SIMULATION MODELS OF FOREST RESOURCE MANAGEMENT

Dieter R. Pelz
University of Illinois

ABSTRACT

The management of forest land for the simultaneous production of timber, recreational opportunities, wildlife food and habitat, and watershed protection requires complex decisions. Simulation models formulated as decision aids or training tools in forest resources management are reviewed, ranging from strictly timber production models to multiple forest use models. The Illinois multiple forest use model was developed to aid the forest manager in his decision making. Alternative management strategies and their effects on the entire forest system can be evaluated with the model. The model is being validated for a private forest and a State Forest in Illinois.

INTRODUCTION

Forest land is capable of producing a variety of goods and services simultaneously. Traditionally timber production often had the highest priority on many forest lands, other goods and services were considered side products. But more recently other products and services became more important; some forests are now exclusively managed for the production of recreational opportunities or the production of watershed values. The majority of forests however is managed for the simultaneous production of several of the forest goods and services. This concept, known as "multiple use" was formally established with the Multiple Use-Sustained Yield Act of 1960 which specified that national forests had to be administered for outdoor recreation, range, timber, watershed, and wildlife purposes. Forest industries and private land owners adopted similar management principles, attempting to find the optimal product mix for their lands.

In some cases the production of these forest goods and services is complementary, the production of one good will increase, or at least not decrease the production of other goods and services. In other cases the production is competetive, an increase in the production of one good will result in an decrease in the production of another.

In multiple forest use management, the number of decision variables is large, in most cases the number of forest stands for which production decisions have to be made is in the hundreds or thousands. Simulation was found to be a useful decision aid in these situations, several models have been developed to aid the forest manager in his decision making, mostly in timber production. In the following some of these models are reviewed briefly before the Illinois multiple forest resources management model is described.

TIMBER MANAGEMENT MODELS

Simulation models of timber management are available since several years. They are being used by public agencies such as the U.S. Forest Service and private industries involved in forest land management.

One of the first forest management simulation models was described by Gould and O'Regan (5). The Harvard Forest Simulation model simulates the basic relationships involved in the management of forest land for a hypothetical forest generated by computer. Alternative management decisions can be examined; the effects of annual harvesting decisions on the forest can be studied. Four different timber harvesting methods can be chosen: improvement cutting, partial harvest cut, stand elimination, and clear cut. Financial variables, prices and costs are considered explicitly, and budgets are preset each period to allow simulating economic conditions of forest management.

Most timber management models developed subsequently followed this basic scheme, with added components to allow simulating more complex situations. For example MAXMILLION described by Clutter (4) was developed for optimizing timber harvesting schedules of industrial forest properties in the South. Another complex simulation model of timber management activities Timber RAM (Resources Allocation Model) developed by Navon (7) is being used extensively by the U. S. Forest Service. Other such models were developed by Myers (6) and Walker (9).

Timber management simulation models for educational and training uses were described by Bare (1) and Pelz (8).

Most multiple forest use or multiple forest resource simulation models were developed for specific situations. For example a model was developed for the Snohomish River Basin (2) that simulates land use in the entire river basin.

This paper presents a general multiple forest resource simulation model developed at the University of Illinois, that was designed to be adaptable to a variety of different conditions with little programming effort. In the following, the multiple resource simulation model and its major submodels are described in detail.

THE ILLINOIS MULTIPLE FOREST RESOURCES MANAGEMENT MODEL

The multiple forest resource model is composed of four major submodels each representing a particular forest résource, i.e., timber, wildlife, recreation and watershed.

The basic units for simulating forest resource management activities are forest stands or compartments of varying size. Each stand is a homogeneous unit with respect to composition and response to external influences. All management activities are applied to these units and all forest uses are defined in terms of these units.

The simulation model is programmed in Fortran IV and is operable on an IBM 360/75 and a Cyber 175. The program consists of one executive main program and 19 subroutines simulating various subsystems. The main program performs the input and output functions, initializes all variables and controls the subroutines.

Input variables are subdivided into four classes: (1) forest data, (2) natural catastrophy probabilities, (3) economic variables, and (4) management decision variables. Forest data include such stand characteristics as stand age, average diameter, average stand height, number of trees, volume, species, site quality, and skidding and trucking distances.

Natural catastrophies simulated are forest fires and storms. The probability of fire occurrence, the probability distribution of the area burnt, and the probability distribution of damage are specified during input. The probability of storm occurrence is also an input variable, the conditional probability of storm damage, given a storm occurred, is specified according to stand height and species.

Financial input variables refer to prices and costs. The price per volume unit of timber is specified for several diameter classes. Harvesting and thinning costs per unit of volume are in the form

$$C = b_0 + b_1/D^2$$

where D = average stand diameter

b_0 and b_1 = coefficient specified during input.

Skidding and trucking costs per unit of distance are $C = b_0 + b_1 \cdot$ Distance. Again b_0 and b_1 are input variables. The costs of site preparation, regeneration, and fertilization are specified per area unit. Additional financial input variables include the interest rate for discounting future costs and revenues, the average price and cost increase per year, and the fee for recreational activities. Management decision variables specify the activities that will be simulated.

Prices and costs are allowed to increase each year a specified percentage. The actual prices and costs for the year are generated from truncated normal distributions. Each year the range and variance of the distribution increase, reflecting the increasing risk associated with predictions extending into the future.

TIMBER MANAGEMENT MODEL

The timber management model simulates all activities associated with timber management. Six subroutines simulate timber management activities, one simulates stand growth, and two simulate natural catastrophies.

Timber management activities include fertilization, site preparation, regeneration, commercial and precommercial thinnings, and harvesting. In the following these submodels are described in some detail.

Fertilization is conducted to increase the growth of trees, resulting in higher volumes at harvesting time. In simulating fertilization the program sets some restrictions with respect to stand age and the total area treated. Stands may only be fertilized if they are less than 70 years old, i.e., stands will not be fertilized if they are within 10 to 20 years of harvesting. The area treated during one year has to be less than ten percent of the total forest area to achieve steady state conditions rapidly. No stand will be fertilized more than once every decade. The effect of fertilization is a growth increase for ten years.

Site preparation is performed before reestablishment of a forest after harvesting, storm damage or fire damage. Three levels of site preparation can be chosen: intensive, medium, and zero. Site preparation increases the regeneration success rate, intensive site preparation by 10 percent, and medium by 5 percent. The response is assumed to be equal for all stands regardless of the site quality.

The regeneration submodel simulates the reestablishment of stands that have been harvested or were destroyed by fire or storm. Stands can be regenerated artificially, e.g. by planting, or naturally by seeding from remaining seed trees or the adjacent stand. In both cases, the regeneration is completed if a success rate of 80 percent is achieved, i.e. 80 percent of all seedlings have to survive after the first year. Regeneration success is a random variable generated from a truncated normal distribution with a mean of 0.80 for artificial and 0.70 for natural regeneration. If the success rate is less than 80 percent the regeneration will be repeated until the cumulative success rate is 80 percent or higher. Natural regeneration can be repeated for up to five years after which the remainder is regenerated artificially. The species composition of the stand will not be changed by regeneration.

Thinnings are performed to increase the growth of the residual stand, to concentrate growth on the most valuable trees, and to obtain revenues before the final harvest. Thinnings performed in young stands are called precommercial thinnings as they normally do not generate any revenues. For precommercial thinnings the program again restricts the area treated each year to 10 percent of the total area, to achieve steady state conditions rapidly. For commercial thinnings, i.e. operations that are performed with the intention of generating revenues, the user specifies the stand age at which the thinning operation is to be performed and the thinning intensity.

Forest stands may be harvested by selective cutting for which the entire harvest period may extend over 10 to 20 years, or by clear cutting for which the harvesting operation will be completed within one period.

If only part of a forest stand is to be harvested a new stand will be generated that comprises the harvested portion of the original stand. The original stand is then reduced to include only the residual stand. Thus, the number of forest stands increases each time part of a stand is clear cut or destroyed by fire or storm.

The user identifies the stand and species to harvest and specifies the area or volume to harvest in the stand. The program simulates the harvesting operations, updates the stand vectors, and summarizes timber volumes and cashflow from harvesting operations.

Timber harvests affect other forest systems to varying degrees. Small clearcuts for example have beneficial effects on wildlife due to the increased edge effect. Similarly, small clearcuts will improve recreation opportunities by providing logging trails for hiking and indirectly by improving hunting conditions. In some cases, these positive effects will be reduced or will with increasing size of the clearcut become negative.

Forest Growth

The development of stand characteristics is simulated for each year. The change of average stand diameter is predicted by a function of the form

$$DD = f(D,S,A)$$

where DD = diameter growth per year
D = initial diameter
S = site quality index
A = stand age

The change of average stand height is predicted by a similar function

$$DH = f(H,S,A)$$

and the change in number of tree per unit area

$$DN = f(N,S,A)$$

To these predictions random effects are added, as the growth of a forest is a random variable and can not be predicted with certainty. The growth of the stand is affected by timber management activities, mainly fertilization and thinnings, which increase the growth of the stand for several years. The timber volume increase of the stand each year is calculated from the changes of diameter, height and number of trees.

Natural Catastrophies

The model simulates the occurrence of forest fires and storms. Each year fire and storm occurrence and the extent of damage are generated for all stands. The probability of fire occurrence and the probability distributions of the area burnt and fire damage are specified during input. Management response to fire depends on its severity. Damage of less than 20 percent does not result in any actions, damage over 80 percent will cause the elimination of the entire stand by subsequent clearcut. At a damage between 20 and 40 percent the response depends on the stand age, at a stand age of less than 20 years the stand will be regenerated. Damage between 40 and 80 percent results in a subdivision of the stand into two parts, one covering the burnt area, the other containing the undamaged portion of the original stand.

Only one fire can originate in one stand during one year, but a fire can spread over several stands.

The probability of storm damage is conditional on the stand height, larger trees have a larger probability of being damaged than smaller trees. Again the management response depends on the severity of damage. Timber in a stand destroyed by storm is assumed to be salvageable, 80 percent of the volume can be salvaged, but at higher costs than in normal harvesting operations.

WILDLIFE MODEL

The objective of this model is to simulate the interactions of the forest and the wildlife system. Many different wildlife species inhabit a forest, however for most species little is known how they affect other forest subsystems or are affected by them. Therefore the model is restricted at present to one game species that is well studied, white tailed deer.

The dynamics of the deer population is simulated for each individual forest stand separately. Deer population characteristics for each compartment, i.e. the number of bucks, does, and fawns is given as input. Changes in deer population are due to management decisions affecting the deer herd directly and indirectly and due to natural causes.

Young and highly variable stands have a high carrying capacity, very homogeneous stands have a low capacity. This difference in carrying capacity is expressed in the model by differences in propagation rates. Timber harvests affect the wildlife system by improving the environment which leads to a higher deer propagation rate resulting in higher deer densities. Deer herds are reduced by hunting and by natural causes, especially winter kill, and by road kill. Mortality is a random variable, the size of the deer herds therefore will fluctuate from year to year.

The effect of deer on the timber management system is represented by the fact that deer browse seedlings and thus reduce regeneration success, and that they damage young trees, increasing tree mortality and decreasing commercial value of the affected timber due to rot. The hunting submodel which is a submodel of both the wildlife and the recreation model is described later.

RECREATION MODEL

The model of the forest recreation system considers three forms of forest recreation: (1) hiking-nature study, (2) camping-picnicking, and (3) hunting.

Hiking-Nature Study Model

This submodel simulates the use of the forest by hikers. The forest manager may in some cases wish to raise a fee for the use of the forest. To determine the number of visitors at different price levels a demand curve has to be derived. This demand curve is site specific, depending on the attractiveness of the forest, the proximity of population centers and the availability of recreational alternatives. Such a curve was derived for one of the applications of the simulation model. At that forest a self guided nature trail already existed that was being visited by more than 5000 persons each year. The demand curve was derived using the travel cost method (3). It is based on the assumption that a visitor presently paying A dollars for travel to the site would behave like a visitor paying A + B dollars if the difference of B dollars were raised as entrance fee. For example the visitor rate for one town was 11.33 per thousand at a distance of 25 miles, the rate for another town 3.70 per thousand at a distance of 40 miles. If a fee was levelled that equalled the travel costs for 15 miles (40-25 miles) we would assume that the rate for the first town would drop to 3.70 per thousand. The total number of visitors at various price levels is determined, the resulting curve allows the manager to evaluate alternative pricing strategies.

Camping-Picnicking Model

This model simulates the management of a campground and a picnicground. The decision variables are the number of sites to provide and the fee charged. Again, the demand curve is site specific and has to be derived for each case separately.

Deer Hunting Model

Deer hunting management is simulated by this model. Decision variables are the number of hunting permits to issue, depending on the difference between actual and desired herd size, and the fee to charge per permit. The maximum fee that can be charged is determined by the demand for permits which is site specific. For one of the applications of the model a demand curve for hunting was derived by using the questionnaire method, i.e. hunters were asked how much they might be willing to pay for one permit. This demand curve shows the maximum amount that can be charged for a given number of permits to be issued.

The effects of alternative pricing and permit strategies upon the wildlife system and the entire forest system can be tested. A small number of permits issued means that a lower number of deer are killed, leading to a deer population increase that in turn will result in more damage to tree regeneration. A high number of permits issued during one year will lead to a decrease in deer population and a lowering of future revenues from deer hunting.

WATERSHED MODEL

In modeling watershed aspects each forest stand is considered an independent watershed. This simplification was necessary as in general no detailed field studies can be made to delineate actual watersheds. The relationships of watershed and other forest subsystems are not well known, no accurate production functions were available to model this system. Therefore, the effects of timber management activities on the watershed system is modeled in broad classes only. Small clearcuts below 10 acres are assumed to increase water yields by two percent and clearcuts between 10 and 30 acres by 5 percent. Presently we do not feel that we can beyond this level of simplicity as we do not have a sufficiently large data base showing the relationships between the watershed system and other forest subsystems.

EXPERIMENTAL DESIGN

The multiple forest use simulation model is probabilistic emphasizing the probabilistic environment of forest resource management. Price and cost variables are generated from probability distributions, effects of management activities are subject to random variation; natural catastrophies may occur at any time during the planning period. To derive valid conclusions about the efects of alternative decisions multiple sets of output have to be generated that allow evaluating the risks associated with these decisions.

To minimize the number of runs necessary to achieve the desired precision antithetic variables were generated. The model was operated with the random number RN during the first run and 1-RN during the second run. It was necessary to use two different random number generators to maintain event equivalency. One random number generator was used for simulating prices and costs, the other for simulating fires and storms.

APPLICATIONS

The model was designed for maximum flexibility that it could be applied to a variety of situations. The model is being applied to two forests in Illinois for model validation.

Sinnissippi Forest is a private forest of about 2800 acres in Northern Illinois consisting of about 75 percent native hardwoods and 25 percent planted pines. The number of tree species exceeded 30 and were distributed over several hundred stands. The problem in the original form would have required excessive computer storage facilities and long solution times because of the large number of variables. To reduce the number of variables individual species were replaced by forest types. A forest type identifies a forest stand according to certain criteria of which species composition is the most important. For example a stand in a black oak type will have black oak as major species. Some information will be lost with this approach but the dimensionality of the problem was reduced to a feasible range. Forest input data were derived from a forest inventory conducted previously. The wildlife model requires deer population characteristics for every stand as input. Detailed wildlife surveys are expensive to conduct, therefore estimates of the deer population were used in this study.

Growth equations for the forest stands had to be derived to allow the simulation model to operate over several years.

Demand curves for hiking and hunting were derived for the forest, camping and picnicking relationships were modeled after State Parks in the vicinity.

Presently we are testing the model for a State Forest in Illinois and encounter similar problems as before with the data gathering. The computer program needed in both cases only minor changes that could be implemented relatively easy but the data collection and the preliminary studies that were necessary for deriving specific functions, growth equations, and demand curves required considerable time and effort.

DISCUSSION

The model in its present form allows for expansion to include additional submodels of various systems and it allows for changes of functions and relationships for local conditions. The model is designed for maximum flexibility, so that it can be used for a variety of different forest conditions with only minor programming changes. The program will be further refined; some of the relationships presently only estimated will be updated as more information becomes available. In addition, several models will be added representing nongame wildlife species.

The model of multiple forest use management can be a valuable guide for forest managers in their decision making process. With it alternative management decisions can be tested and their effects on the entire forest system can be evaluated.

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