is addressed.

¹ Research Working Group No. 2--Mensuration and Management is one of several groups set up by the Australian Forestry Council. It consists on one or two planners from each of seven government forest services, as well as representatives from industry and universities. Members of the group are concerned both with developing new models and with the routine preparation of management plans based on their results.

The extent to which modeling has been adopted, and the type of models developed, in each region have been determined largely by the data required and available. Data collection in the mixed-species, mixed-age, natural hardwood forests is very difficult and has often not been warranted by the slow growth and low value of the stands; very few models have been built for these forests. By contrast, extensive inventory, growth, and experimental data have been collected for long periods in the single-species, even-aged, fast-growing, and valuable plantations. It has been found often that the available data did not cover as wide a range as was needed to enable models to examine new options for the future. In particular, existing inventory data has rarely been suitable for the construction of growth models. Wider ranges are being included in the designs of many new experiments.

Thorough testing of the models is of great importance and is generally done on a continual and long-term basis by comparing estimated yields with actual deliveries to mills. Several effects, such as errors of growth estimation or modeling thinnings, quantity of residues, degree of utilization and conversion factors, are confounded in such comparisons. However, adequate performance in the tests is essential for management acceptance of the forecasts made by the models.

SIMULATION OF GROWTH AND YIELD

The simulation of growth and yield with computer models has been a considerable advance on the use of standard yield tables because the effects of many more silvicultural and management options can be examined quickly, and because the individual conditions of each stand can be allowed for.

Each model described comprises several biometric functions, forecasting the development of various stand parameters, which are combined into a compatible system enabling the stand as a whole to be characterized. The key functions are those to forecast height and basal area or volume growth and to estimate the effects of tree breeding and alternative silvicultural options such as cultivation, fertilization, or thinning. Almost all these functions were constructed with data from repeated measurements of permanent growth plots and designed experiments and only a few from stem analysis or inventory data.

Some other functions, such as those describing stem form or volume, basal area, and height relationships, are also needed. Useful functions were often prepared initially by hand-drawn graphical analysis, and early modeling was based on computerized versions. Linear regression analysis has now almost entirely replaced graphical analysis. More advanced forms of analysis are being introduced such as nonlinear estimations and generalized least squares. As some extrapolation has almost always been necessary, the forms of the growth functions have had to be chosen very carefully.

There has been a gradual shift towards more intensive silviculture in Australia, as elsewhere in the world. The stands now being planted are expected to grow differently from those which provided the data for the growth functions currently used. The methodology needed to allow for this difference, the nature of interactions between effects (e.g., tree breeding and thinning), and the long-term upper limits to growth of stands grown under new conditions are matters requiring considerably more research.

Stand Simulation Model 1

Organisation	: A.P.M. Forests Pty. Ltd., P.O. Box 37, Morwell, Victoria 3840.
Information	: J.B. Dargavel
Forest	: 40,000 ha of P.radiata supplying a pulpmill and & a sawmill. There is a wide range of sites and there is very little land available for purchase economically.
Objective	: Generate alternative strategies for each stand for subsequent selection by optimisation model.
Time Span	: 25 years
Input	: Inventory plot data from existing computer system.
Method	: Functions constructed by linear regression from permanent growth plot data forecast height and basal area increments. Responses to fertiliser, weed control and tree breeding estimated from experiments. Volume yield by thinning and clear felling calculated by size and wood basic density classes.
Output	: Stand development, yield, cash flow for each of an average of 50 alternative strategies for each of 200 stands. Each strategy represents a different combination of 1. establishment method (2 alternatives) 2. thinning method (3 grades) 3. later fertilisation (Yes/No) 4. clear felling age (10 possible ages)
Application	: Provide input to plantation optimisation model.
Evaluation in Organisation	: Has enabled wide range of silvicultural options to be examined. Major difficulties are estimation of how stands will grow under combinations of alternatives that have not yet been tried. Research needed on interactions and upper limits to growth.
Assessment for Developing Countries	: Useful for generating yield tables. Tabular presentation of standard or example strategies necessary if immediate computer access not available. Accuracy depends on relevance of growth functions incorporated.
Reference	: Turner, B.J., Bednarz R.W. and Dargavel J.B. (1977). A model to generate stand strategies for intensively - managed radiata pine plantations. Australian Forestry 40 (4) : 255-67.

Stand Simulation Model 2

Organisation	: Queensland Forestry Department, 388-400 Ann Street, Brisbane, Queensland 4000.
Information	: B. Stark
Forest	: 38,000 ha of native conifers (predominantly Auracaria cunninghamii) and 60,000 ha of Pinus species, predominantly P.elliottii and P.caribaea but also P.radiata , P.taeda and P.patula .
Objective	: To calculate both short and long term yields, cash flows and standing volumes and values at any nominated time, for various management alternatives.
Time Span	: Short term up to 20 years and long term up to 60 years.
Input	: Inventory plot data and 1% dbh strip samples from existing computer system.
Method	: Functions constructed from inventory and experimental data forecast height and basal area increments and are used to calculate new diameter distributions. Currently the model requires the alternative strategies for any given stand from a measured sample, but in the future the model will generate the strategy, given certain broad guide lines. A wide range of alternative thinning strategies can be examined.
Output	: The model projects and thins the stand table in 1 cm dbh classes for each cutting unit producing estimates of basal area, predominant height, volumes and values. A very wide range of groupings or listings is available including time period options, stand conditions (basal area, predominant height, age etc.), size assortment by quality classes for the stand and thinnings, volumes and values for the stand or thinnings using current pricing, and tables of predominant height, volume and basal area information for direct comparison with the actual plots, giving a continuing check on the model predictions.
Evaluation in Organisation	: A plantation simulation is provided by aggregating the simulations of each stand. The resulting short term calculation (up to 5 years) has been very successful in organising logging and new sales.
Assessment for Developing Countries	: Possibly the basal area increment prediction method could be very useful to countries with young plantations and limited data.

Stand Simulation Model 3

Organisation	: Woods & Forests Department, P.O. Box 162, Mount Gambier, South Australia 5290.
Information	: N.B. Lewis, A. Keeves and J.W. Leech.
Forest	: 70,000 ha of P.radiata plantations, managed on an approximately 50-year rotation with up to six commercial thinnings, and with a comparatively even distribution of age classes.
Objective	: To predict the yield of plantation stands of radiata pine from age 9 1/2 site quality assessment to the end of rotation.
Time Span	: 10 - 50 years.
Input	: Permanent sample plots data - plots measured for volume every 2-3 years. Some plot trends exceed 40 years.
Method	: Graphical methods using the directing curve technique.
Application	: Incorporation in long term planning models for even-aged stands.
Evaluation in Organisation	: The technique has been used successfully for over 30 years to regulate the total cut from a profitable state afforestation enterprise, keeping the cut as near sustainable maximum as possible. The model is very nearly as precise a prediction model as the best nonlinear model developed.
Assessment for Developing Countries	: Advantages - 1. it is simply revised as more data becomes available. 2. being subjective, local knowledge of data relevance and accuracy can be incorporated. 3. does not need computer. 4. does not need statistical expertise. Disadvantages - 1. precision is unknown. 2. it may be biased.
References	: Lewis, N.B., Keeves, A. and Leech, J.W. (1976) "Yield regulation in South Australian Pinus radiata plantations". Woods & Forests Bulletin 23. Adelaide.

Stand Simulation Model 4

Organisation	: Woods & Forests Department, P.O. Box 162, Mount Gambier, South Australia 5290.
Information	: J.W. Leech.
Forest, Objective, Time, Input	: As for Model 3.
Method	: An alternative to the method used in model 3. Nonlinear regression analysis using Generalised Least Squares and optionally, Bayesian informative priors.
Output	: It will be incorporated in a revision of the South Australian plantation simulation model for long term planning.
Application	: Incorporation in long term planning models for even-aged stands.
Evaluation in Organisation	: The algorithms used offer considerable advantages over the commonly used linear regression analysis using Ordinary Least Squares:- 1. alternative biologically sound, hypothetical models can more readily be formulated as nonlinear models than as linear models. 2. Generalised Least Squares provides a statistically sound way of utilising long term trend data. 3. Bayesian statistical methods enable thinned and unthinned plot data to be incorporated in the one analysis. These complex techniques are necessary if a mathematical model for radiata pine is to be a superior predictor to yield tables developed by the directing curve trend technique. Further, these extensions provide a more precise prediction model that is statistically sound.
Assessment for Developing Countries	: The technique used requires good long term data which could be obtained only from - 1. remeasured plots, or, 2. stem analysis.

Stand Simulation Model 4 contd.

Further the technique requires access to computing facilities and also requires a sound statistical knowledge.

Given these factors the technique offers considerable promise for yield prediction in even-aged stands.

References : Ferguson, I.S. and Leech, J.W. (1978)
"Generalised Least Squares estimation of stand yield functions". Forest Science (in press).

Stand Simulation Model 5

Organisation : Tasmanian Forestry Commission,
199 Macquarrie Street, Hobart, Tasmania 7000.

Information : P.R. Lawrence.

Forest : 29,000 ha of **P.radiata** plantations managed for sawlog and pulpwood production on rather conservative thinning regimes, delayed to varying degree because of poor current market demand.

Objective : To predict thinning and clear-felling yields from stands of various ages, site indices, stocking class and thinned states. Inclusion in forest simulation model, assuming current treatment regimes.

Time Span : Up to 40 years in periods of up to 3 years.

Input : Either data from sample plots or, when used in the forest model, estimated values of mean dominant height, basal area and mean dbh obtained from age, site index and thinned state of each patch of forest recorded in the area information system.

Method : The three basic parameters predicted are mean dominant height, basal area increment and increment in mean dbh. The height/age relationship was obtained by non linear methods, the other two by linear least squares, all from permanent plots. Thinning yields and the new starting point after thinning are predicted from past records of standard treatment. Volumes are calculated from stand volume equations.

Output : Values required for the forest simulation model including mean dbh, entire stem volume and volume to four top diameter limits for either thinnings or clear-fellings.

Application : Simulation of a forest.

Evaluation in Organisation : The major limitation is that the results can only apply to stands treated in the same manner as in the past. Since new treatment regimes are being adopted, the use of these models is very limited. The major source of inaccuracy of prediction was found to be in estimating the starting points.

Assessment for Developing Countries : Few developing countries are likely to adopt the very conservative thinning regimes modelled.

Stand Simulation Model 6

"STANDSIM"

Organisation : Forests Commission, Victoria,
601 Bourke Street, Melbourne, Victoria 3001.

Information : R.B. Smith.

Forest : Even aged monospecific natural stands Eucalyptus regnans, **E.delegatensis**, **E.sieberi** and approximately 75,000 ha of **P.radiata** plantations.

Objective : The future growth of a stand of any age is modelled for any period, for various sites and thinning regimes.

Time Span : Commonly 25 -40 years, with annual or 5 yearly growth cycles.

Input : Individual tree data by 10 cm size classes also rotation length, site index, thinning regimes.

Method : STANDSIM is a deterministic model which projects the development of a hectare of forest for various sites and thinning regimes, operating on individual tree data stored mainly as an array of tree diameters. In each growth cycle the trees are grown and if necessary thinned by natural mortality or cutting. Growth takes place by updating the diameters according to gross basal area increment and other functions.

Output : At the end of each growth cycle, stand data including basal area, stocking and dominant height of live trees, gross increment, net increment, mortality, and thinning information.

Application : Output from this model is used in systems for scheduling the cut from large areas of forest. It can also be used to study a range of cutting options, for example, the number and timing of thinnings, and timing of final harvest. A stochastic version of this model has been developed for studies of risk and uncertainty. [sic]

Stand Simulation Model 6 contd.

Evaluation in Organisation	: The model has been highly successful because users were involved in construction and testing.
Assessment for Developing Countries	: A simplified form of the basic growth model would be potentially useful in even-aged forest areas for which large scale industrial developments are proposed. Advantage - 1. the ability to study a whole range of thinning and clear felling options. Disadvantages - 1. the model refers to monospecific stands only, 2. model assumes fairly regular spacing, 3. no allowance for defective stands.
Reference	: Opie, J.E. 1972. STANDSIM - a general model for simulating growth of even-aged stands. Proc. 3rd Conf. Advisory Group of For. Statisticians, Section 25, IUFRO, Jouy-en-Josas, France, Sept. 1970.

SIMULATION FOR CUTTING PLANS AND YIELD REGULATION

Computer models which simulate the future yield of entire plantations, that is, all stands considered together, have become indispensable aids for preparing 1- to 5-year cutting plans and for regulating the yield over 20- to 60-year periods.

The models described in this section simulate the development of the plantations and the production of wood according to initial starting values of such things as the area and conditions of existing stands, land availability, planting rate, and the quantities of wood demanded for industrial developments. Some models include forecasts of cash flows and economic results.

For each year of the simulation, the plantation models forecast the growth of each stand using yield tables or the stand simulation models described earlier. Stands are then scheduled for cutting according to built-in decision rules and the overall yield for the year calculated.

By altering the starting values and repeating the simulations, a range of alternatives can be generated from which the planner can select the most suitable. The models are used to schedule stands for clear felling and to evaluate the timing and type of thinning operations, particularly in relation to the demand for small-diameter roundwood. In long-term planning, the models are used to evaluate alternative planting rates and investigate how proposed new industries might be supplied.

The models vary considerably in their complexity depending on the extent to which the variations in site are identified and on the nature of the decision rules used for selection. The simplest models consider only the average site and extend the areas of each age class by a standard yield table. By contrast several of the models consider each separate stand and simulate their development with stand growth and yield models imbedded within the overall plantation model.

Plantation Simulation Model 1

CUTTING PLAN

Organisation	:	A.P.M. Forests Pty. Ltd., P.O. Box 37, Morwell, Victoria 3840.
Information	:	J.B. Dargavel.
Forest	:	40,000 ha P.radiata plantations.
Objective	:	Schedule stands for cutting to supply a pulpmill and sawmill.
Time Span	:	6 months - 3 years.
Input	:	The age, basal area, height and stocking of each cutting unit, its area and suitability for summer or winter cutting.
Method	:	Includes a stand growth model. Selects stands for cutting by priority rules based on operation due, need for thinning, quality of sawlogs and volume to be met.
Output	:	Schedule of stands to be cut and volume of each product.
Application	:	Preparation of operational cutting plans.
Evaluation in Organisation	:	Comparatively cheap to develop. Easy to use and amend.
Assessment for Developing Countries	:	Cost effective. Scheduling could be done manually.
Reference	:	Dargavel J.B., and Marshall P.J. 1976. Annual cutting plans for developing plantations. Proc. IUFRO Working Group S 4.02.4 XVI World Congress. Oslo.

Plantation Simulation Model 2

CUTTING PLAN

Organisation	:	Woods & Forests Department, P.O. Box 162, Mount Gambier, South Australia 5290.
Information	:	A. Keeves and J.W. Leech.
Forest	:	Some 70,000 ha of P.radiata plantations, managed on an approximately 50 year rotation with up to six commercial thinnings, and with a comparatively even distribution of age classes.
Objective	:	To predict the yield of a group of plantation stands of radiata pine in the next commercial thinning.
Time Span	:	1 - 6 years.
Input	:	Inventory data, yield prediction models, proposed thinning treatment and tree size assortment tables.
Method	:	Linear regression analysis was used to predict tree volume and increment from tree diameter, stand height, site quality and stand density for both thinnings and clear felling. Inventory data are from temporary 0.1 ha plots.
Output	:	A tabular five year cutting plan listing operations to be carried out and expected yields in a range of size assortments.
Application	:	In preparing the next 5 year cutting plan which will direct where commercial thinning and clear felling will take place to meet commitments to utilisation plants in a variety of required size and quality assortments.
Evaluation in Organisation	:	A limited test using independent data indicated the approach was satisfactory for practical use.
Assessment for Developing Countries	:	This type of model is of use when short term (1-6 year) increment is considerable and will affect planning. This is of particular importance when a fast growing plantation resource is being utilised close to its capacity.
Reference	:	Lewis, N.B., Keeves, A. and Leech, J.W. (1976) - "Yield regulation in South Australia Pinus radiata plantations". Woods & Forests Bulletin 23, Adelaide.

Plantation Simulation Model 3

CUTTING PLAN

Organisation	:	Forests Department of Western Australia, Barrack Street, Perth, Western Australia 6000.
Information	:	H. Campbell.
Forest	:	45,000 ha P.radiata and P.pinaster plantations.

Plantation Simulation Model 3 contd.

Objective	: Development of 1 and 5 year logging plans. Planning the timing and extent of forest industry expansions.
Time Span	: Open ended, but generally 1 or 5 years.
Input	: Continuous inventory plot measurement data.
Method	: Simulation of growth by a stochastic model. Thinning operations and silvicultural and marketing priorities are set interactively.
Output	: For each year of the planning period a list of areas to be treated and volumes by assortments is produced. Also a resource summary is prepared.
Application	: Scheduling thinning operations in pine plantations could also be used to develop strategies for input to an optimising program.
Evaluation in Organisation	: After a slow start the model is gaining in use and acceptance in direct proportion to the degree of pressure put on the plantation resource.
Assessment for Developing Countries	: The growth routines are specific to radiata and pinaster pine. The modifications required to adapt them to other coniferous species would probably be minimal. Extensive modifications would probably be necessary to adapt them to hardwood species.

Plantation Simulation Model 4

YIELD REGULATION (Four Models)

Organisation	: A.P.M. Forests Pty. Ltd., P.O. Box 37, Morwell, Victoria 3840.
Information	: J.B. Dargavel.
Forest	: Plantations of P.radiata , P.elliottii , E.regnans and E.grandis in New South Wales, Queensland and Victoria developed to supply pulpmills.
Objective	: Development planning. Determine if mills of given size can be supported from nominated land areas and planting rates.
Time Span	: 20 - 30 years.
Input	: 3 models assume one average site; 1 model assumes 4 different sites, models require areas of each age, standard yield table for each site, and standard costs.
Method	: Yield table projection. Areas scheduled for clear felling to meet mill demands by nominated priority rules, mostly oldest first.
Output	: Schedule of areas planted, thinned, felled. Times at which demands can not be met or surplus available. Condition of plantations at end of planning period.
Application	: Development planning, particularly at initial stages of plantation development prior to industries being established.
Evaluation in Organisation	: Simple models, easy and cheap to construct and run only require small computers. Very successful when operated in inter-active mode. Used when only limited data available i.e. before extensive inventory data base has been built up. Difficulty is that they ignore real site differences and full range of opportunities that become apparent when inventory and experimental evidence has been assessed; complex optimisation models then developed to evaluate.
Assessment for Developing Countries	: Very high as models can be limited to the data available. Cheap and simple to construct and use. Highly cost effective.
Reference	: J.B. Dargavel. 1969. Yield forecasting for industrial plantations. Australian Forestry 33 (3) : 153-62 gives details of an early, rather more elaborate model than is currently used.

Plantation Simulation Model 5

YIELD REGULATION

Organisation	: Woods & Forests Department, P.O. Box 162, Mount Gambier, South Australia, 5290.
Information	: A. Keeves and J.W. Leech.
Forest	: 70,000 ha of P.radiata plantations, managed on an approximately 50 year rotation with up to six commercial thinnings, and with a comparatively even distribution of age classes.
Objective	: To predict the long term yield of the resource.
Time Span	: 60 years.

Plantation Simulation Model 5 contd.

Input	: Inventory data, yield prediction models, potential thinning regimes, information from the short-term planning model and stand size assortment table.
Method	: Currently uses yield tables to predict the growth of a logging unit allowing for variations of site potential, but will incorporate mathematical models recently developed. Logging units are thinned according to a variety of commercial thinning regimes and potential yields are aggregated by assortments into years. Yields between years were balanced by varying the clear felling age for some logging units over the first 25 years of the planning horizon.
Output	: Tables listing thinning and clear felling operations, areas and volumes by assortments included in each year's potential cut, and summaries by five year periods and by forests.
Application	: Strategic planning of the long term permissible cut.
Evaluation in Organisation	: The technique has been used successfully to determine long term cutting strategy from a limited forest resource that is now fully committed to industry. A limited range of management strategies can be evaluated, depending on the range of data used to develop the model. The model is deterministic not stochastic. These limitations have not proved significant and the accuracy of the predictions is satisfactory for long term strategic planning in an environment subject to short term change.
Assessment for Developing Countries	: This type of model is applicable in many developing countries as it can use simple growth - yield - inventory data to estimate wood availability under a variety of management strategies.
Reference	: Lewis, N.B., Keeves, A. and Leech, J.W. (1976) "Yield regulation in South Australia Pinus radiata plantation." Woods & Forests Bulletin 23, 174 pp.

Plantation Simulation Model 6

YIELD REGULATION

Organisation	: Tasmanian Forestry Commission, 199 Macquarie Street, Hobart, Tasmania 7001.
Information	: M. L. Higgs.
Forest	: 29,000 ha of plantation, predominantly P.radiata , supplying privately owned sawmills, pulpmills and other utilization plants.
Objective	: To predict thinnings and clear-felling yields by various classes given specified felling age prescriptions and volume constraints.
Time Span	: Varies depending on need, generally 15 - 30 years.
Input	: Uniform batches of forest are classified by stand parameters including age, site index class and thinned state.
Method	: Initially each patch is assigned thinning and clear-felling priority values based on its stand parameters. Stands are then ranked in decreasing priority order for clear-felling or thinning. Yields for stands eligible for felling are accumulated subject to volume constraints.
Output	: Stand volume, growth, and felling yields are estimated by means of functions comprising the stand simulation model.
Application	: Annual schedule or areas available for felling. Deficits or surpluses if volume constraints applied. Summary of growing stock at five year intervals.
Evaluation in Organisation	: Resource level planning of sawlog and pulpwood sales.
Assessment for Developing Countries	: The model is good where economic considerations with respect to management have not been emphasized.
Countries	: Represents a simple, inexpensive system with potential where optimisation involving cost criteria is not required. Disadvantages are in lack of diverse range of cutting strategies and in not having log assortment output.

Plantation Simulation Model 7

YIELD REGULATION "FORSIM"

Organisation	: Forests Commission, Victoria, 601 Bourke Street, Melbourne, Victoria 3001.
Information	: R.B. Smith.
Forest	: 75,000 ha of P.radiata plantations.
Objective	: To predict woodflows and cash flows from a forest consisting of a set of diverse even-aged stands.
Time Span	: Up to 50 years.
Input	: Inventory plot records for each section of the forest (sections uniform in age, species, site index).
Method	: Growth simulation of plot basal area and height, and simulation of harvesting operations (thinning and clear fellings) depending on the cutting regime.
Output	: For each strategy output includes volumes (by size classes), areas and section numbers for each year, areas by age classes, growing stock volumes for nominated years, revenues and discounted revenues for each operation for each year.
Application	: Planning and scheduling the cut, testing and comparison of cutting strategies.
Evaluation in Organisation	: Highly successful although initial problems with change of staff, change of computing environment, change of measurement units. Ideal application for P.radiata plantations where a large number of possible cutting strategies is involved.
Assessment for Developing Countries	: The complex FORSIM package would have little potential for forests coming under management for the first time. The simplified version ASSIM may have potential as a short term growth simulator.
Reference	: Gibson, B.F., Orr R.G. and Paine D.W.M. 1971. FORSIM - a computer program for planning management of even-aged forests. Forests Commission Bulletin. Melbourne.

OPTIMIZATION FOR FOREST YIELD REGULATION

The three optimization models described in this section were designed for yield regulation. The optimization models represent a significant advance on the simulation models described earlier because they enable the full combination of the silvicultural alternatives, for each stand times the number of stands, to be explored. For example, if there are 50 alternative strategies for each of 200 stands, an optimization model finds the best set out of the $50 \times 200 = 10,000$ possible alternatives. The best set consists of the strategy selected for each stand, with a few stands being divided into 2 or 3 parts each with a different strategy. Thus a little over 200 alternatives out of 10,000 are selected in a single run of the model. By contrast the simulation models only allow those combinations to be evaluated that are defined in the built-in decision rules.

Two of the models are concerned with large fast-growing exotic plantations of P. radiata and one is concerned with extensive fast-growing even-aged natural stands of E.regnans and E.delegatensis. All the models evaluate various silvicultural alternatives for each stand while meeting overall constraints, such as markets or budget, for the plantation as a whole.

Each model uses a linear program for optimization formulated along the lines originally developed by Clutter (Ware and Clutter 1971) in the Type 1 model of Johnson and Scheuman's (1977) classification. Standard computer packages are used to solve the linear programs and obtain extensive marginal analysis.

The models require extensive data prepared, by a "matrix generator" program, in a form suitable for input to the standard packages. The source data consists of the yields, cash flows, etc., for each alternative strategy considered for each stand. This extensive data is generated by stand simulation models.

The optimization models have been found to be many times more expensive to develop and operate than simulation models. They require very extensive data and considerable expertise. Because of this, they have been found difficult to maintain when specialist staff move. They do, however, provide very powerful insights into interactions between the alternative strategies available for different stands. Their use can best be justified when forest structure and conditions are complex and the supply/demand relationship is critical.

The optimization models were only constructed after substantial experience had been gained both with stand and plantation simulation models.

Optimisation Model 1

Organisation	: A.P.M. Forests Pty. Ltd., P.O. Box 37, Morwell, Victoria 3840.
Information	: J.B. Dargavel.
Forest	: 40,000 ha of P.radiata in Victoria supplying a pulpmill and a sawmill. There is a wide range of sites, and very little land is available for purchase economically. Some outside wood and chips are purchased.
Objective	: Plan plantation development, and ration capital between buying land, planting and fertilisation. Also, find how much outside wood to buy, schedule thinning and clear felling and find best silvicultural regime for each stand.
Time Span	: 25 years.
Input	: An average of 50 alternatives for each of 200 stands showing yields, cash flows and contribution to objectives, produced from stand model. Volumes and costs of outside wood purchase options. Many other data on conversion factors, costs etc.
Algorithm	: Linear programming.
Output	: Extensive reporting of: 1. silvicultural regime (planting method, fertilisation, thinning method, clear felling age) for each stand, 2. Wood purchase schedule, 3. Planting, thinning and clear felling schedules, 4. Rationing of capital between all plantation activities, 5. Forecasts of size and density distribution to mills, 6. Marginal costs of all constrained opportunities.
Evaluation in Organisation	: Development brought all sections of organisation together. Proved to be a very powerful tool in giving insights into operation of plantation system. Very demanding in data requirements and staff time. Expensive to construct and operate. Requires ready access to large computer. Difficult to modify quickly to changing conditions.
Assessment for Developing Countries	: Considerable data and staff time required for both construction and continued modification and maintenance of model in usable and valid condition.
Reference	: J.B. Dargavel. 1978. A model for planning the development of industrial plantations. Australian Forestry. 41. (in press).

Optimisation Model 2

"RADHOP"

Organisation	: Forestry Commission of N.S.W., 93 Clarence Street, Sydney, N.S.W. 2000.
Information	: R. Wilson and M. McMullen.

Optimisation Model 2 contd.

Forest	: 100,000 ha of P.radiata plantations with irregular age-class distribution supplying 2 particleboard plants and numerous sawmills. One or two pulpmills are planned for the early 1980's.
Objective	: Rationalise yield flows through time to meet market requirements.
Time Span	: Either short term (commonly five years) or long term (commonly 35 years).
Input	: Inventory plot data plus financial information.
Algorithm	: Stand simulation by deterministic functions constructed from research and inventory data. Optimisation by linear programming, which selects regimes to apply to management units to maximise returns while meeting volume constraints.
Output	: Details of regime to be applied to individual areas, size and time distribution of volume.
Application	: Short term harvest planning, and long-term prediction of quantity of industry that can be supported at various times.
Evaluation in Organisation	: Successfully accepted as major management aid because of demonstrated reliability. Functions continually adapted as conditions change and more data becomes available.
Assessment for Developing Countries	: Useful for providing estimate of plantation requirements to meet markets. Operates on sample data, but requires sophisticated computing capacity. An aid also to planning industry establishment. Predictor functions are not an integral part of model, and can be altered easily. Simulation model provides much useful information and can be used alone for predicting volumes.

**Optimisation Model 3
"MASH"**

Organisation	: Forests Commission Victoria, 601 Bourke Street, Melbourne, Victoria 3001.
Information	: R.B. Smith.
Forest	: 120,000 ha of regrowth forest predominantly E.regnans and E.delegatensis principally 1939 origin.
Objective	: To define the cutting schedule that maximises the present net worth of the wood resource, subject to woodflow constraints.
Time Span	: Up to 100 years.
Input	: Stand data including diameter distribution, thinning strategy, road and transport costs, royalty values, harvesting constraints.
Algorithm	: Parametric linear programming, to maximise the present net worth subject to constraints on wood flows. MASH incorporated several features of STANDSIM.
Output	: Optimal cutting strategy and wood flows, cash flows and present net worth associated with that strategy.
Application	: The definition of sustainable woodflow levels, supply area and broad harvesting strategies.
Evaluation in Organisation	: The technique has been successful in broad applications over the resource as a whole. There are problems with further application at district level because of change of staff and computing environment and intricate rules for operating the model.
Assessment for Developing Countries	: MASH would be a useful aid in planning the management of a forest of complex structure with respect to age, density, site quality and species. Depends on good inventory and this may be a drawback. Also requires sophisticated computing system, which may be a difficulty in applying MASH to developing countries.
Reference	: Weir, I.C.A. 1972. Planning of wood production using systems analysis. APPITA 26 (2) :107-112.

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Operations Research Techniques in the Management of Large-Scale Reforestation Programs

Joseph Buongiorno

D.E. Teeguarden

Abstract: A reforestation planning system for the Douglas-fir region of the Western United States is described. Part of the system is a simulation model to predict plantation growth and to determine economic thinning regimes and rotation ages as a function of site characteristics, initial density, reforestation costs, and management constraints. A second model estimates the expected value of alternative reforestation projects and determines the optimum allocation of scarce resources to these projects via linear programming. The applicability of the system to developing countries is briefly considered.

INTRODUCTION

This paper describes a system of computer programs developed by the authors to assist in the design and selection of reforestation projects. Given an initial set of resource and policy constraints, the system permits managers to select the set of reforestation projects to execute, the method of reforestation to employ, and the initial stocking in new plantations. The system was developed for use by managers of large-scale, public land reforestation programs in the Douglas-fir region of the Western United States. A more technical and detailed description of the system, as well as a discussion of the economic principles on which it is based, can be found in Buongiorno and Teeguarden (1973).

Problem Definition

Every year during the months of July and August, the reforestation staff of each district of the U.S. Department of interior, bureau of Land Management (BLM) in Western Oregon receives a commitment of funds, seeds, and seedlings, from the State Director. Given the limited amount of resources and the available land, the reforestation plan which best satisfies BLM goals must be prepared. The model is designed to answer, for each tract of land available for reforestation, the following interrelated questions:

How many acres should be reforested:

What site preparation should be applied?

Is it better to plant or seed?

How many trees, or pounds of seed, per acre should be used?

From what sources can necessary seeds or seedlings be obtained?

Management Objectives

It was determined that the Bureau of Land Management guidelines are consistent with the objective of maximizing present net worth (PNW), under constraints. Some constraints are explicitly stated, e.g., minimum rotation age allowed on BLM lands, minimum number of trees to be maintained on thinned plantations, minimum commercial volume extracted from thinning operations. Other constraints are implicit. These are reflected by the system of accounting, or by the shadow prices used in PNW computations. These prices may, and often should, differ from market prices, which cannot be the only basis for public project evaluation, although they may be very useful indicators of the supply and demand of reforestation inputs and outputs.

System Overview

The reforestation planning system is composed of two main computing programs named FOREST and REGEN (fig. 1). FOREST is a simulation model capable of predicting the growth of Douglas-fir plantations as a function of site quality and initial density. FOREST also includes optimization algorithms which allow for the determination of optimum thinning regimes, and optimum rotation ages, as a function of site quality, initial density, and reforestation costs, given the objective of maximizing PNW, under constraints. The results obtained from program FOREST are part of the input in program REGEN. This second program determines the expected PNW of reforestation alternatives applied to the various tracts of land available. The program also generates and solves a linear programming model which describes the interaction of all projects competing for a limited budget, and limited stocks of seed and seedlings. The program FINAL simply displays the solution in a form readily understandable by reforestation managers.

FOREST: A SIMULATION MODEL FOR MAN-MADE FOREST MANAGEMENT

As indicated earlier, PNW maximization, under constraints, is the guide to making plantation investment decisions. FOREST applies this principle in deriving estimates of future plantation yields. The management decisions considered by FOREST are (1) initial densities in plantations, (2) schedule of intermediate cuttings as the plantation matures, (3) rotation age. The final output of FOREST is a set of yield tables (fig. 2) showing the expected PNW of a plantation as a function of site index, initial density of the plantation, and establishment costs. PNW is always computed assuming that an optimum thinning regime and rotation age will be applied to the plantation, within policy constraints specified by the manager.

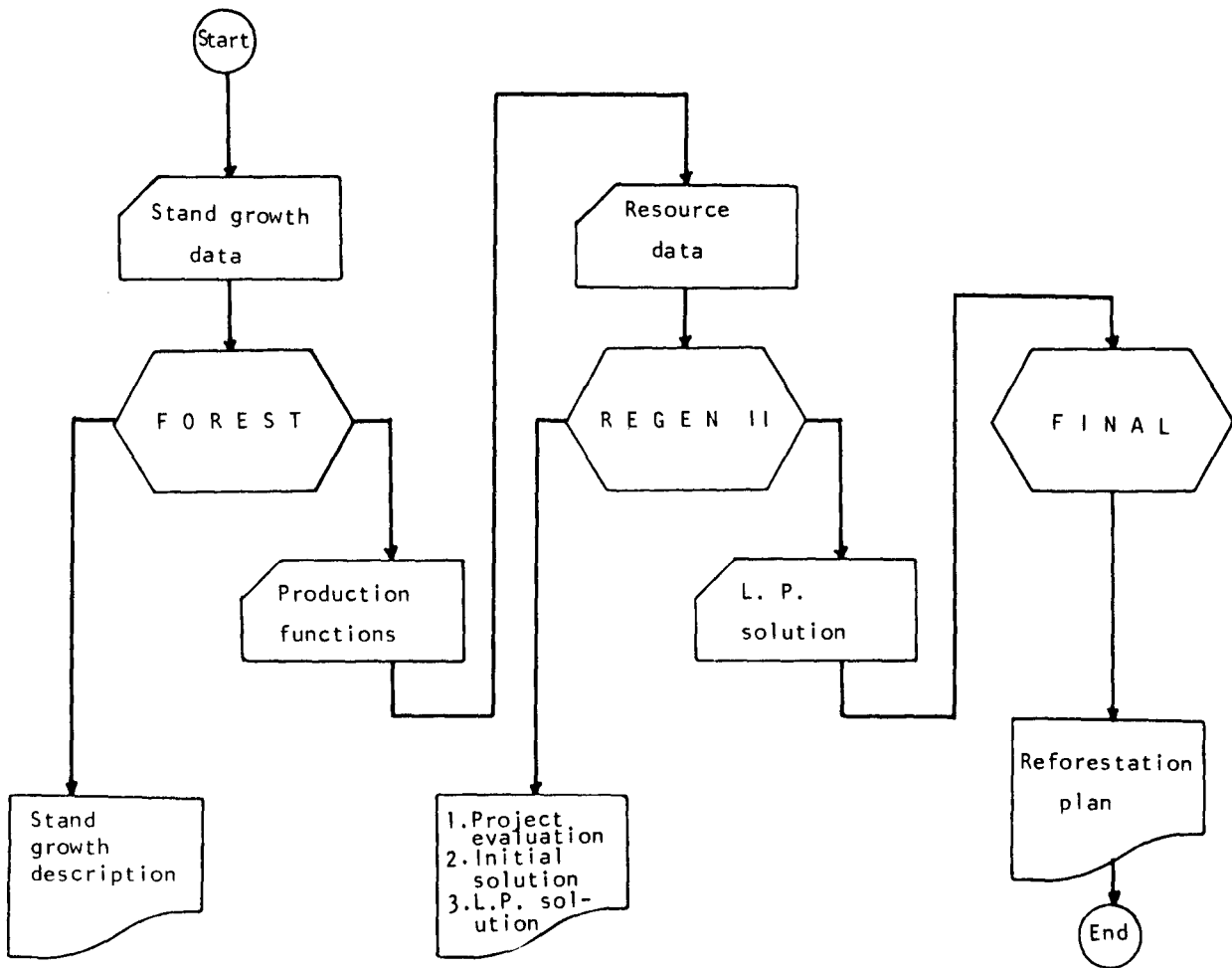


Figure 1. Elements of the reforestation planning system.

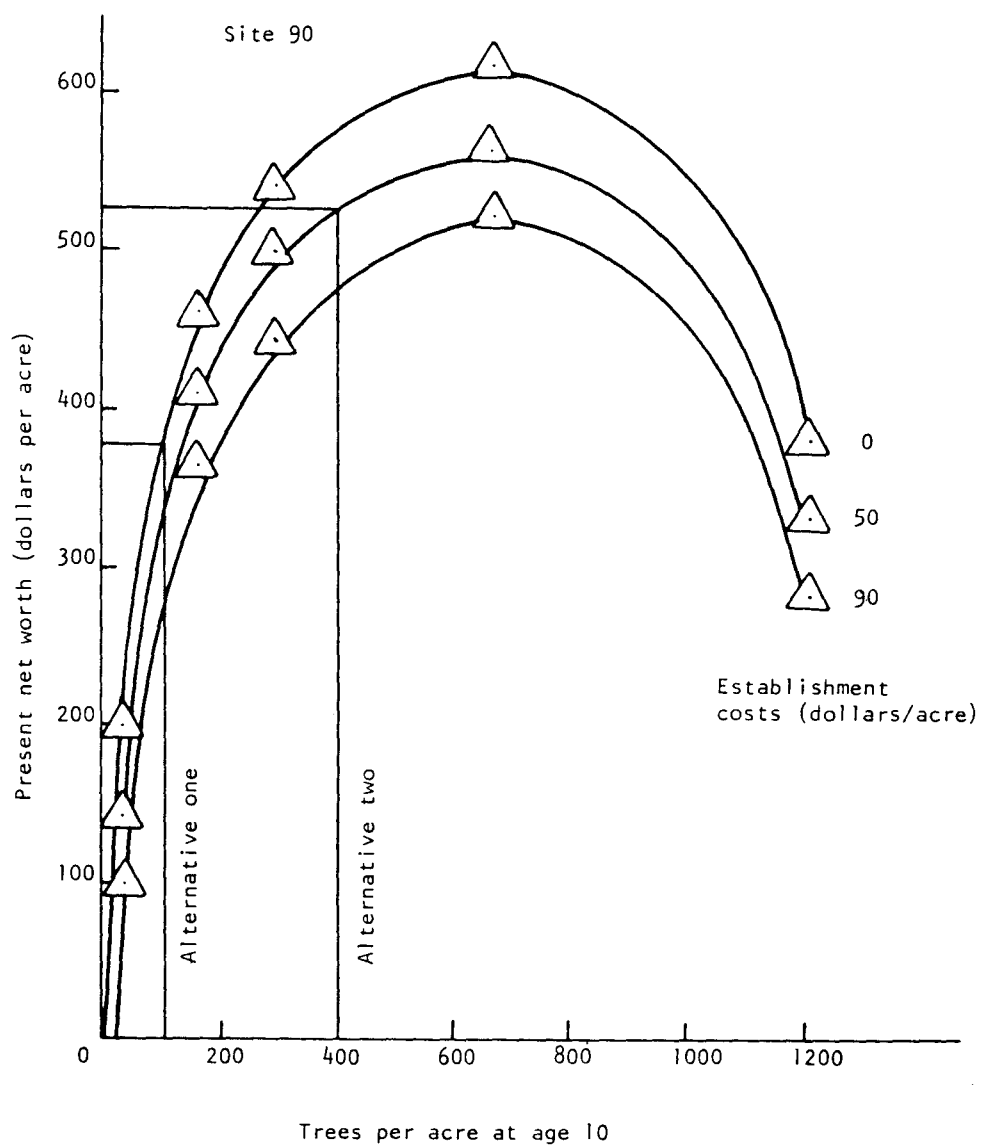


Figure 2. Present net worth of reforestation alternatives.

FOREST is composed of two basic elements. The first one simulates the growth of an even-aged stand of Douglas-fir trees. The second element models the decisionmaking process (thinning regime, and final harvest). Stand growth is determined by modeling the behavior of individual trees. Individual tree growth is computed as a function of tree age, and competition from neighboring trees, using deterministic functions. Individual tree mortality is instead a random process in which the probability of death, within a specific time span, is a function of tree age, site index, and competition. Figure 3 shows the behavior of entire stands, as predicted by FOREST, for three different initial densities, when no thinning is applied.

The decisionmaking element of FOREST is designed to apply a thinning regime which maintains an optimum stocking in plantations, i.e., a stocking such that the marginal value growth of the stand will be equal to the guiding rate of interest used. Managerial constraints regarding the minimum volume of thinnings which should be extracted, and the minimum number of trees remaining after a thinning operation, may also be specified. Thinning regimes obtained from FOREST have often doubled the PNW of plantations. FOREST determines the age of final harvest by maximizing soil rent, but longer rotations may be specified by the user.

REGEN: A MODEL FOR PROJECT ANALYSIS AND RESOURCE ALLOCATION IN REFORESTATION PROGRAMMING

This model is designed to find the set of reforestation activities which yield the plan of maximum PNW in a given year. This is done by defining the set of available alternatives and by representing mathematically the interaction of all alternatives in their use of common resources.

When a tract of land is reforested, the following alternatives are available: (1) the tract can be partially reforested, (2) the tract can be seeded or planted, (3) before seeding or planting, the site can be prepared in different ways, (4) planting or seeding can be carried at alternative densities, (5) the tract can be reforested from seeds or seedlings originating from different zone-elevation classes.

The first set of operations in REGEN determines the expected PNW of each available alternative, assuming all resources would be available to execute them. This is done from the yield functions resulting from FOREST (fig. 2), and from other data describing the characteristics of each tract available for reforestation (including location, brush cover, slope, area, site, current stocking, etc.), as well as the alternative reforestation techniques to be considered, and their respective cost. From these data REGEN determines the expected survival in plantations, and the expected PNW of each alternative. At this stage, a simple ranking of alternatives may yield the optimum program if no resource, or a single resource, is constraining. The ranking criterion used by REGEN may be PNW per acre, or PNW per dollar of available budget, or PNW per pound of seed or per seedling, depending upon the constraining resource. In general, however, several resources are constraining. The problem of determining the optimum reforestation plan then takes the form of a linear program

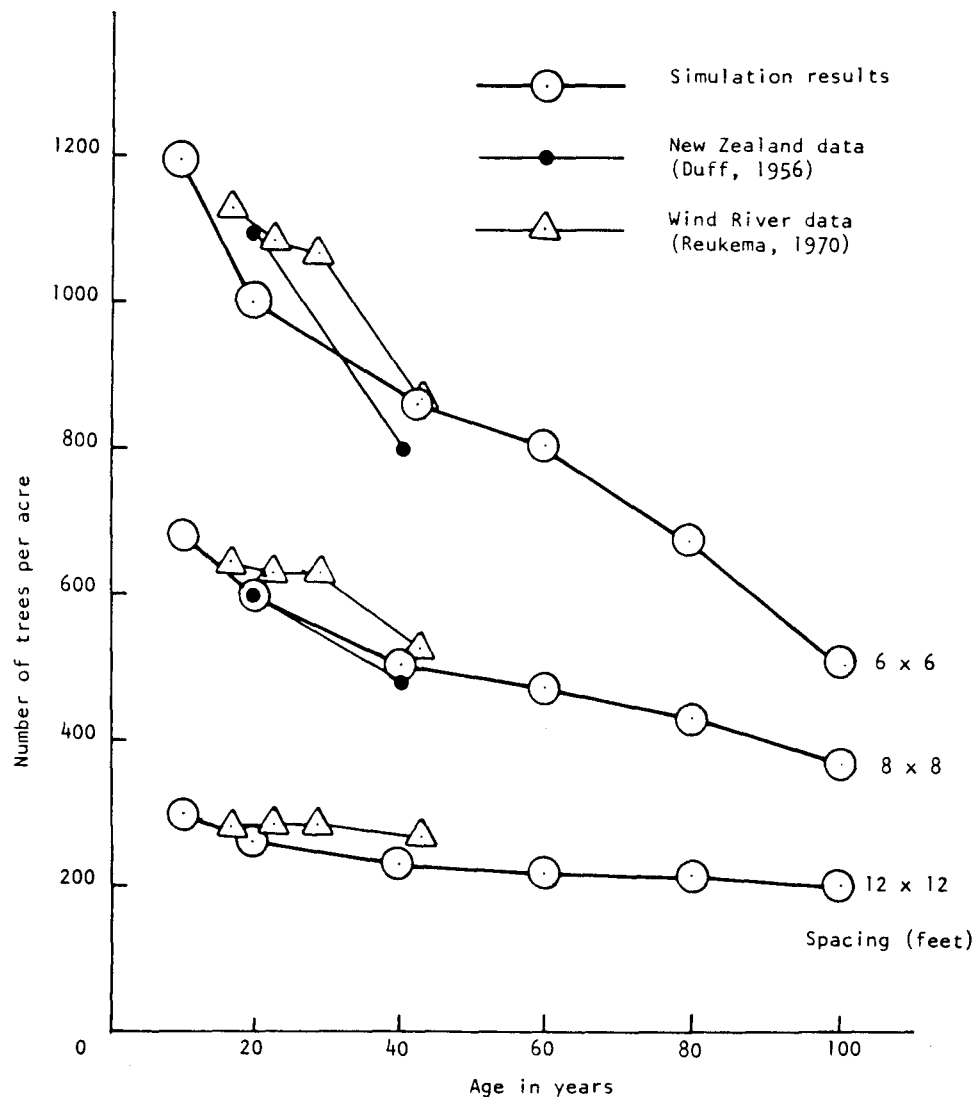


Figure 3. Predicted and observed survival in plantations.

in which the objective function is the total expected PNW of the plan, while the constraints specify that (1) the stocks of seeds and seedlings originating from each zone-elevation class, (2) the available budget, and (3) the land area on each tract cannot be exceeded. This large linear program is generated and solved automatically by REGEN, using user-supplied data on the amounts of resources available. The FINAL program lists all projects recommended for reforestation in the current year, method of treatment, seedling density or original spacing in plantations scheduled for hand planting, budget requirements, and quantity and origin of seed and seedlings stock.

CONCLUSIONS AND POTENTIAL FOR DEVELOPING COUNTRIES

It has been found in applications that the system presented here may yield reforestation plans whose PNW is 25% higher than what would be obtained by using simple ranking criteria (e.g., benefit/cost ratios). The gain with respect to traditional rules of thumb may be more important. However, such comparisons assume that the assumptions underlying the system, in particular the system of shadow prices used, are correct. The reforestation technicians liked the system's simplicity. In particular, it requires little input. A single data card is sufficient to describe each tract available for reforestation. Furthermore, the required input is readily available from reforestation records. Nevertheless, the system ran into implementation hurdles; the main one being that data were prepared by field foresters, while programs were run at headquarters. The availability of remote terminals at field stations should decrease this problem.

We believe that the basic methodology should find applications in developing countries. The program FOREST in particular should be useful in determining the economic effect of varying initial density in plantations, in computing economic thinning regimes and rotation ages, and in determining the economic feasibility of man-made forests. Naturally, the growth functions used in the program would have to be calibrated to reflect each specific site and species combination. Often this will require some informed guessing. The program REGEN may have more limited applications as it was tailored to the situation faced by the Bureau of Land Management in southwestern Oregon. In other reforestation projects, limiting resources may be very different; however, the principles of evaluating all alternatives and allocating resources optimally remain universal. Determining appropriate shadow prices for plantation products, interest rates, wage rates, and other inputs will be a very important step in a developing country, where market prices are unlikely to reflect adequately all the objectives of a reforestation project (FAO 1974).

Acknowledgments: Preparation of this manuscript was supported by the School of Natural Resources, University of Wisconsin, Madison and by the College of Natural Resources, University of California, Berkeley.

TRACT	ZONE-ELEV.	TREATMENT	DENSITY	AREA
XXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXXXX	XXXX
001	1	1	3	8.03
001	1	1	4	1.97
002	1	3	1	20.00
SEEDLINGS	FROM ZONE-ELEV.	1	QUANTITY =	1000.00
SEEDLINGS	FROM ZONE-ELEV.	11	QUANTITY =	2000.00
SEEDS	FROM ZONE-ELEV.	11	QUANTITY =	15.00
003	2	3	1	40.00
003	2	3	2	10.00
SEEDS	FROM ZONE-ELEV.	2	QUANTITY =	30.00
SEEDS	FROM ZONE-ELEV.	11	QUANTITY =	15.00
TOTAL AREA = 80.0				

Figure 4. Example of a small reforestation plan, as displayed by subroutine FINAL.

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Wood Transportation Systems-A Spin-Off of a Computerized Information and Mapping Technique

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Abstract: A computerized mapping system originally developed for planning the control of the spruce budworm in Maine has been extended into a tool for planning road network development and optimizing transportation costs. A budgetary process and a mathematical linear programming routine are used interactively with the mapping and information retrieval capabilities of the system to determine the allocation and association of wood sources and markets.

INTRODUCTION

In December 1975, a short term project (see Appendix) was completed that allowed the computerized mapping of locations and levels of spruce budworm infestation in Maine. This conformed to a sampling system employed by state officials whereby data on infestation was taken periodically by a series of sample units each equal to an area of approximately 600 acres. Each unit became the basis for a data (information) point and it became clear that the mapping routine offers potential well beyond its original intent. It is currently in use for the annual state budworm survey (Simmons and others 1976).

Besides the opportunity for additional informational overlays beyond budworm infestation indices, the relational properties of each unit to another possessed the potential to be mathematically manipulated, thus allowing location strategies of wood origins and potential markets to be correlated very accurately and rapidly. Transportation phenomena is the focus of the correlation. Existing road networks have been visually and mathematically related to data points. Specific requirements for new roads are integrated onto the overall system, and transportation and handling cost formula are available to interpret wood movements strategies in terms of a definable optimum. The system is designed to be open-ended in regard to this formulization so as to allow logical choices as to appropriate cost components. Algorithms for selecting applicable cost configurations depending on the trafficability of various road classes and/or transportation means (trucking or rail) have been developed within a framework of resource available and consumption requirements. Mathematical programming offered high potential for selection of

optimal transportation strategies. These strategies involved not only specifics on the movement of wood, but also priority criteria for the resource areas on which to concentrate harvesting efforts when large wood surpluses are in excess of short-term market needs.

The budgetary process as well as the mathematical programming routine is directly interactive with the mapping and information retrieval system, and is designed to be a sub-system to the overall system. Aspects of costing in any category of operating expenses for transportation or handling and those expenses relating to new roads can be included in the whole system and are relatable to data points. Existing road networks are known by the system and also referenced to specific data points where information on trafficability, etc., can be stored. Travel patterns are developed by summarizing data points between any combination of wood origins and wood destinations which are themselves merely data points. Preliminary estimates indicate that the accuracy in measures of various forms of distance exceeds the probable accuracy of maps from which data point references were established. New roads are hypothetically constructed between appropriate wood origins and existing roads by logical rules internally maintained by the computer system. Rapid and precise evaluations can then be made for given market transport possibilities when periodical levels and locations of available wood and of market requirements are offered to the system. Optimal strategies can be made available directly from this system, which allows ready updating of information on any data point and selection of modes in costing suitable to the planner.

The methodology suggested may well have wider application beyond Maine, possibly on a regional basis or for other state or provincial areas in North America. The techniques are structured so that implementation elsewhere can readily be facilitated and not necessitate a new total effort.

THE TRANSPORTATION SPIN-OFF

Since the spacial arrangement of wood origins, wood markets, and transportation networks can be determined from the data organized by map location, it is possible to automatically develop transportation routes from each wood origin (source) to each wood market (destination), where each of these is represented by a map data point. Transportation routes are developed so as to minimize transportation costs; they assume cost linearity (that is, the cost from A to C through B equals the cost from A to B plus the cost from B to C).

The transportation cost is composed of two elements--the cost of building new roads (or transportation networks) and the unit cost of transporting the material over the transportation network. New roads are generally costly both to build and maintain; therefore, in developing routes, a goal is to approach a minimum of new road construction. This is accomplished by a two-pass computer processing of source points. During the first pass, the closest road is located through an outward scanning of surrounding data points and the straight line distance to this road is calculated. The source points are then sorted for reprocessing such that those points closest to a road are processed first. During the second pass, another search for the closest road is made. When it is located, a hypothetical new road connecting the source point with the road

is added to the map road system by the computer program. This hypothetical road then becomes available to subsequent source point processing. Although this method does not necessarily yield an absolute minimum amount of new road construction, it should closely approximate the minimum.

With roads to each source point, minimum transportation cost from each source point to each destination can be calculated. Computer scanning of map data allows transportation networks to be followed. Starting from a destination point and successively adding the cost of transporting to all adjacent road points, a transportation cost to the destination is determined for all road points including all source points. Always extending from the least cost end first produces minimum cost values with a single scanning of road points. The cost of transporting to an adjacent point can either be based on a function of distance (as determined from the geometry of the area represented by a data point), or with known costs of traversing a particular area, can be uniquely specified for each point and thus can include trafficability factors-- e.g., road quality, average speed, and traffic load.

Following these methods, the cost of transporting from all source points to all destination points is determined. This information, combined with data on wood volumes available at each source and the requirements at each market, is fed into a linear programming transportation model to determine allocation and association of wood sources and markets.

BACKGROUND INFORMATION

The extent and importance of the wood-using industries in Maine can be summarized (for 1973) as follows:

- (1) Three out of ten Maine workers are employed in the wood-using industries.
- (2) The industries ranked first in value of manufactured product (1.3 billion dollars).
- (3) Eighty-six percent of Maine's land area is in commercial forests (17 million acres).
- (4) A total of 3.14 million cords of pulpwood was harvested, with 56% of this in spruce-fir. For sawlog harvest, the total was 354 million board feet, with 57% in spruce-fir.

Approximately one-third of the State's forest area is currently under the threat of spruce budworm devastation. The epidemic can be expected to produce high mortality, particularly in balsam fir and to a lesser degree in spruce, if adequate control measures are not forthcoming. Trees that succumb to the insects' attack must be harvested within a two- or three-year period or the physical deterioration of the wood will be too advanced to allow its commercial use. The timing of a planning effort becomes more critical considering that the area represented to be approaching an epidemic stage contains, at a minimum, a twelve-year supply at Maine's current wood consumption levels.

Under normal harvesting procedures, species present in a forest stand with fir and spruce, and not affected by the budworm, would also have to be removed with economical wood handling and transportation methods.

Preliminary study by the Corps of Engineers on the feasibility of a major hydroelectric project in Maine was begun this past year. The associated dam and its head waters will take out of production thousands of acres of Maine's timberlands. Agents of the Corps of Engineers have already contacted this investigator for estimates on the market potential of salvaged timber and for information on harvesting-transportation problems relating to the salvage. These estimates represent only preliminary appraisals; actual planning will eventually be required if the timber area is to contribute effectively to this State's wood resource requirements.

Considering the potential for an evaluation system such as those discussed here, at least three areas of immediate concern are benefited. These include planning in regard to wood flow within the region:

- (1) As typical yearly wood consumption patterns are encountered.
- (2) As wood surplus resulting from budworm devastation occur.
- (3) As timber area losses in hydroelectric development are considered.

The need to expand the opportunities for systematic evaluation of wood movement strategies is most timely as the concerns for wood utilization, especially in light of the budworm and the hydroelectric development, are and will surely remain key issues in the State of Maine, in New England, and in Eastern Canada for the remaining years of this decade.

Models developed from the proposed investigation are not intended to be useful solely in the shortterm, as suggested by problems like the budworm and developments that affect large forest acreages, nor will they necessarily remain local in the spread of their use. Their nature fully dictates that they can find application in the evaluation of transportation aspects inherent in marketing strategies of a long-term nature. The techniques utilized, if not the data structures, should prove of value to other regions as well.

PREVIOUS STUDIES

Past efforts of a statewide scope have proved fruitful in understanding wood distribution and the means thereof (Corcoran 1964, Schroeder and Corcoran 1965, Corcoran and others 1966). These particularly focused on truck-supported wood movements and included not only descriptive information but system planning pertinent to the times. Forest road location theory continues to be advanced (Ashley and others 1973, Corcoran 1973). Appraisals of the current situation are available in regard to enterprises that produce Maine's wood supply (Corcoran and Sarna 1973), to computer-based mapping routines (Phillips and others 1976) and to export market potential (Corcoran 1976). Wood movement strategies have also been explored in regard to general models

for regional applications (Holland and Judge 1962, Thompson and others 1968, Anderssen 1971) and to the budgetary planning of a single firm (Bartelheimer 1973, Sowell and others 1975, Newham 1975, Wimble 1975, Bailey 1973). Mapping by computer has found favor in recent years (Harding 1973, Nez 1971) especially for visual descriptions of use patterns, vegetative cover, and urban planning schemes. However, those for the most part were subjective in nature and have not taken advantage of mathematical potential inherent in a computer-based system. Numerous other works could be listed that are commonly known and well documented in established computer bibliographies on operation-research (Martin and Sudak 1973, Field 1974) and on the budworm itself (Corcoran and Simmons 1975). Information systems and decision theory have been explored by many authors within a workshop format (Stone and Ware 1971) and in a publication supporting needs for an information bank (Wolf 1970). Information systems pertaining to Maine have received international attention (Corcoran and Simmons 1976, Corcoran 1976).

APPENDIX

Effective planning for control of the spruce budworm in Maine requires knowledge of the distribution of the budworm as well as the condition and susceptibility of the trees in the areas of infestation. Currently, a hazard rating based on sample measurements of such factors as previous damage, current defoliation, tree vigor, and egg mass density is calculated for various localities throughout the state. A map of the state showing the location and hazard rating of each of the sampled points is prepared and areas of infestation are marked. These provide a visual indication of the distribution of budworm threat to the forests of Maine, and allow planning of such activities as spraying and salvage.

In order to facilitate the production of these maps, a computer program has been developed which will produce maps of the state on a computer line printer. The state is divided into small sections corresponding to the state fire control divisions. These sections are subdivisions of the U.S Geological Survey 15-minute quadrangle maps and are found by dividing each of the U.S.G.S. maps into 9 blocks and each block into 25 sections, each 1 minute by 1 minute. Thus a section is 1/225th of a U.S.G.S. quadrangle and covers approximately 591 acres.

A two-dimensional array is allocated within the program storage with each cell corresponding to one of the sections of the state. The section of the state in which the sample was taken, along with the data collected, is fed into the program. The rather complex designation of U.S.G.S. quadrangle, block, and section used in the field is converted by the program into a two-value designation indicating the row and column of the section within the state and thus the cell of the array corresponding to the location. This simplification allows adjacent cells to be easily determined and examined. The program calculates the hazard rating from the data and stores the computed value in the appropriate cell within the array. Both the array of computed hazard ratings and the original data for additions and further analysis can be saved.

From the data stored in the array, requests can be made to print all or portions of the state. Increasing integer digits indicate increased hazard value. Cells which fall inside the state boundary are distinguished from those that do not. This allows the portions of the state not sampled to be indicated by a printed character or characters while areas outside the state are void of such characters.

The size of the map produced may be varied by specifying a scaling factor. The smallest (largest scale) map produced uses one character to represent a single section. This map is approximately 27 inches wide by 34 inches long when the entire state is printed. Because the spacing on a printer is relatively fixed, the small map distorts the state slightly, making it an average of 14% wider than it should be. For most applications, this level of distortion presents no problems since a general feeling for spatial distribution is the primary goal. Specific locations can be determined from grid coordinates and the U.S.G.S. maps if required. The distortion can be virtually eliminated if a larger map is formed using multiple characters to represent one section. This could have the additional benefit of allowing more than one piece of information about a sector to be printed on a map. Any of these maps may, of course, be reduced to a more convenient size through photoreduction techniques.

Although the current program would only replace the manual system being used at present, several factors make this system more desirable. One is the speed with which maps can be produced. This will allow the production of preliminary maps as the data is collected. These could then be used to help define areas which require more sampling to delineate spray, salvage or other boundaries.

Another factor is the capability for future expansion existing in the system. Among some of the more interesting possibilities are extensions which would allow any specified linear combination of the current or previous year's hazard rating factors to be mapped. This could be used to compare visually the distribution of such factors as previous damage and current infestation level, which might provide insight into changing trends in infestation. Comparisons of linear combinations of current and previous year's samples might be used to refine the formula used to compute the hazard rating. Another possibility for extension is the inclusion of fixed information about a section. Such information as forest cover type might be used to modify the hazard rating. The inclusion of information on road networks and market locations would be used to determine the most economical and efficient salvage locations and transportation routes in the event of high losses.

A second potential capability is use of the system to display a variety of other forest-related surveys. Other forest insects and forest diseases could be mapped annually from annual survey data. Annual tree mortality data could be mapped as well as forest age data or, for that matter, any resource data base covering the state or portions of the state. Such a system might eventually form the basis of a general resource data base display system for the entire state of Maine.

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Optimal Control of Raw Timber Production Processes

Ivan Kolenka

Abstract: This paper demonstrates the possibility of optimal planning and control of timber harvesting activities with mathematical optimization models.

The separate phases of timber harvesting are represented by coordinated models which can be used to select the optimal decision for the execution of any given phase. The models form a system whose components are connected and controlled by means of information flows.

A mathematical model is presented for the optimal planning of harvesting activities for the forest enterprise. The use of a mathematical model contributes to the balancing of supply and demand, to the coordination of forest management plans with other activities of the national economy, and finally, to the minimization of production costs.

INTRODUCTION

Planning in Czechoslovak forestry has a long tradition, and is highly developed. The present stage of development of the society imposes demands on the planning and control of production processes in the form of requirements for maximum utilization of production sources and for meeting the demands of the society. In the process of planning and control it is necessary to follow the efficiency principle which states that (a) the planned yield must be obtained at the lowest cost or effort, or conversely that (b) the highest yield is to be obtained from given resources.

This type of planning and control requires a well-elaborated information and decision system, and the use of advanced techniques for the transfer and processing of information.

PROBLEMS

In this paper I shall deal with the processes of decision in planning and control of harvesting, and point out the possibilities of utilizing the optimization models of operational research for the selection of the planning alternatives.

The harvesting of timber, in the context of Czechoslovak forestry, represents a complex system and requires the solution of several problems. Each country has its specific conditions and requires a different approach to the formulation of the task. Generally, it is necessary to recognize that mathematical models cannot be based upon the principles of maximum utilization of the forest for this would result in the decrease of its permanent production capacity and would simultaneously affect the biological balance adversely. With long-term planning models it is necessary to consider this principle in the formulation of the mathematical model. In short-term models, this principle is observed by insuring that the forest management plan (decennial plan) is constructed so as not to allow the decrease of the production potential of the forest.

The harvesting of timber is divided into felling, gathering at landings, primary conversion (production of wood assortments), and hauling of timber. The structure of the harvesting process is illustrated in figure 1. Each stage of timber production is represented by coordinated models leading to the selection of the optimal decision at a given stage.

The models form a system of components connected by information flow in such a way that the output from one model represents an input into a "lower" model. To date some of the mathematical models have been used in planning (e.g., optimal control of timber hauling); others have been theoretically validated or are in the process of being tested.

MODEL FOR SHORT-TERM PLANNING OF HARVESTING ACTIVITIES

The model solves the problem of optimal scheduling of quarterly harvesting activities, and of controlling the management of the "gravitational" areas of forest enterprises. "Gravitational" areas consist of a collection of stands which form a contiguous area and which have approximately the same production conditions. The annual tasks in each stand are given by the forest management plan, and the sum of these tasks represents the annual tasks for the gravitational area.

The mathematical model for short-term planning of cutting activities must fulfill the following conditions:

- Coordinate sustained harvesting activities with the demand for timber assortments as specified by contracts between supplier and customers

- Recognize the limited availability of labor

- Take into account the capacity of landings with respect to the logging techniques available for gathering timber at landings

- Concentrate as much as possible the harvesting and the silvicultural activities in each gravitational area

Elaborate quarterly plans which minimize the costs of harvesting and of other management activities.

This task can be formulated as a linear programming model:

$$\text{Minimize } z = \sum_{ijk} g_{ijk} \cdot x_{ijk} + \sum_{ijp} r_{ijp} \cdot y_{ijp} + \sum_{ijl} u_{ijl} \cdot z_{ijl}$$

$$\sum_i x_{ijk} = a_{jk} \quad \text{for } j = 1, 2, \dots, n; k = 1, 2, 3, 4$$

$$\sum_{ip} y_{ijp} = b_j \quad \text{for } j = 1, 2, \dots, n$$

$$\sum_i z_{ijl} = c_{jl} \quad \text{for } j = 1, 2, \dots, n; l = 1, 2, \dots, g$$

$$\sum_j f_{ijp} \cdot y_{ijp} \leq F_{ip} \quad \text{for } p = 1, 2, \dots, m; i = 1, 2, 3, 4$$

$$\sum_j x_{ijk} \geq s_{ik} \quad \text{for } i, k = 1, 2, 3, 4$$

$$x_{ijk}, y_{ijp}, z_{ijl} \geq 0$$

Additional relations determining the levels of y_{ijp} must be specified to represent the particular types of management practiced.

Notation:

x_{ijk} - volume harvested of assortment k , in period i , from area j

y_{ijp} - timber logged in m^3 with method p , during period i , in area j

z_{ijl} - silvicultural activities l carried out during period i , in area j , expressed in various units (ha, km, etc.)

a_{jk} - annual volume requirement in m^3 for assortment k from area j

b_j - annual target volume logged--by all methods--in area j

c_{jl} - annual target for silvicultural activity l on area j

i - quarter of the year, $i = 1, 2, 3, 4$

j - gravitational areas, $j = 1, 2, 3, \dots, n$

p - kind of logging method, $p = 1, 2, 3, \dots, m$

- k - combination of the type of harvest and species group (e.g., final-coniferous: $k = 1$, intermediate-coniferous: $k = 2$; etc.), $k = 1, 2, 3, 4$.
- l - kind of silvicultural activities, $l = 1, 2, \dots, g$
- F_{ip} - available inputs for logging with method p in period i
- f_{ijp} - quantity of input per m^3 required to log with method p in period i and area j
- s_{ik} - total volume required by the sale plan in quarter i for the k th combination of type of harvest and species group
- $g_{ijk}, r_{ijp}, u_{ijl}$ - coefficients of objective function, giving the costs for technical unit according to the kind of silvicultural activity

Because the planning problem has been specified as a linear program, it is relatively easy to solve it with a computer, in spite of the large dimension of the linear program required under real conditions.

The planning problem is specified as a deterministic model in spite of the stochastic characteristics of forest production. This shortcoming of the model may be compensated for by solving the model for various values of the coefficients of the LP matrix or of the objective function.

A mathematical model requires information which can be divided into technical and economic parameters. The technical parameters include the knowledge of possible technological alternatives for work procedures, available resources or capacities and scheduled means of production. Economic parameters represent data on costs which vary with the location of the activity and its technical characteristics.

To obtain all the necessary information for the model usually requires changes in the information system. Our present experience indicates that the information system must be developed concurrently with the mathematical model.

CONCLUSION

The use of this mathematical model contributes the following positive elements to planning:

It balances the requirements of production and technical means and workers available

It balances the sources of wood, with the wood assortment requirements of the national economy

It coordinates the distributing of production over time with the requirements of national economy

It realizes the plan specification at minimum costs

The results which we have obtained establish the possibility of planning and controlling production in forestry. These results also indicate that by using operations research models, planning and control can be made more effective.

Large-Scale Budget Applications of Mathematical Programming in the Forest Service

Malcolm Kirby

Abstract: Mathematical programming applications in the Forest Service, U.S. Department of Agriculture, are growing. They are being used for widely varying problems: budgeting, land use planning, timber transport, road maintenance and timber harvest planning. Large-scale applications are being made in budgeting. The model that is described can be used by developing economies.

INTRODUCTION

Two modern techniques of optimization that can be applied to complex resource problems are ADVENT (Kirby and others 1976) and the Eldorado model (Bell and Kirby 1971; Kirby 1971a, 1971b). They are so closely related that it is convenient to refer to both as "the model." The basic premise is that land management requires more than one input (men, money) and usually results in more than one output. The model uses linear programming to handle trade-off relationships and to evaluate the effects of imposing or relaxing levels of inputs, outputs, or both. The management objectives for the model were to prepare a budget request relating outputs to inputs; and once funds are allocated, to select projects that will either meet a set of output goals at minimum cost or will maximize a selected output (Bell and Kirby 1971).

Traditionally, work planning in the National Forests was based on specific resource functions: timber, range, recreation, watershed, etc. Each function used its funds to maximize specific outputs. Through so-called "multiple use" coordination, the effects of one function on another's outputs were considered but seldom explicitly evaluated. But the model does this explicitly, and this is what makes some managers uncomfortable with it. It requires that goals be stated in specific terms: animal unit months (AUM) of forage rather than acres reseeded; cubic feet of timber produced rather than acres planted; specific effects on all outputs as a result of building a road: rather than miles of road built.

A list of outputs from a typical National Forest include timber, recreation, water, wildlife grazing, and livestock grazing. In addition, there are

miles of spectacular scenery, numerous lakes, miles of fishing streams, wilderness, power houses, summer homes, ski resorts, irrigation canals, roads, trails, dams, pipe lines, organization camps, and other sundry special uses such as a temporary high altitude training camp for the Olympics.

National Forest planners are faced with three limitations: limited land, limited funds, and pressures for fulfilling the needs of an ever-increasing population. The planning problems are very complex. Goals include meeting the demands for outputs and maintaining the local economies, maintaining a trained work force, and maintaining the productivity of the larva.

Work done on National Forest lands requires multiple inputs--land and money (let money here represent tools, equipment, supplies and manpower). These inputs result in multiple outputs--forage, water (both quantity and quality), soil stability or erosion, camping, picnicking, fishing, hunting, timber growth, and timber cut. There are also more nebulous outputs (or effects) such as aesthetics, fire risk, air quality, and so on. These effects vary depending on the productive capability of the land, the primary purpose of the work being done, the methods used, and the spatial position of the land being treated.

The model is used for preparing proposals either for one or more future fiscal years or for the fiscal year that is about to begin. It is now being used for both budgeting and long-range planning at the local and national levels. We have also used ADVENT for trade-off analyses in land use planning, where long range timber yield considerations are not important.

The model is designed to generate a large number of feasible alternative programs. The design criteria are that the model be multiple-output oriented, able to generate alternative programs that are feasible, able to report the future implications of various alternatives, and able to generate optimal alternative programs on the basis of output-oriented criteria.

PROBLEMS IN INPLEMENTATION

Some of the problems in implementing such a model are these:

People: To begin with, when you say, "here is a better way to prepare a budget request," you have insulted those who have been following another system for a number of years. They have two reactions: "What's wrong with the way we've been doing it?" and "Show me."

Data: The amount of data needed for a complex mathematical model is formidable. Everything must be reduced to numbers.

Goals: They must be specific and quantifiable; narrative statements cannot be used. The manager may have to use hunches in interpreting the results, but the model cannot.

The people problem is very real. There is a generation gap between the top managers and a fast-growing group of mathematicians and economists. Managers

are not used to thinking in terms of abstractions. It behooves both the teachers and the practitioners to take the time and effort to strip away the mystery, interpret the jargon into terms that can be understood, forget the theory, and show by actual examples what is meant. If we seem to labor this point, it is because we fear that if young people, exposed to new methods and techniques, do not recognize the problem, they will be frustrated when their ideas are not received with enthusiasm.

The land manager can have faith that these models work with great mathematical accuracy. However, he should scrutinize the figures, make sure they are correct, and test the final answers on the basis of reasonableness.

What about data? After all these years of research, we do not have all the information needed. For example, we have fairly reliable information as to the effect of a specified thinning regime on the volume growth of timber over time, when we know the site class. What we do not always know is the effect of the thinning on the forage output for domestic or wild grazing animals, or the effects on water runoff, or the tons of fuel per acre resulting from one thinning operation, or whether leaving the slash on the ground is more beneficial for protecting the site than it is detrimental as a fire hazard. During the development of the Eldorado model, we reviewed nearly a thousand research papers and found less than 20 that were helpful in assessing effects on more than one output.

What about goals? Traditionally managers set goals in rather general terms--for example: meet the allowable cut, thin 1,000 acres, eradicate 500 acres of sagebrush, build 5 miles of fence. The model requires goals that are related directly to outputs such as cubic feet of timber growth, AUM's of forage produced, or tons of soil per acre that would remain in place if a protective fence were built. Specific goals such as these are very difficult to set. The output goals that we considered included the following:

Timber Cut	Water Quality
Timber Growth	Soil Stability
Timber Regeneration	Recreation Environment
Livestock Grazing	Recreation Visitor Days
Wildlife Grazing	Fire Hazard Reduction
Water Runoff	Fire Accessibility

The manager who is comparing two alternative forest-wide programs can scan the computer printouts and decide if one program is better or worse than the other and if the increase in output is worth the decrease in some other output. Inasmuch as output information is limited at this time, he cannot make his decision on the basis of actual physical outputs alone.

BASIS FOR DECISIONS

Some managers are uncomfortable with the model because there is no single criterion that indicates the "best" choice. To overcome this drawback some economists suggest converting everything to dollars and selecting projects based on benefit/cost ratio, or present worth, or internal rate of return, etc. This approach would be ideal except for four problems:

Difficulty of measuring all of the desired outputs for each project
Difficulty of assigning dollar values to all of the outputs
The specific statement in the "Multiple Use Sustained Yield Act" that the management of National Forest lands is not to be based upon the highest dollar return
The non-uniqueness of dollar values which give the same answer

There are many kinds of values--for example, market value, consumer value (a willingness to pay), producer value (the cost to produce), increasing gross national product, monopoly revenue value, and expenditure value. Whaley (1968) defines six different value methods. he points out that the value system must be appropriate for the model, must use the same method for achieving values for all outputs and must allow the values to be empirically quantifiable. The point is that since so many different kinds of values exist, the absence of a value system means the choice of method for valuing outputs can be rather arbitrary. To date, such a system has not been adopted for the Forest Service.

What then is the basis for decisions? Again, Whaley (1966) lists four measures of program effectiveness which may be used in public resource management: meet established production goals at least cost, establish the budget level and maximize some outputs, claim that no rational solution exists (we don't make this claim!), and maximize economic development. The Annual Budget Model and ADVENT were designed for using any of these measures. Therefore, when values for outputs are developed, by any value system, they can be easily employed in the model. Regardless of the manager's value systems, he still needs alternative programs from which to choose, and the model makes it easy to generate alternative programs. The models simply process information, bringing into focus the sociological, economic, and organizational consequences of alternative decisions. The final selection rests with the land managers and Congress, who must weight the socio-economic and political impact of their decisions.

The linear programming part of the model can carry out the following steps:

- (1) determine whether or not the problem can be solved
- (2) if it is solvable, give an optimum solution
- (3) allow constraints of outputs, money, manpower, activity types
- (4) maximize an output for, a given budget or, provide a specified output level at minimum cost
- (5) provide a budget which includes all the costs of the various projects

ADVENT also has a goal programming option to minimize the deviations from a set of goals or "targets".

The model has reporting capabilities to transform the original data into a series of abbreviated reports or complete reports as desired by the manager. Information available for each solution includes manpower, needs by skills, by sub-units; money needed; list of projects selected; and list of total outputs.

One of the drawbacks, in the opinion of some managers, is that using it requires that more work be planned than there will be money to do. This represents extra effort which in times of tight budgets seems useless. Extra projects must be provided or there is no choice. Another drawback is that the

time frame of 1 year is too short. This is admittedly a disadvantage, but budgeting, particularly fund allocation, is a year-to-year process. As already pointed out, there is a shortage of estimates of multiple outputs and "relative effects" are an unfamiliar substitute. The model requires that goals be set in quantitative terms. This has proved difficult at first.

Positive advantages of the model are that it considers the joint effect of inputs on outputs; it gives the manager a tool to explore a series of alternatives; and it focuses attention on specific measurable goals rather than broad overall objectives.

NUMERICAL EXAMPLE

To illustrate how the model works, let us consider a small hypothetical numerical example of eight projects, as follows:

Item	1	2	3	4	5	6	7	8
Land management and administration:								
Expenditures (million dollars)	2	3	3	2	4	2	4	4
Manpower (man-years)	100	100	100	50	300	100	100	100
Road construction and maintenance:								
Expenditures (million dollars)	7	6	3	1	1	3	2	3
Manpower (man-years)	200	100	100	100	100	200	100	100
Timber-, for the next decade:								
Average annual cut (1000 bd. ft.)	8	9	8	7	5	4	5	2
Average annual net growth (1000 bd. ft.)	9	9	8	7	6	5	5	3
Benefits and costs:								
Total value of output (million dollars)	28	27	15	6	9	8	8	7
Total expenditures (million dollars)	9	9	6	3	5	5	6	7
Administrative priority rating:	1	1	2	3	5	4	5	5

Suppose we wish to select a project mix that meets the following specifications:

- (a) Include project 1 because it is already under contract
- (b) Include all projects with priorities 1 and 2
- (c) If project 7 is included, project 8 must also be included, and vice versa
- (d) Do not permit both projects 5 and 6: one or the other, but not both (they are close substitutes)
- (e) Achieve a minimum level of timber growth of 4;
- (f) If there is a tie, then choose the combination of projects that minimizes total land management costs

(Note that in addition to constraining the level of individual inputs and outputs, or their combinations, the user can control individual projects or their combinations).

The solution is as follows:

Project No.:	1	2	3	4	5	6	7	8
Percentage:	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes

The solution is presented below in the format of one of the 22 reports which can be prepared with ADVENT. Both the input data and the information contained in the LP solution can be displayed in these reports. The user can also employ ADVENT in a pure simulation mode by selecting a set of projects on the basis of experience and intuition, and call for a report detailing the corresponding costs, revenues, outputs, activities, manpower requirements, etc.

ADVENT report corresponding to the LP solution of the numerical example

*** PROJECTS SELECTED ***

AGGREGATE WORK/ACTIVITY DESCRIPTION	AMOUNT
.....	
PLANTING & SITE PREPARATION	600 ACRES
SLASH REDUCTION	1,000 ACRES
PRECOMMERCIAL THINNING	400 ACRES
TIMBER SALES PREPARATION	2,000 ACRES
ROAD MAINTENANCE	300 MILES
ROAD CONSTRUCTION	75 MILES

AGGREGATE OUTPUT DESCRIPTION	AMOUNT
.....	
DISPERSED RECREATION USE	20,000 VISITS
TIMBER HARVESTED	80,000 MBF
TIMBER SOLD	85,000 MBF
WILDLIFE HABITAT IMPROVEMENT	5,000 ACRES
VALUE OF TIMBER HARVESTED	47,000,000 \$

AGGREGATE COST DESCRIPTION	AMOUNT
.....	
TOTAL EXPENDITURES	50,000,000 \$
TOTAL ROAD CONSTRUCTION & MAINTENANCE	25,000,000 \$
TOTAL LAND MANAGEMENT & ADMINISTRATION	25,000,000 \$

MATHEMATICAL FORMULATION

For the reader interested in the mathematical formulation we present a simplified version of the linear programming problem.

maximize $\sum_j d_j x_j$ subject to:

$$\sum_j a_{ij} x_j \geq f_i, \quad i = 1, 2, \dots, I,$$

$$\sum_j c_{kj} x_j \leq b_k, \quad k = 1, 2, \dots, K,$$

where:

$x_j = 1$ if the project is selected and zero otherwise

a_{ij} = amount of the i th output per unit of x_j

c_{kj} = amount of the k th input per unit of x_j

f_i = constraint on the total amount of the i^{th} output

b_k = constraint on the total amount of the k^{th} input

I is the set of output categories

K is the set of input categories

and where d_j may be chosen as

a_{ij} if the i^{th} output (e.g. timber growth) is to be maximized

or

$-c_{kj}$ if the k^{th} input is to be minimized

or

$-\sum_{k \in K^*} c_{kj}$ "here K^* is a subset of commensurable inputs such as costs or manpower

The term d_j may also be specified as the discounted or undiscounted total net revenue.

Note that the problem is formulated as an integer program, but it is solved, by means of a linear programming routine. The reason is that the solution generally turns out to be an excellent approximation to the integer solution, and the computer time is very short compared to the time required to solve the corresponding integer program. It is this feature that makes ADVENT a practical tool for widespread use. A discussion of why these approximations work as they do may be found in McConnen and others

CONCLUSION

ADVENT can be used by developing economies for both budgeting and long range planning. It has been tested in many different uses, over more than 4 years, by more than 50 organizations. The model's flexible design permits other planning applications such as road maintenance, capital investment analysis, project selection and other trade-off analyses. It is designed for use by relatively unskilled users of computers. The cost of a typical computer run, for 400 projects, is about \$50.

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Forest Management Planning for Timber Production: A Sequential Approach

Krishna P. Rustagi

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

INTRODUCTION

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

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

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

UNCONSTRAINED OPTIMIZATION

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

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

Where

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

R = current value upon harvest

i = interest rate

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

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

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

CONSTRAINED OPTIMIZATION

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

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

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

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

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

THE SEQUENTIAL APPROACH

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

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

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

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

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

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

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

Long-Range Plan (Reforestation)

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

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

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

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

Short-Range Plan (Harvest Schedule)

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

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

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

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

DISCUSSION

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

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

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

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

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

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

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

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

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

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

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A Two-Phase Method for Timber Supply Analysis

Stephen Smith

Abstract: There is an increasing need to clarify the long-term wood supply implications of current harvesting rates. To assess the wood supply and to set timber production objectives, different linear programming techniques are applied to the short and long term. The transportation method is applied to the short term and the B. C. Forest Service computer-assisted resource planning method is applied to the long term.

INTRODUCTION

Of all the decisions facing forest policymakers, probably the most critical, because of its economic importance, is the rate at which timber is to be made available for harvesting. The timber-producing base is diminishing through increased recognition of an array of legitimate non-timber users, through environmental protection measures, and through changes in the economics of logging. The nature of the productive forests is changing from unmanaged large old-growth to young-growth forests whose products will be smaller and in different proportions by species. In this changing world the British Columbia Forest Service must maintain a continuing wood supply to support a healthy competitive forest industry and ensure the productive integration of land uses. All these factors generate an increasing need to clarify the long-term wood supply implications of present timber harvesting rates.

In 1976 the Royal Commission on Forest Resources (Pearse 1976) recommended changes in the current methods of timber yield regulation. In particular it recommended that yield controls should (1) apply to Timber Supply Areas (TSA's) serving manufacturing areas and communities, (2) recognize log supply patterns and transportation facilities within the timber supply area, (3) embody reasonable expectations about future trends in forest growth and values, and (4) recognize the uncertainty surrounding long-term forecasts. This paper describes a small part of the response by the British Columbia Forest Service to these recommendations.

TIMBER SUPPLY AREAS

Within the regions of the Province, timber supply areas can be identified which serve manufacturing areas and communities. The supply areas have largely evolved from establishment of forest industry and the development of associated communities. Insofar as public policy is to be directed toward supporting the income and employment base of forest-dependent communities, yield controls must be designed to apply to the relevant timber supply areas. There should be some flexibility in setting short-term harvesting rates, together with a mechanism for clearly showing their long-term implications for the future wood supply.

TWO-PHASE METHOD

To meet the described requirements for revised yield controls, the approach has been to separate the relatively short term (the next 20 years) from the very long term (about two rotations). In defining timber production objectives over the 20-year horizon, the Forest Service must ensure that the short-term rate of cut will not result in an unacceptable decrease in the future wood supply. Accordingly a practical, conceptually simple process consisting of two phases has been developed, from which timber supply area wood production goals can be derived.

Phase 1 (Short Term)

Develop and describe 20-year production goals in the form of a simple wood flow plan. The plan describes a feasible, efficient movement of wood from the different localities within the timber supply area to the different broad industrial sectors. In practice this 20-year "look ahead" would be used to set 10-year objectives. The 10-year production objectives are to be reviewed every 5 years.

Phase 2 (Long Term)

Determine the projected timber production curve over one or two rotations for the entire timber supply area, setting the overall cutting rate for the first two decades equal to that developed in phase 1.

If the results of phase 1 cause the long-term rate of cut to drop below the 90% of the long-run sustainable yield, then phase 1 must be modified until it is in harmony with the long term goals.

FORMULATION OF THE SHORT-TERM ANALYSIS

The supply area can be described as a network in which there are localities (supply points) supplying industrial sectors (demand points). The 20-year horizon can be divided into four 5-year periods. Each supply point has an inventory of accessible, usable timber; each demand point has a minimum

demand to be satisfied and a physical capacity which cannot be exceeded. The objective is to select, for the duration of the horizon, a routing plan which satisfies all the demands, does not exceed the supplies and physical plant capacities, and attempts to maximize the value of the routing plan.

One formulation of the problem is given below:

Maximize $\sum_{ijk} r_{ijk} x_{ijk}$

Subject to the demand constraints:

$$\sum_j x_{ijk} \leq D_i \quad \text{minimum total sector demands over the 20 year horizon} \quad (1)$$

$$\sum_j x_{ijk} \geq M_i \quad \text{maximum total sector demands over the 20 year horizon} \quad (2)$$

$$\sum_j a_{ijks} x_{ijk} \leq SD_{iks} \quad \text{maximum sector demand by species and time period} \quad (3)$$

where - $SD_{iks} = \sum_k P_{ik} g_{iks}$

$$\sum_j x_{ijk} \leq P_{ik} \quad \text{minimum total demand by sector i in time period k} \quad (4)$$

and subject to the supply constraints:

$$\sum_{ijk} x_{ijk} \leq T \quad \text{total wood supply} \quad (5)$$

$$\sum_{ijk} x_{ijk} \leq S_j \quad \text{total wood supply for each management unit} \quad (6)$$

$$\sum_i x_{ijk} \leq MS_{jk} \quad \text{wood supply for each management unit in each time period} \quad (7)$$

$$\sum_k x_{ijk} \leq SS_{ij} \quad \text{total supply available to sector i from management unit j over the 20 year horizon} \quad (8)$$

x_{ijk} = volume of wood allocated to sector i from management unit j in time period k

r_{ijk} = value of a unit of wood allocated to sector i from management unit j in time period k

D_i = total minimum demand for sector i over the 20 year horizon

M_i = total maximum demand for sector i over the 20 year horizon

P_{ik} = maximum demand for sector i in time period k

a_{ijks} = proportion of species s in a unit of wood from management unit j which can be used by sector i in time period k

SD_{iks} = maximum demand by sector i for species s in time period k

g_{iks} = the average proportion of species s used by sector i in time period k

PD_{ik} = minimum total demand by sector i in time period k

T = total wood supply in the supply area available for cutting in the next 20 years

S_j = total wood supply in the j th management unit available for cutting in the next 20 years

MS_{jk} = total wood supply from management unit j in time period k

SS_{ij} = total supply available to sector i from management unit j over the 20 year horizon

$i = 1,5 \quad j = 1,10 \quad k = 1,4 \quad s = 1,6$

LONG-TERM ANALYSIS

Obviously it is not sufficient to allocate existing mature timber inventories from the management units within the supply area, without looking at the long-term consequences for the supply area as a whole. Use of a subset of the Computer Assisted Resource Planning System (Williams and others 1975) allows calculation of a long-term production curve for the entire timber supply area, constrained for the first two decades to the harvest level set in the short-term calculation. In this calculation the harvest scheduling formulation is that produced by Timber-RAM (Navon 1971).

APPLICATION OF THE METHOD

After assessing present and projected industrial demands and the net timber supply, a simple question-and-answer sequence can be followed to arrive at a set of timber production goals. Those questions, in the order that they are addressed in the process, are:

Can the present cutting rates be maintained over the next twenty years?

What effect will maintenance of the present cutting rate have on long-term timber supply?

What are the projected increased industrial demands over the next twenty years and can cutting rates be raised to meet them?

If increased demands can be met over the next twenty years, what will be the effect on the long term supply?

The method also has the following capabilities:

Likely periods of scarcity for a particular industrial sector can be highlighted.

Areas that have to be developed by a certain time to meet wood supply needs can be pinpointed.

The effects of changing sector demands on the wood supply picture can be predicted.

The effects of changing the log supply pattern on the wood supply picture can be predicted.

A starting point is given for long-range strategies to ameliorate impending wood supply problems if they are indicated.

RELATING TO NONTIMBER RESOURCE USES

An initial wood supply analysis provides valuable input to determining overall resource use policy. With this information "out on the table" other resource managers can participate effectively in the development of alternatives for a timber supply area and, later on, for a complete region.

Once alternatives are developed which express the needs of other resources, one can be chosen by the decisionmakers, or additional alternatives can be prepared prior to the decision.

RESULTS OF THE PROCESS

Tables and graphs are generated showing planned rates of harvest for the timber supply area in each of the next four 5-year, periods. Planning harvest rates are broken down by management unit and industrial sector.

For the long term, graphs and tables are generated allowing an assessment of the long-term wood supply which will result from implementing the 20-year harvesting plan.

These results enable the Forest Service to set timber production objectives and are a starting basis for the development of associated reforestation and silvicultural goals.

The method outlined in this paper is part of the Forest Service planning system (British Columbia Forest Service 1978).

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Timber Management Planning with Timber RAM and Goal Programming

Richard C. Field

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

INTRODUCTION

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

Timber RAM

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

can also produce a matrix for solution by Univac's linear programming package ILONA. Earlier versions of Timber RAM are available for CDC and IBM computers.

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

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

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

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

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

Goal Programming

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

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

METHODS

Timber RAM Input

Forest Data

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

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

Problem Constraints and Decision Criteria

The National Forest Management Act of 1976 and current Forest Service policy may be interpreted as prohibiting any harvest greater than the long-

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

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

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

Matrix Alternatives

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

Alterations during Matrix Generation

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

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

Alterations after Matrix Generation

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

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

Goal Programming Formulations

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

The second GP formulation minimized the sum of the deviation from the total volume goal and the deviations from each periodic volume flow goal. The original right-hand side of the constraint equation was used as the goal for

each periodic flow. Thus, the objective function included the underachievement of the current cut by the harvest in the first period, the underachievement of the previous harvest by each subsequent harvest during conversion, the overachievement of the long-term average by the last harvest in conversion, and the over- and under- achievements of the long-term average by each post-conversion harvest. Variations in flow goals and economic goals, with a variety of weights, were tested only on the small problem.

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

RESULTS

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

Linear Programming Solutions

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

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

Goal Programming Solutions

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

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

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

Postoptimal Solutions

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

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

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

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

CONCLUSIONS

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

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Analytical Aids in Land Management Planning

David R. Betters

Abstract: Quantitative techniques may be applied to aid in completing various phases of land management planning. Analytical procedures which have been used include a procedure for public involvement, PUBLIC; a matrix information generator, MAGE5; an allocation procedure, linear programming (LP); and an input-output economic analysis (EA). These techniques have proven useful in the development of land management plans for a number of National Forests in the United States.

INTRODUCTION

The typical planning process used for developing land management plans follows a sequence of several phases. Although this overall process might be described in many ways, the major steps, shown in detail in Table 1, are (1) the identification of issues and objectives, (2) the development of the resource system and management options, (3) the analysis of tradeoffs, with the decision and feedback.

Various quantitative techniques may be applied to aid in completing these basic phases. The Systems Application Unit for Land Management Planning (SAU-LMP) of the Forest Service, U.S. Department of Agriculture, has utilized several types of analytical procedures in the successful development of land management plans for National Forests in the United States. Specifically, those used most often by SAU-LMP are a procedure for public involvement, abbreviated PUBLIC; a matrix information generator, called MAGE5; an allocation procedure, known as linear programming, LP; and an input-output economic analysis, called EA.

Table 1--The land management planning process

<u>Systems Approach Terminology</u>	<u>Major Phases</u>	<u>Detailed Phases</u>	<u>SAU-LMP Analytic tools</u>
	I. ISSUE IDENTIFICATION	<u>Pre-Plan Organization</u> -Establish time frame for plan -Establish personnel requirements for plan -Define degree of public involvement	
Set Objectives	II. FORMALIZATION OF PLANNING	<u>Identify Issues and Set Objectives</u> -Define critical issues and their source -Define assumptions concerning decisions environment -Define hierarchial set of goals -Define criteria to be used to test performance	PUBLIC
System Design	III. DEVELOPMENT OF ALTERNATIVES	<u>Define Resource System</u> -Stratify land base to address issues -Designate management options -Define resources and products <u>Define the Responses</u> -Identify information needs, sources of information and detail necessary -Determine resources and economic responses to manage activities	MAGE5
System Analysis	IV. ANALYSIS OF TRADEOFFS AND FORMULATION OF A RECOMMENDED	<u>Analyze the Resource System</u> -Define the processes to be used in analysis -Generate alternative management strategies -Define tradeoffs between strategies -Develop a scenario to describe tradeoffs -Test each alternative in terms of meeting criteria of performance	LP EA

Decision and
Feedback

Decision

- Select a preferred alternative
- Prepare a written plan directive and draft impact statement

Feedback

- Describe procedures for monitoring plan implementation and revision when necessary
- Insure tasks are carried out effectively and efficiently
- Insure work plans are developed

PUBLIC

PUBLIC is the procedure used during the issue-identification and objective-setting phase to make quantitative estimates of public preferences and of conflicts among those preferences (Case and others 1976). The program is used at public workshops where the participants are asked to rank ordinally the uses of various National Forest resources from what "should be most emphasized" to what "should be least emphasized." PUBLIC is then used to analyze this input, to estimate agreement and disagreement in the total group, and to determine the least disliked priority ranking of Forest resource uses. The program constructs this ranking by creating an array of responses which indicate the "votes" for each preference. Then through a process of elimination, it assigns preferences to an order on the base of whether a use preference receives either the majority of first-place votes or the majority of the "most disliked" votes. At the same time the procedure identifies subgroups which seem to have like interests or preferences. A statistical procedure, factor analysis, is used to subdivide the respondents into these subgroups. An estimate of the level of agreement within these subgroups is measured by the Kendal Concordance Coefficient. This is a statistic which generates on a scale of 0 to 1 a measure of subgroup agreement, 1 representing total agreement and 0 total disagreement.

This type of information is useful during the workshop session to group participants with like interests so they can work on specific alternative descriptions and resource-use levels or requirements. The procedure also supplies information which is useful for many different types of analyses to be conducted later, including comparisons of local preferences to overall regional preferences, comparisons of U.S. Forest Service staff preferences to local preferences, and analysis of public perception of agency priorities. Further, and most importantly, PUBLIC helps develop the type of public involvement information necessary to construct alternatives for analysis in subsequent phases of Forest level planning. The following table shows an ordering arrived at by means of PUBLIC:

<u>Overall ordering entire workshop</u>	<u>Subgroup 1</u>	<u>Subgroup 2</u>
Wildlife	Watershed	Wilderness
Scenic beauty	Range	Scenic Beauty
Dispersed Rec.	Timber	Dispersed Rec.
Watershed	Wildlife	Wildlife
Timber	Dispersed Rec.	Range
Developed Rec.	Developed Rec.	Developed Rec.
Mineral Extraction	Mineral Extraction	Timber
Wilderness	Wilderness	Mineral Extraction

The preference patterns shown could be used to develop strategies which might be described in scenario form as:

Strategy 1 (Overall ordering): Emphasize wildlife, scenic beauty, and dispersed recreation, with less emphasis on watershed, range, and timber, and give low priority to developed recreation, mineral extraction, and wilderness.

Strategy 2 (Subgroup 1): Emphasize watershed, range, and timber, with less emphasis on wildlife, scenery, and dispersed recreation, and give low priority to wilderness, mineral extraction, and developed recreation.

Strategy ; (Subgroup 2): Emphasize wilderness, scenic beauty, and dispersed recreation, with less emphasis on wildlife, watershed, and range, and give low priority to timber , mineral extraction, and developed recreation.

These strategies could be used as part of the basis for construction goals and priorities for a Forest plan.

MAGE5

The next planning phase involves defining various aspects of the resource system. This phase of planning employs both the information concerning use preferences described above and information concerning the land base, to construct specific management options and resource uses for each of the management strategies previously identified. Once the management options have been determined, the consequences of each on the environmental resource, and the economic responses, must be defined. The U.S. Forest Service uses MAGE5, a matrix generator, to help the planner identify, develop, and store the necessary bits of information (U.S. Dep. Agric., Forest Serv. 1973). Since most plans cover a planning horizon of several years, one of the most significant benefits of using MAGE5 is that it allows for the time factor and attendant time changes in developing the appropriate dynamic data for the matrix. MAGE5 uses a concept called "timestreams" to adjust resource uses, benefits, and costs to changes which occur with time; it automatically constructs a matrix whose coefficients reflect this time dimension.

For example, suppose that the planning horizon is ten years subdivided into two periods of five years. A management option involving timber harvest might be applied either during the first period or during the second period. The values calculated for MAGE5 for the matrix rows and columns are as follows:

	Present condition	Management option involving timber harvest applied in	
		First period	Second period
Average sediment/ha/yr in the first period	0.4	0.64	0.4
Average sediment/ha/yr in the second period	0.4	0.68	0.64

Since the sediment yields are constant under present conditions in this land area, the average yields in each period are 0.4 cubic meter per hectare per year provided nothing changes. The average values for sediment yields where timber harvest is involved assume that the application of the option to an acre might occur at different years in the period. For example, the timber harvest might take place in any one of the five years of the first period. The various possibilities and the subsequent timestreams for sediment yield per year during the first period are as follows:

Option applied in	Year 1	Year 2	Year 3	Year 4	Year 5
First year	0.8	0.8	0.8	0.8	0.8
Second year	0.4	0.8	0.8	0.8	0.8
Third year	0.4	0.4	0.8	0.8	0.8
Fourth year	0.4	0.4	0.4	0.8	0.8
Fifth year	0.4	0.4	0.4	0.4	0.8

Note that if the option is not applied until a later year in the period, the present condition yield of 0.4 applies to all preceding years. The average value 0.64 for the sediment yield in the first period is the sum of the possibilities divided by their number, or $16/25 = 0.64$. The other matrix entries are calculated in a similar manner, with the timestream depending on what period is being considered.

This concept is used to develop average yearly values for resource uses or commodities and for costs and benefits. These values are stored in a matrix format which can be utilized along with other tools, such as LP, which are used in later phases of the planning process.

LINEAR PROGRAMMING AND ECONOMIC ANALYSIS

Once the phases described so far are completed, the next step in the planning process is to analyze the resource system in order to determine how to allocate management options that best meet the preferences specified by the various strategies, and in order to identify the biological and socio-economic tradeoffs among strategies. In making these assessments the planner uses the information developed thus far in conjunction with two analytical aids: linear programming (LP) and an input-output economic analysis (EA). In the process of land management planning, a separate LP analysis is made for each management strategy so that the allocations which best meet the requirements and constraints stated for each strategy may be determined. For example, a separate analysis might be made for each of the three strategies specified earlier. Requirement levels are typically based on both the information developed in the earlier stage of public involvement and the kind of production of which the land is capable. Limiting factors might be such things as the number of acres available for possible options, the available budget, environmental constraints, and policy considerations such as nondeclining timber yield from the Forest. The objective functions might include such considerations as the maximization of present net benefits or minimization of costs over the term of the planning horizon.

The management options are selected on the basis of land suitability and in line with the public involvement process. There is usually a wide range of possibilities including wilderness management, big game management at various levels, various types of recreation management, and various kinds of timber management treatments. Each of these options might require a number of activities. For example, recreation management (type I) might require monitoring use, closing roads, and constructing trails.

A comparison must be made between LP results in order to show the trade-offs among allocations, resource outputs, constraint levels, costs, and benefits. A good deal of additional information can be derived from the sensitivity or post-optimality analysis, which indicates how resource uses, constraints, and benefit values may change without affecting the LP optimal allocation. This is useful for a number of different purposes, such as determining what parameters may be most sensitive to changes in the plan and ascertaining whether additional inventory in certain areas may be appropriate.

The linear programming results are further utilized with the EA analysis package to estimate the impact which each of the possible strategies would be likely to have on local economic activity and employment levels (Palmer and Layton 1973). Given a particular strategy's predicted resource use or level of output, the EA analysis measures both the direct effects and the indirect or multiplier effect on various sectors of the local economy. This economic analysis results in a measure of the change in economic conditions likely to develop as a result of the application of a particular strategy. The significance of this impact depends, in part, on the magnitude of the change from what is the present condition and, in part, on the degree of influence this change has on the overall local or regional economy.

Table 2 is an example of the results of using the input-output portion of EA, which shows both the sectors affected directly and others which are indirectly affected as the impact of the change "ripples" through the economy. In the example, this effect amounts to \$131,863 in total gross output. The EA package also estimates the effect the change will have on local employment according to individual occupation and month of the year.

Table 2--Sample results of using the input-output package of EA

SECTOR	FINAL DEMAND (\$1000)	TOTAL GROSS OUTPUT (\$1000)	CONSUMPTIVE WATER USE (ACRE-FEET)	LABOR MAN YEARS	INCOME \$1000	VALUE ADDED \$1000
1. AGRICULTURE	225.308	270.084	0.000	3.884	45.790	71.964
2. MINING	.001	.131	0.000	.003	.071	.106
3. CONSTRUCTION	9.339	13.495	0.000	.245	3.517	3.774
4. LOGGING	.005	.089	0.000	.004	.035	.049
5. SAWMILLS	.000	.206	0.000	.005	.045	.070
6. OTHER MANUFACTURING	.248	.321	0.000	.009	.088	.125
7. TRANSPORT & WAREHOUSING	.530	5.395	0.000	.179	2.114	2.902
8. COMMUNICATION & UTILITIES	3.742	14.806	0.000	.288	7.618	10.640
9. AUTO DEAL & GAS STATIONS	4.932	6.330	0.000	.427	4.265	4.855
10. EATING & DRINKING PLACES	3.056	3.291	0.000	.257	1.038	1.698
11. WHOLESALE & OTHER RETAIL	7.251	9.211	0.000	.544	5.378	6.200
12. FINANCE, INSUR. & R E	2.474	6.638	0.000	.267	3.669	5.571
13. LODGING	1.284	1.293	0.000	.051	.511	.701
14. SKI AREAS	.000	.000	0.000	.000	.000	.000

15. OTHER SERVICES	6.454	43.774	0.000	1.776	17.672	23.209
PRIVATE SEC- ICES, TOTAL	264.623	375.064	0.000	7.939	91.811	131.863
GOVERNMENT & MISCELLANEOUS TOTAL POP. 26.		.000	0.000	1.553	.000	.000
			0.000			
TOTAL	264.623	375.064	0.000	9.492	91.811	131.863

The linear programming and input-output results provide quantitative estimates of differences between strategies which can be used to illustrate tradeoffs as well as to demonstrate compatible relationships between possible alternatives. This type of information, because it is presented in easily understandable formats, is valuable for public presentations of the various strategies illustrating what might be expected then a particular plan is implemented. The public reaction to these strategies and tradeoffs is useful in developing; a final plan which will be acceptable to the largest segment of the interested public.

APPLICATION

These techniques have proven successful in aiding in development of management plans for the Beaverhead, Willamette, Custer, Boise, Nezperce, Payette and Monongahela National Forests. In addition to being usable as a package for Forest plans, the techniques may be used individually for specific problems. For example, MAGE5 was used to help construct the area guides for U.S. Forest Service Rocky Mountain Region (R-2). EA is being used for a portion of the analysis necessary for the wilderness RARE II study. PUBLIC has been used in Alaska to develop local preference patterns and to compare these to preferences stated by Forest Service and Congressional representatives in Washington, D.C.

The programs have been used with UNIVAC and CDC computer systems. All these programs are coded in standard FORTRAN IV, and as such should be readily adaptable to other systems. Most of the problems related to National Forest applications have been solved through training and personal contact with technical staff provided at the Forest Service Regional Office or at the SAU-LNP in Fort Collins, Colorado.

The use of these quantitative techniques in planning provides for a comprehensive analysis of complex situations. The techniques offer an effective and efficient means to develop land management plans. They can handle information in large amounts, of differing types, and concerning diverse interrelationships between biological, social, and economic factors which would be impossible to deal with by any other means. The quantitative procedures used here offer a consistent, systematic approach to land management planning.

ACKNOWLEDGMENTS

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Nutzwertanalyse

A. Henne

Abstract: Nutzwertanalyse (NUWA) is a psychometric instrument for finding the best compromise in the multiple use planning of forestry, when the multiple objectives cannot be expressed in the same physical or monetary unit. It insures a systematic assessment of the consequences of proposed alternatives and thoroughly documents the decision process. The method leads to a ranking of alternatives based upon weighting of the objectives and evaluation of the contribution of each alternative to these objectives. The use of the method is illustrated with hypotheticalal data.

INTRODUCTION

In management planning of multiple use forestry the situation for the planner is as follows:

Many possible alternatives must be compared in the light of a great number of more or less consistent or conflicting objectives (aims, goals) between which functional relations cannot be specified.

In the process of comparing and assessing the consequences of the alternatives, it is unavoidable that the subjective preferences of the decision-maker and planner and of institutions play a vital role.

Consequently, psychometric methods have to be introduced to obtain solutions corresponding to objectives which cannot be expressed in physical or monetary units.

To overcome these difficulties neither intuition nor, mathematical models are of much help. In NUTZWERTANALYSE (NUWA) an instrument is at hand with which finding the best compromise can be made easier and more rational. The decision process will at the same time gain in clarity, and it will be reproducible in all its steps.

OUTLINE OF THE NUTZWERTANALYSE METHOD

The technique of NUWA consists of the following steps (see Abb. 1):

Step 1: The objectives (aims, goals) relevant to the situation are defined and arranged hierarchically according to means-objectives relations. At the end of the "chains of objectives" will be found "aims criteria" (Zielkriterien) K_j sufficiently precise to serve as the basis of analysis and evaluation.

Step 2: The weights g_j (Gewichte der Zielkriterien), i.e., the importance each objective shall assume in the process of evaluation, are given by the deciding authority according to its preferences.

Step 3: The consequences of each project alternative (alternative action) A_i with respect to each "aim/criterion" K_j are described in a matrix (Zielertagsmatrix). The elements E_{ij} of this matrix can be formulated in words or numbers.

Step 4: By "measuring" the consequences of the alternatives, each element E_{ij} is transformed into an element W_{ij} of the "value-matrix" (Zielwertmatrix). The scales (nominal, ordinal, or cardinal) by which the consequences are measured depend on the form and the precision of their description.

By these four steps the evaluation of an alternative has been divided up into m part evaluations, m being the number of criteria (objectives) to be taken into account.

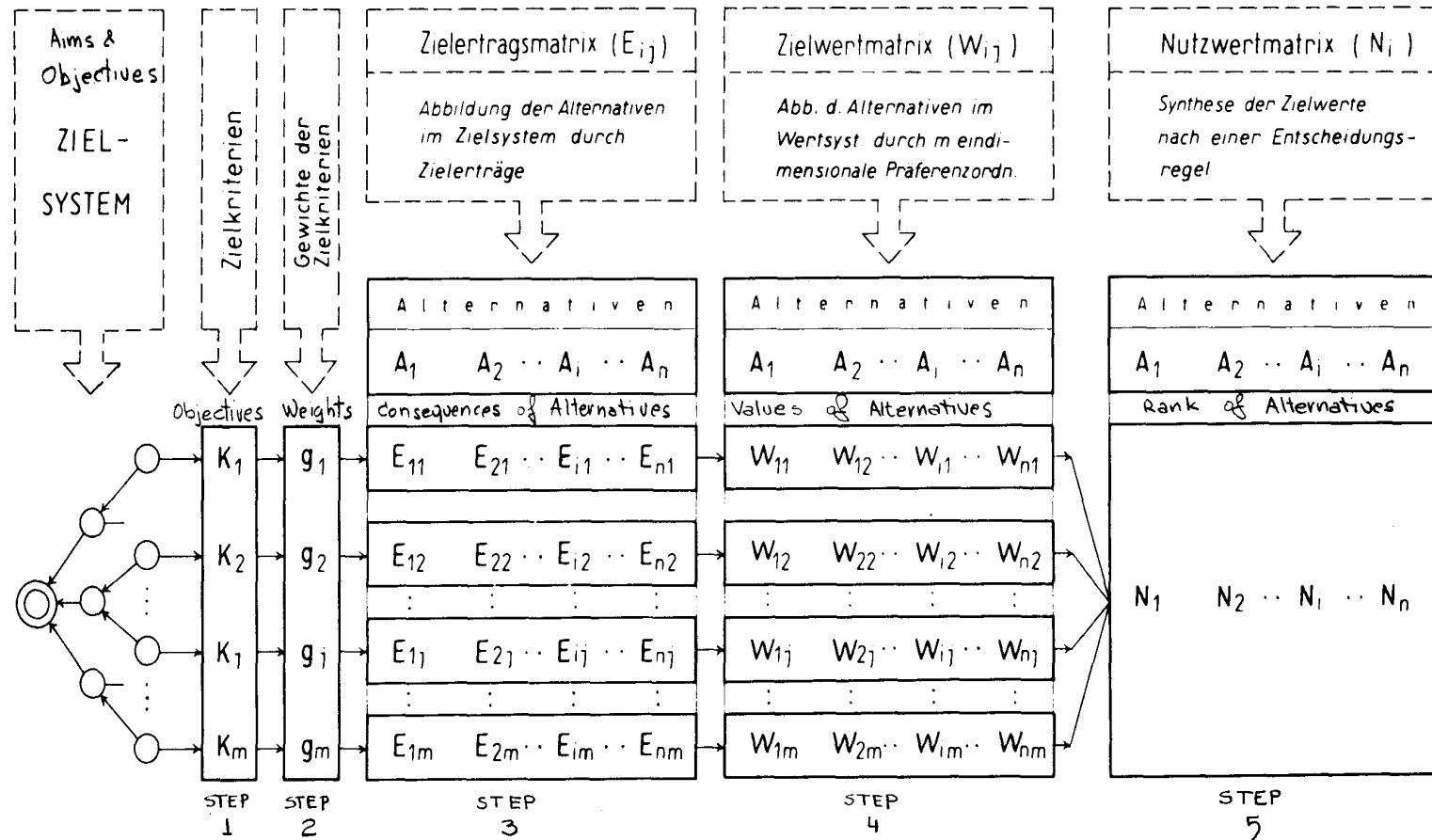
Step 5: For each alternative A_i the NUTZWERT N_i is found by combining the weighted "values," according to a set of decision rules, which are consistent with the type of measurement scale used. The result (Nutzwertmatrix) gives ranking of the alternatives analyzed.

So NUWA may be briefly described as a method, with which a number of project alternatives are analyzed and assessed, with respect to a multidimensional system of objectives, by ranking the alternatives according to the preferences of the decisionmakers.

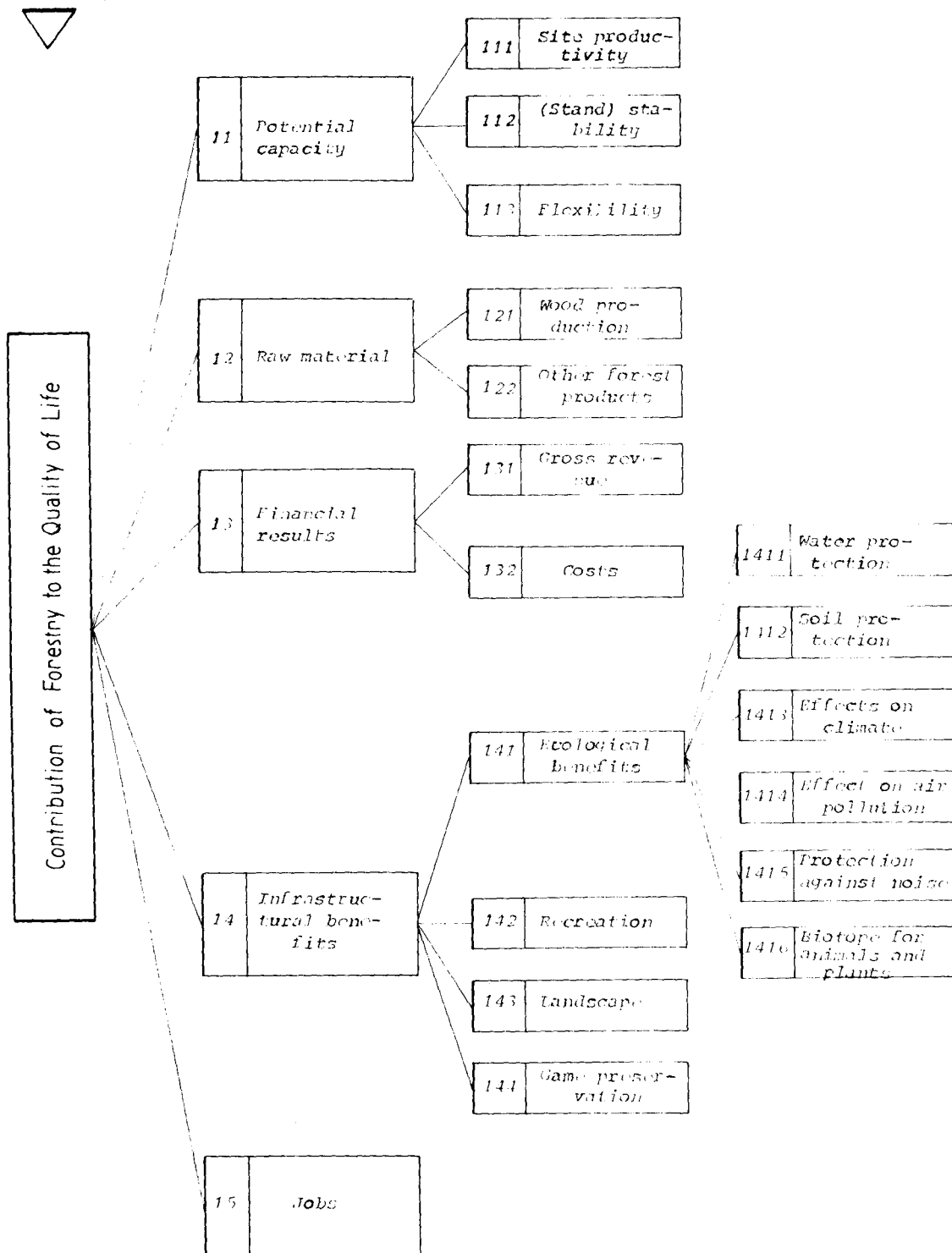
The following considerations in using NUTZWERTANALYSE may help to clear up some of the more difficult aspects:

System of General Objectives

The first requirement for using NUWA is to formulate a complete system of well-defined and carefully arranged objectives. In Abb. 2 you will find a "System of General Objectives in Forestry" which I presented in Oslo at the XVIth IUFRO Congress. These objectives are to maximize, minimize, conserve, promote etc., the criteria listed in Abb. 2. This system is only a first try and I hope a start for further joint efforts. Meanwhile in our country a guide for forest regional planning has been published that contains this system in a slightly different form.



Supreme Objective



Heights of Objectives

An example for step 2--the "weighting" of the objectives--is given in Abb. 3. Using the presented system of objectives, the weighting is simulated for the state forests of Hessa, using the method of "pairwise comparison." You find the preliminary weights calculated in percentage numbers in column (3) of the table. After a transformation by means of an interdependence factor, the final general weights are given in column (6) of the table. (These numbers correspond to the weights g_j (Abb. 1). A detailed description of the method is given in another paper by the author (Henne 1976). Other methods are described in Zangenmeister.

Evaluation Scheme

In forest management planning certain types of planning situations constantly recur, e.g., planning the treatment of a stand to be harvested and regenerated (see the following simulation). In such a case an evaluation scheme (Abb. 5) for use in all similar situations can be prepared, in which step 3 and 4 of the NUWA logic are combined and systematized: the possible consequences of alternatives are put in increasing order and a corresponding scale is put above the resulting matrix (in Abb. 5 a cardinal scale is used). With respect to only four "objectives" can the consequences of the alternatives can be measured in numerical units: woods production in cubic meters, gross receipts, costs in marks, and amount of labor in hours. In all other cases only qualitative descriptions can be given--for the time being. The vagueness of these descriptions and even some blanks show the field of research yet to be cultivated before intuition can be efficiently replaced by rational thinking in complex planning situations.

Simulation of a NUWA

One of the most important tasks in medium and long-term multiple use management planning of unevenaged forests is to decide

When and how to cut a mature stand,

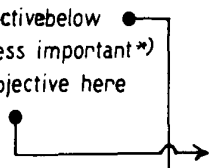
How and with what species to regenerate the cleared area.

In Abb. 4 a planning situation of this kind involving five silvicultural alternatives ($A_1 - A_5$) is analyzed. You will find the following information:

In column 1 the objectives, drawn from the System of General Objectives in Forestry presented in Abb. 2

In column 2 the general weights of these objectives, drawn from column 6 in Abb.

In column 3 a transformation of the general weights to account for local conditions, and in column 4 the corresponding normalized value of these adjusted weights.

HESS. FORSTEINRICHTUNGSANSTALT		Weighting of Objectives														Abb.				
Nutzwertanalyse		Using the method of "pairwise comparison" (KOELLE)														3				
Is the objective below more or less important *) than the objective here  *) Scale reaching from + 5 = very much more import. 0 = equally important to - 5 = very much less important		Site productivity	(Stand) stability	Flexibility	Ecological benefits	Recreation	Landscape	Wood production	Gross revenue	Work conditions	Jobs	Costs	Other forest products	Game preservation	Sum line	Col. 1 + (13 - 1) x 5	Preliminary general Weight (Col. 2 ÷ 0,780)	Interdependence factor	Final general Weights Col. 3 x Col. 4	Normalized general weights Col. 5 ÷ 1,023
		111	112	113	141	142	143	121	131	152	151	132	122	144	①	②	③	④	⑤	⑥
111	Site productivity	--	0	+ 1	+ 1	+ 2	+ 2	+ 3	+ 3	+ 3	+ 4	+ 4	+ 4	+ 5	+ 32	92	11,8	1,016	12,0	11,7
112	(Stand) stability	0	--	0	+ 1	+ 2	+ 2	+ 3	+ 3	+ 3	+ 4	+ 4	+ 4	+ 5	+ 31	91	11,7	1,295	15,2	14,9
113	Flexibility	- 1	0	--	0	+ 1	+ 1	+ 2	+ 2	+ 3	+ 3	+ 4	+ 4	+ 5	+ 24	84	10,8	1,131	12,2	11,9
141	Ecological benefits	- 1	- 1	0	--	+ 2	+ 2	+ 3	+ 3	+ 3	+ 4	+ 4	+ 4	+ 5	+ 28	88	11,3	0,918	10,4	10,2
142	Recreation	- 2	- 2	- 1	- 2	--	+ 2	+ 2	+ 3	+ 4	+ 4	+ 4	+ 4	+ 5	+ 21	81	10,4	0,935	9,7	9,5
143	Landscape	- 2	- 2	- 1	- 2	- 2	--	+ 1	+ 1	+ 2	+ 2	+ 3	+ 4	+ 5	+ 9	69	8,8	0,984	8,7	8,5
121	Wood production	- 3	- 3	- 2	- 3	- 2	- 1	--	+ 2	+ 2	+ 3	+ 3	+ 4	+ 5	+ 5	65	8,3	0,951	7,9	7,7
131	Gross revenue	- 3	- 3	- 2	- 3	- 3	- 1	- 2	--	0	+ 1	+ 2	+ 4	+ 5	- 5	55	7,1	0,869	6,2	6,1
152	Work conditions	- 3	- 3	- 3	- 3	- 4	- 2	- 2	0	--	+ 2	+ 3	+ 4	+ 5	- 6	54	6,9	1,049	7,2	7,0
151	Jobs	- 4	- 4	- 3	- 4	- 4	- 2	- 3	- 1	- 2	--	+ 2	+ 4	+ 5	- 16	44	5,6	0,967	5,4	5,3
132	Costs	- 4	- 4	- 4	- 4	- 4	- 3	- 3	- 2	- 3	- 2	--	+ 4	+ 5	- 24	36	4,6	1,049	4,8	4,7
122	Other forest products	- 4	- 4	- 4	- 4	- 4	- 4	- 4	- 4	- 4	- 4	- 4	--	+ 2	- 42	18	2,3	1,000	2,3	2,2
144	Game preservation	- 5	- 5	- 5	- 5	- 5	- 5	- 5	- 5	- 5	- 5	- 5	- 2	--	- 57	3	0,4	0,836	0,3	0,3
		- 32	- 31	- 24	- 28	- 21	- 9	- 5	+ 5	+ 6	+ 16	+ 24	+ 42	+ 57	0	780	100,0	13,000	102,3	100,0

FEA - GIESSEN		Example of a Nutzwertanalyse Regeneration of a Beech Stand (130 years)														Abb. 4	
1		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Objectives		weights			Value of Alternatives					Teilnutzwerte (Col. 6 10x Col. 4)							
		General weights Abb. 3 Col. 6	Local weights	Normalised local weights (Col. 3 : 0,978)		Leaving the beech stand for another 40 years, then Douglas fir	Nat. regen. of beech, compl. by planting Larch + Norway spr.	Clear cutting, planting of Norway spruce	Clear cutting, planting of Douglas fir								Clear cutting, pl. of Dougl. fir, along road gradual reg. by select. cutting
						A1	A2	A3	A4								A5
111	Site productivity	117	117	120		9	10	7	6	8		108	120	84	72	96	
112	(Stand) stability	14,9	14,9	15,2		5	9	4	2	5		76	137	61	30	76	
113	Flexibility	11,9	11,9	122		10	8	2	1	3		122	98	24	12	37	
1411	Water protection	10,2	-														
1412	Soil protection		-														
1413	Effects on climate		1,0	1,0		5	5	5	5	5		5	5	5	5	5	
1414	Eff. on air pollution		-														
1415	Protection against noise		20	2,0		3	6	5	4	7		6	12	10	8	14	
1416	Biotope for animals o. plants		1,0	1,0		8	10	3	1	6		8	10	3	1	6	
142	Recreation	95	120	123		7	10	5	4	7		86	123	62	49	86	
143	Landscape	85	100	102		7	10	6	5	8		71	102	61	51	82	
121	Wood production	77	77	79		8	5	10	7	8		63	40	79	55	63	
13	Financial results	61	61	62		6	3	10	8	8		37	19	62	50	50	
152	Work conditions	70	70	72		9	4	9	9	8		65	29	65	65	58	
151	Jobs	53	53	54		4	6	10	9	7		22	32	54	49	38	
132	Costs	47	47	48		10	6	3	4	5		48	29	14	19	24	
122	Other forest products	22	22	23		3	1	10	5	9		7	2	23	12	21	
144	Game preservation	03	03	03		5	5	3	3	8		2	2	1	1	2	
		100	978	100		Nutzwert						726	760	608	479	658	
							Rank						2	1	4	5	3

HESS. FORSTEINRICHTUNGSANSTALT		Evaluation Scheme Methods of Regeneration and Choice of Species										Abb. 5
Nutzwertanalyse		Z i e l e r t r a g e										
Value of alternatives	Objectives	0	1	2	3	4	5	6	7	8	9	10
111	Site productivitiy	Biological activity of soil										
		strongly negative influence	slightly negative influence	not influenced	slightly favourable influence	strongly favourable influence						
112	Stand stability	very low	low	medium	high	very high						
113	Flexibility	conversion possible only in long intervals and technically difficult and/or costly	conversion possible during life-time of stands, few options in the next generation							conversion easy, several alternatives, many options in the next generation		
121	Wood production	mean annual volume increment (m ³)										
		0 - 3,5	3,5 - 7	7 - 10,5	10,5 - 14	14 - 17,5						
122	Other forest products	negligible	low	medium	high	very high						
131	Gross revenue	mean annual gross revenue, DM per ha, price basis 1976:										
		0 - 240	240 - 480	480 - 720	720 - 960	960 - 1200						
132	Costs	mean annual direct costs, DM per ha, prices and wages 1976:										
		50 - 80	80 - 110	110 - 140	140 - 170	170 - 200						
1411	Water protection	effects										
		very unfavourable	unfavourable	none	favourable	very unfavourable						
1412	Soil protection	intensity and depth of root penetration										
		very low	low	medium	high	very high						
1413	Effects on climate	effects on local climate										
		very unfavourable	unfavourable	neutral	favourable	very favourable						
1414	Effect on air pollution	limited to certain seasons, missing during regeneration phase	limited to certain seasons, reduced in regeneration phase	medium	high during most of the year, only short-term interrupted during regeneration phase	very high in all age phases and during most of the year						
1415	Protection against noise											
1416	Biotope for animals and plants	number of species										
		very low	low	average	high	very high						
142	Recreation	open for activities during lesser part of rotation, no shelter by old trees in regeneration phase, snow cover higher and longer, no sunlight in winter									open for activities during greater parts of rotation, shelter by old trees even during regeneration phase, seasonal change between shadow and sunlight	
143	Landscape	monotony with regard to tree species, age, stand structure etc., prevailing of "unaccustomed" species, no transparency of stands									harmonious change of tree species, age classes, stand structure, silvicultural intensity, prevailing of well known species, transparency of stands	
144	Game preservation	as habitat for game on the average										
		hardly qualified	less qualified	normally qualified	well qualified	highly qualified						
151	Jobs	mean annual volume of work, hours per ha										
		2 - 5	5 - 9	9 - 12,5	12,5 - 15,5	15,5 - 18						
152	Work conditions											

In columns 6 ... 10 the value matrix for the five alternatives obtained by applying the given evaluation scheme

In columns 11 ... 16 the "Teilnutzwerte" found by multiplying the values in columns 6 ... 10 with the "local" normalized weights drawn from column 4

At the foot of columns 11 ... 16 the "Nutzwerte" of the alternatives, ranging from 479 to 760, calculated by summing up the corresponding column of Teilnutzwerte

The alternative with the highest numerical value A2 is assigned rank 1. This alternative will yield a mixed stand of deciduous trees and conifers, produced by natural regeneration of the existing beech stands, using a shelter-wood method, supplemented by planting larch and spruce.

This solution is the best compromise under the local conditions, the area being part of a nature park on the border of the Rhine-Main-Industrial Region.

A look at columns 11 to 16 in the "Teilnutzwerte" (Abb. 4) shows which objectives contribute the most points to the "Nutzwert" of A2.

On the one hand it is the high importance attributed to the objectives of site preservation, stability and flexibility, in which the principle of sustained yield--of all the benefits of forests--is reflected. On the other hand it is the importance of recreation and landscape under the special circumstances of the example.

CONCLUSIONS

In conclusion, I hope I have been able to show not only how much more transparent the decision processes can become by using NUWA, but also how much weight the ecological, hygienic and aesthetic objectives are given in the silviculture and forestry of our country.

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A Methodology for Decisionmaking in Project Evaluation in Land Management Planning

A. Weintraub

Abstract: In order to evaluate alternative plans, wildland management planners must consider many objectives, such as timber production, recreational use, and community stability. The method presented utilizes the type of qualitative and intuitive information widely available to wildland management planners, and structures this information into a format suitable for decisionmaking. The method makes possible the determination of a measure of overall desirability for alternative plans, and permits the evaluation of plans under alternative value systems. Alternatives are compared through a small set of values assigned to each one. Each number in the set represents a measure of desirability not directly comparable to the others. The planner assigns weights to each measure and obtains a unique number for each alternative. The method is simple to use and flexible, to permit modifications as planners gain expertise in its use.

INTRODUCTION

The method proposed consists of a set of steps which provide a structured framework for choosing among alternatives, when multiple objectives or criteria have to be considered, and uncertainty exists. At each step, the method provides for the participation of decisionmakers, specialists, analysts, and possibly, the general public.

The scheme requires the limited participation of decisionmakers and deviates little from generally used organizational patterns. Several concepts which are essential for correct and efficient evaluation are emphasized:

- (a) Screening, which allows the elimination of alternatives simply on the basis of "rough cut," general evaluations.
- (b) Evaluation of the accuracy and certainty of information used in the determination of the impacts of the alternatives.
- (c) Reduction to a manageable number of the impacts necessary for the evaluation of alternatives.

- (d) Visual presentation of results in tables and "scoreboards" which present information to the decisionmaker and to the public in a clearer way and with a simpler format of analysis.
- (e) Generation of potentially attractive new alternatives, through modification and combination of already defined alternatives.

Concepts (c) and (d) are essential in presenting the decisionmakers with a clear summary of the impacts with respect to the declared goals. Note that with this scheme there is no need for the decisionmaker to specify his utility function or explicit preferences. Although these weights simplify the selection of the preferred alternatives, they introduce serious methodological complications rooted in the complexity of utility functions.

The scheme is applicable to a broad range of planning problems. It is presently being used in the decision process for a recreation area project (skiing and summer activities) in the Tahoe National Forest, in California. The main goal of this project is to provide recreation facilities to satisfy increasing demand in a location with very attractive possibilities. The site will be developed by private capital, but a large percentage of the land needed belongs to the Forest Service, U.S. Department of Agriculture. As a public agency, the Forest Service must consider, when evaluating alternatives, the preservation of environmental quality, as well as the socioeconomic impacts a recreation complex will have on neighboring communities.

The steps of the scheme will be illustrated with examples, most of which are drawn from this recreation project.

THE SCHEME

The basic steps are the following:

1. Define the boundaries of the problem: the area of study, the types of alternatives to be considered (e.g., Area--Tahoe region; Types of alternatives--develop recreation facilities for winter use or for winter and summer use).
2. Identify decision-influencing elements, criteria, or goals. Goals can be defined at different levels of aggregation: (1) a general goal, such as to preserve environmental quality, which can be refined into (a) preserve air and water quality, (b) maintain wilderness, etc.; or (2) a primary goal, such as to enhance social well-being of the population, and secondary goals such as (a) promote acceptable patterns of employment, (b) avoid overcrowding of services, etc.
3. Identify major forms of activities and areas in which they can be carried out (e.g., logging and range in unit A).
4. Define basic alternatives to be considered (e.g., alternatives emphasizing recreation, logging, preservation of wilderness, etc.)
5. Define the major types of impacts of each alternative in relation to the goals established. Include secondary effects only if they are important.

6. Screen the alternatives. Determine a set of criteria which would make an alternative unacceptable. Based on these criteria, find which alternatives can be eliminated without additional collection of data or finer analysis (e.g., general analysis may be sufficient to determine that a practice of intensive timber cutting in a given area results in unacceptable environmental and recreation impacts. Then, any alternative with that practice would be screened out). Screened-out alternatives will be reconsidered later in the light of the additional insights gained from the analysis.

7. For those alternatives passing the screening process, determine their impacts in a disaggregated and quantified form in relation to the declared goals. Several models can be used for estimating partial impacts (i.e., econometric models to predict ski demand, input-output models for estimating income and employment effects, etc.).

Impact information can appear in different forms:

- (A) Hard information: data which is quantified, relatively accurate and certain.
- (B) Nonquantifiable information: impacts which may be estimated from accurate and certain input-output data, but which are expressed as qualitative ratings and therefore depend on subjective evaluation (e.g., the acreage and condition of wilderness and scenic areas may be known but the impact of management alternatives can only be assessed intuitively).
- (C) Soft information: insufficient information exists about conditions or about the consequences of management (e.g., impacts on timbered areas where no appropriate survey has been made).
- (D) Uncertain information: impacts that cannot be predicted with precision. The sources of uncertainty may be:
 - (a) Uncertainty about the "future of the world" (e.g., what is going to be the rate of increase on overall demand for recreation in the future).
 - (b) Technical uncertainty in projections, that is, the impossibility of predicting exact impacts, even if the setting in which they occur is known with certainty.
 - (c) Uncertainty about the implementation of each phase of the project exactly as it is defined in the study.

8. Reduce the number of impacts to be considered in this evaluation for each alternative by discarding and aggregating impacts according to the goals established.

This step is needed to reduce the normally large number of impacts generated in Step 7 to a much smaller number of representative impacts, which will make the evaluation process in relation to the declared goals more manageable.

The reduction of impacts to evaluate is accomplished by eliminating from consideration the impacts which are not likely to affect the decision (i.e., exclude impacts of negligible importance, or those that do not vary much among the alternatives), and aggregating sets of impacts into one representative of the set which may be quantified through an index (i.e., aggregate into one those impacts which may be considered as one goal or subgoal, such as different measures of water quality, or which are highly correlated under all alternatives, such as wilderness and wildlife impacts).

The elimination and aggregation process may be modified as new alternatives are generated. Control over this process can be maintained by reverting to Step 7 at any stage.

9. Check the legal, institutional, environmental, political, and economic acceptability of each alternative.

The detailed and aggregated information of Steps 7 and 8 allows for this analysis, which can be carried out according to the specifics of the situation. For example, a disaggregated impact of Step 7, such as air pollution measures, allows a check for compliance with legal requirements, while the aggregated use of impacts of employment, in housing and community services, regional economy, etc., facilitate a political evaluation of the alternatives.

10. Generate new, potentially attractive, basic alternatives which are significantly different from those already proposed, and return to Step 6. This step can be carried out through major mitigating actions (modifications of alternatives) or by combination of "good" elements of alternatives already specified.

The steps for generating new alternatives are these:

- (A) For each basic alternative, describe the main actions and their location.
- (B) For each action evaluate the main positive and negative impacts on the defined goals. Also analyze composite effects of the global project.
- (C) For each impact, determine which changes in primary conditions would reduce negative effects, or increase positive effects.
- (D) For changes in primary conditions which would improve impacts, determine which actions would bring about those changes and what are the trade-offs implied (i.e., which other impacts are also affected through those actions).
- (E) (a) For major mitigating actions, determine which actions have acceptable trade-off to improve impacts. Generate new alternatives introducing these actions.

- (b) For combination of alternatives, determine, for two or more alternatives studied, which actions lead from one to another in some aspects. This procedure is used to determine combinations of elements of each alternative to generate a new one.
Alternatives generated must be technically and economically feasible.

A partial example of the procedure is the following:

- (A) Basic alternative: one action is to build a large ski facility in a designated area.
 - (B) One negative effect: overflow of visitors from the area in winter creates serious social problems in neighboring communities.
 - (C) This negative impact can be mitigated by reducing the number of people going into the neighboring towns.
 - (D) Actions which would bring about this reduction are to reduce the size of the planned ski facility or to increase substantially the lodging and eating facilities in the recreation complex (to keep visitors in the area).
 - (E) Consider a major mitigating action with a substantial increase in lodging and eating facilities. The trade-off of this action, which in this case consists of additional negative impacts, is increased water usage, waste disposal problems, reduced attractiveness of the resort, reduced profitability of the project. If the trade-off seems acceptable, a new basic alternative can be generated incorporating the new lodging and eating facilities.
11. Determine if new areas of concern or types of impacts need to be defined. If yes, go back to Step 6 and check alternatives. This step acts as a control, as new knowledge is gained in the process.
12. Present the summarized results in adequate visual format. Impacts will be presented in tables by indexes (expected values and ranges will be used). Colors may be used to highlight differences among alternatives. See tables 1 and 2 as examples.

These tables show visual presentation possibilities for the described recreation project, for three proposed alternatives--A, F, and G.

- A: Accept a project proposed by the Walt Disney Corporation to build a large winter and summer recreation complex in a designated area.
- F: Leave the designated area untouched, promote the expansion of existing recreation sites.
- G: Call for bids for a smaller recreation complex in the designated area.

Table 1. Reduced Impact List

Impact	Alternatives		
	A	F	G
Environmental			
Overall Physical-Biological	(-2, <u>3</u> , -5)	(0, <u>-1</u> , -2)	(-1, <u>-2</u> , -3)
Water, Air, Waste	(-7, <u>-8</u> , -9)	(-2, <u>-3</u> , -4)	(-4, <u>-5</u> , -6)
Effect on Tahoe Basin	(+3, <u>+4</u> , +6)	(-3, <u>-5</u> , -6)	(+1, <u>+2</u> , +3)
Economic			
Impact neighboring counties	(+5, <u>+6</u> , +8)	(-1, <u>0</u> , 0)	(+2, <u>+3</u> , +4)
Economic feasibility	(+5, <u>+7</u> , +8)	(+2, <u>+2</u> , +3)	(+1, <u>+3</u> , +4)
Regional, Tahoe Basin impact	(1, <u>+2</u> , +2)	(+1, <u>+2</u> , +2)	(0, <u>+1</u> , +1)
Social			
Pressure on social structure, Traffic congestion	(-5, <u>-6</u> , -9)	(-1, <u>-1</u> , -2)	(-3, <u>-5</u> , -6)
Pressure on services, controllability of growth, distribution of negative effects	(-3, <u>-4</u> , -6)	(-2, <u>-3</u> , -4)	(-1, <u>-2</u> , -3)
Effect in Tahoe Basin	(+2, <u>+3</u> , +5)	(-6, <u>-7</u> , -9)	(+1, <u>+2</u> , +3)
Recreation			
Winter	(6, <u>8</u> , 8)	(4, <u>5</u> , 6)	(3, <u>4</u> , 5)
Summer (include wilderness recreation lost)	(4, <u>5</u> , 6)	(0, <u>0</u> ,)	(1, <u>3</u> , 4)
Effect Tahoe Basin	(2, <u>+4</u> , 5)	(-3, <u>-5</u> , -6)	(+1, <u>+2</u> , +3)
Institutional			
Effect on other FS activities	(-3, <u>-4</u> , -5)	(<u>-1</u> ,)	(<u>-1</u> ,)

Table 1 is a list of main impacts. Impacts are rated from 0 to 10 for positive impacts, 0 to -10 for negative impacts (+10, -10 correspond to the most positive and the most negative respectively). In each case, the circled number corresponds to the expected value of the impact, the other two represent the range due to uncertainty. (Note: creating a recreation complex in the designated area will take away pressure from the Tahoe basin). Colors (not shown in table) are used to highlight differences, e.g., most positive values are circled in blue, next values in green, etc.

Table 2--Impact list with information about causes of uncertainty

The main causes of uncertainty are:

- 1 Growth of Reno (Reno is a fast-growing city, with high tourism, which shares with the designated area the freeway linking to the main population center in the region, the San Francisco Bay Area.)
- 2 Secondary impacts on neighboring counties
- 3 growth of overall recreation (ski) demand
- not sufficient information (soft information)
- Δ technical uncertainty

Impact	Alternative		
	A	F	G
Environmental			
Overall Physical-Biological	-3	-1	-2
Water usage	③ Δ 8 ②	-3	③ -6 ②
Waste disposal	③ -8 ②	-3	③ -5 ②
Air quality	③ -7 ① ②	-4 ①	③ -5 ① ②
Effect on Tahoe Basin	③ +4 □	③ -5 □	+2 □

In this case, water usage for alternative A for example is: ③ | Δ 8 | ② and

is equivalent in Table 1 to (-7, ⑧, -10). The information provided is:

- ② If secondary impact is larger than expected, water usage impact tends to grow in absolute value.
- ③ If ski demand is less than expected, water usage impact tends to decrease in absolute value.
- Δ There exists technical uncertainty in the projection.

Table 2 is a more detailed list of impacts in a different format. The number between vertical lines represents the expected impact. The number of vertical lines indicate the level of uncertainty in each direction, and the circled numbers refer to notes on the causes of this uncertainty.

13. Evaluate alternatives presented in Step 12. Determine the most attractive alternatives (or the better alternatives). To make this determination, sensitivity analysis should be carried out on uncertain, soft, or nonquantified data. Sensitivity analysis should include two aspects.

- (a) The analysis of the stability--or robustness--of solutions. For example, an alternative may look very attractive when expected values are considered. However, once uncertainty is included, it may look much less desirable, due to a high probability of the least desirable outcome.
- (b) The indication on where more and better information is needed, for sound decisionmaking. For example, an estimate with 15% error in the projection of timber demand may be sufficient in some cases. In others, a finer estimate may be crucial in the decision as to a project's financial soundness.

The overall impact of each alternative should also be considered; that is, besides a comparison of each attribute, it is important to view the global effect of the alternatives, and to include the intangible impacts in this assessment.

If none of the alternatives selected appears completely satisfactory, study what new aspects should be considered to generate new alternatives (i.e., new decision-influencing elements, criteria to improve overall impact or evenness of alternatives, criteria to reduce uncertainty, etc.). Then go back to Step 5. Otherwise continue to Step 14.

14. Generate new potentially attractive alternatives, marginally different from the ones selected in 13. This is done through proposing minor mitigating actions or combination of characteristics of the (similar) alternative selected. The mechanics of this step are similar to Step 10, where now detailed characteristics are considered. A minor mitigating action might be a small modification in the time stream of timber logged, to provide a more even supply to nearby mills. Alternatives generated at this stage should be technically feasible and economically efficient. Go back to Step 7. If no new alternative is generated, go to Step 15.

15. Select preferred alternative.

CONCLUSION

The scheme presented here has been well received by the professionals in charge of the Tahoe National Forest recreation project, and is currently being used in the decision process.

The scheme allows for flexibility, and some variations may be recommended in different applications. It can be used effectively in a variety of plan-

ping situations. For example, for the Tahoe project it was determined that the screening process--Step 6--should be introduced after Step 9 to permit a thorough evaluation of the major impacts for every alternative. This was done in order to avoid the adoption of intransigent opposition by interest groups whose preferred alternative might be screened out.

The method presented is designed to be used for land management planning, e.g., alternatives which emphasize the multiple use and value of land: timber, range, recreation, wilderness, ecology, etc. This form of decisionmaking is somewhat different from the evaluation and selection of single projects, as in the case of the recreation project, since it involves the determination of a combination of different forms of activities on areas with diverse characteristics which will make up a land management plan for a forest or land unit. This multiplicity of activities allows for a richer variety of possibilities in combining elements forming a plan and must be considered particularly in Steps 3, 8, 10 and 14.