

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

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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.

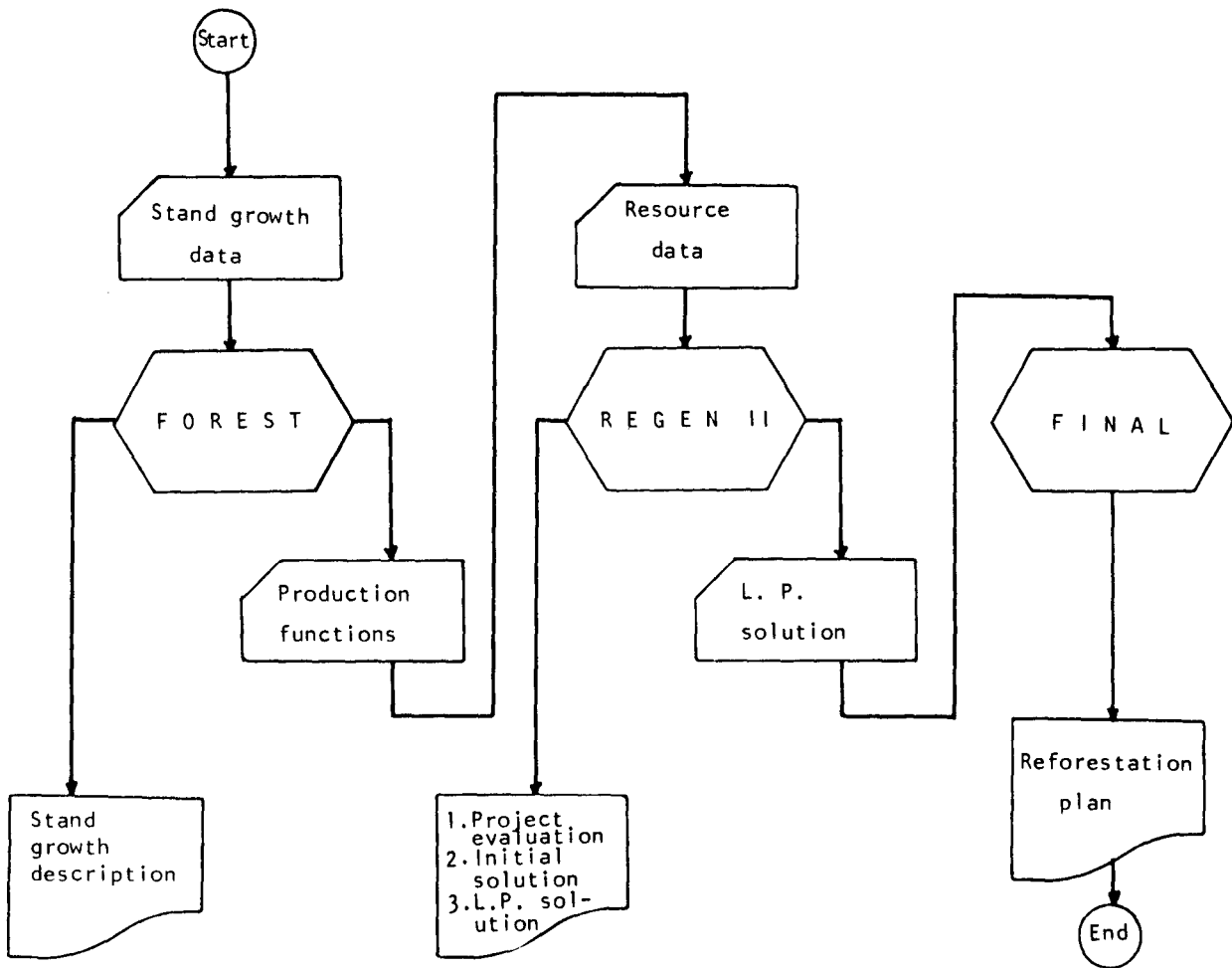


Figure 1. Elements of the reforestation planning system.

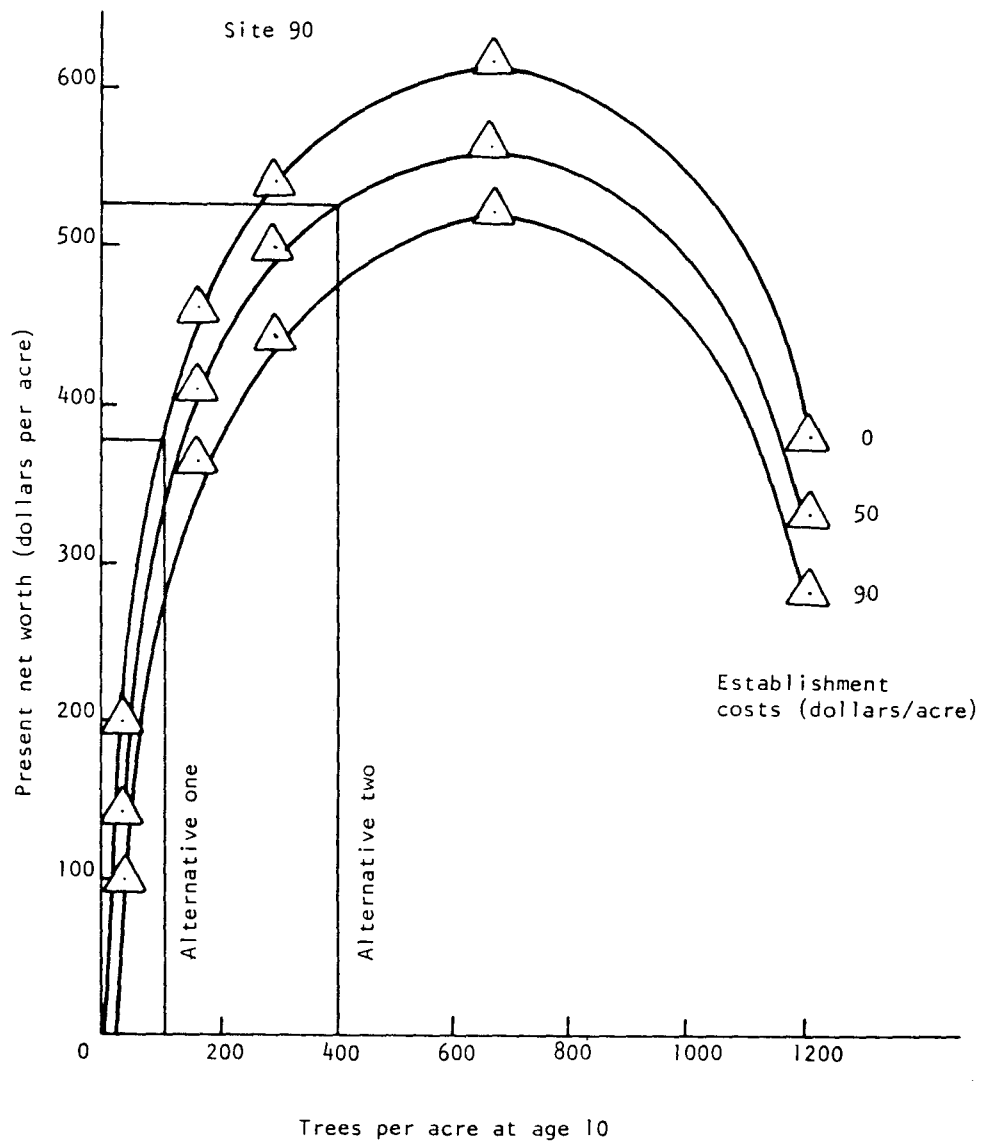


Figure 2. Present net worth of reforestation alternatives.

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

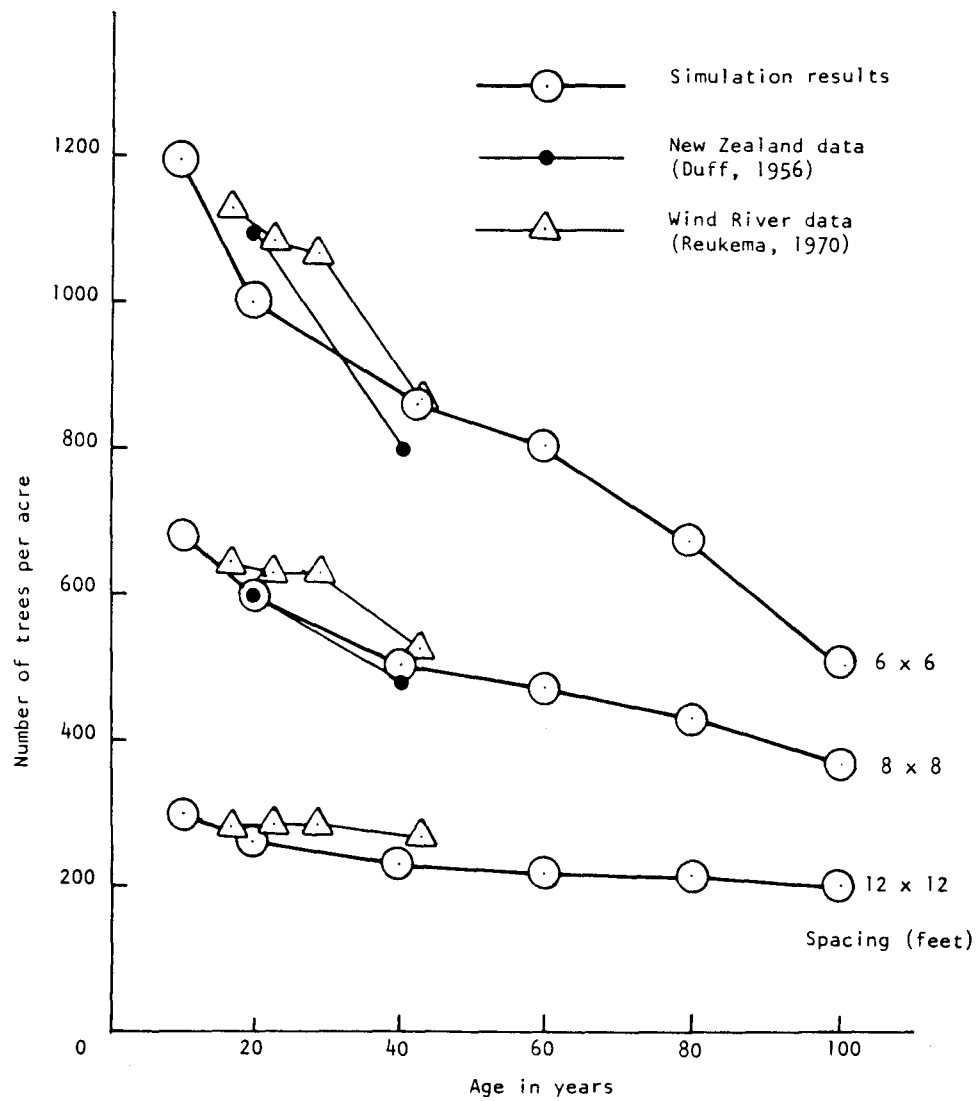


Figure 3. Predicted and observed survival in plantations.

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).

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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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