The Application of Simulation in Forest Management

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INTRODUCTION

In this paper I will present a brief introduction to the subject of simulation and then describe several applications of the technique in the area of forest management. Following this I will briefly introduce the topic of management games and show the value of this technique in an educational environment.

Although the word simulation has been used for many decades, the origin of the word in a more contemporary sense can be traced back to the development of the term "Monte Carlo analysis" by von Neumann and Ulam in the late 1940's[19]. They used Monte Carlos analysis to solve certain deterministic mathematical processes by simulating a probabilistic process that incorporated the desired probability distributions of the original deterministic process. They used this approach in developing the atomic bomb during World War II. Since that time the rapid growth of the digital computer industry has made it possible to construct and experiment with various types of mathematical models. In addition, the use of simulation has been adopted by economists, social scientists, operation researchers, agriculturalists, business firms, etc. In fact, there is hardly an academic discipline existing which has not been subjected to analysis by the simulation approach.

DEFINITIONS OF SIMULATION

While I have used the word simulation several times I have not given a formal definition of the term. One reason for this is that no two authors agree on a single definition. Therefore, I will provide several definitions of the term. The simplest definition of simulation is that it is a "representation of reality." A second definition is that simulation is "a dynamic process of building a model and moving it through time."(2) A third definition is that it is "the process of conducting experiments on a model of a system rather than on the real system."(15) A last definition is that simulation is "a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behavior of a business or economic system over extended periods of real time."(21)

MODELS

Each of these definitions either implicitly or explicitly involves the use of the word model. Therefore, some time should be devoted to a discussion of this very important subject. From the observation and familiarization of some real system we form a set of hypotheses concerning the functioning and organization of the system. A model is an idealization or further abstraction of this set of hypotheses which we formalize into a logical and sequential series of operational steps. The ultimate use of a model is for purposes of prediction and control of the real system.

The basic concept inherent in model building is that of abstraction. All models involve the abstraction of some real physical system, but the degree of this abstraction varies from model to model, and is dependent upon the ultimate use to be made of the model. During the process of abstracting some real system we must be careful to include the relevant factors and processes so that our model remains a valid representation of the real system. This then allows us to experiment with the model and to apply the results back to the real system. To insure this representation of reality the natural tendency is to include many variables or processes in the model without first formulating the basic structure of the model. The result is that the model becomes unduly complicated so that the experimenter or modeller can no longer understand what the model is doing, That is, the internal workings of the model become untractable. This then is the basic paradox of modeling and of simulation in general (i.e., how to make a model as realistic as possible without making it as complicated as the real system).

From this discussion it can be seen that a model itself is neither true or false, but its value is judged by the contribution which it makes to our understanding, prediction, and control of the system under study[17]. Thus, the proper criterion for judging the validity of a model is whether or not it accurately predicts the relative effects of alternative courses of action in order to permit a sound decision.

CLASSIFICATION OF MODELS

Various classification schemes have been used to categorize models. I will use the following scheme proposed by Naylor, et al[21] and Ackoff and Sasieni[1].

a) iconic (physical) models
b) analogue models
c) mathematical models
d) deterministic models
e) stochastic models
f) static models
g) dynamic models

Without going into any great detail I will illustrate the differences between the different types of models listed above. It should be noted that the above classification scheme does not provide a mutually exclusive set of classes. For example, a model may be both mathematical and stochastic, or mathematical, static and deterministic.

A physical model is a model that retains a physical resemblance to the real system being described. The principal difference between the real system and the model is that of size. Examples of this least-abstract type of model are model airplanes, pilot plants, wind tunnels, etc. An analogue model uses one set of properties to represent a second set of properties found in the real system. Examples of this type of model are contour lines on a map representing elevations, or the lines on a graph representing the relationship between a set of variables. A mathematical model is the most abstract of the models. In this case, symbols and equations are used to describe the real system under study. If a mathematical model is transformed into a form suitable for processing on a digital computer, it is called a computer model. This is the type of model that is normally thought of when one talks about simulation, but it should be clear that simulation models encompass a much wider area than just computer models. However, it was the development of computer models that caused the tremendous growth and interest in modern simulation techniques.

A deterministic model is one in which neither the internal nor external variables are allowed to be random variables. That is, for a given set of input parameters successive runs of the model will produce identical sets of output. In deterministic models all internal relationships are assumed to be known with certainty. Stochastic, or probabilistic, models are those which incorporate random processes. Thus, for a given set of input parameters successive runs of the model will produce different sets of output. However, the values of the output variables will follow some previously determined distribution. In stochastic models all, or some, of the internal relationships are not known with certainty, but instead are described by some probability function. Simulation is widely used to experiment with stochastic models because of the lack of analytical techniques for directly solving models of this nature.

Static models are those which do not explictly consider the time element. Conversely, dynamic models are those which deal with processes which occur over time. While classical analytical techniques have concerned themselves with the solution of static - deterministic systems, simulation has been more widely applied to the investigation of dynamic - stochastic systems.

One point that should be stressed at this time is that simulation is not an optimizing technique. That is, when we experiment with, or run, a simulation model we have no assurance that we will manipulate the system in an optional fashion. While repeated experimentation may give some indication that a certain set of input decisions causes the model to behave in an optimum fashion, there is no mathematical proof that this is the true optimum. Clearly then, simulation is quite different from many other operations research techniques which search for optimum solutions.

APPLICATIONS IN FORESTRY

I will now turn from a general description of simulation and modeling to some specific uses of these concepts and procedures in forestry. Perhaps one of the earliest uses of simulation in forestry was in the testing of alternative sampling designs, useful in forest inventory[3,16,27,29]. Studies of this type involve the repeated sampling of a mapped stand according to various sampling strategies. The required input consists of the rectangular coordinates of all trees on a given forest. Once this information is read into the computer it is possible to generate the location of the sample plots and to determine whether a given tree is to be sampled. The sample plots may be distributed randomly, systematically, or randomly within pre-determined strata. Further, it is possible to vary the sample size and to experiment with fixed radius plots or variable radius plots.

A second use of simulation is in the development of stand models. Using simulation procedures it is possible to describe the effects of competition, spatial arrangement, growth and yield, and mortality of a given stand as it develops over time. Several models of this type have been developed for Douglas-fir, lodgepole pine and white spruce[18,22,23]. In addition to these stand models simulation has been used to generate various spatial distributions and frequencies of mortality for even-aged stands[28].

A third use of simulation is the determination of the most satisfactory way to allocate a fire detection budget[13]. Using simulation it is possible to re-construct: (a) fire weather for a given time period; (b) the fire danger; (c) the rate of spread; (d) the visibility for a given day; (e) the probability of a fire occurring on a given day, etc. Within the simulated environment it is possible to determine the effectiveness of a fixed-location fire tower system, an aerial surveilance system, or a combination of both of these. Various combinations of detection systems have been tried on successive runs of the model in order to determine that detection system which gives the best results for the dollars spent.

Simulation has also been used in determining the effect of spatial distribution of trees, size of stand, pattern of cutting, etc., on the type of harvesting equipment to use to harvest a particular forest area[5,12,14,24,25].

APPLICATIONS IN FOREST MANAGEMENT

While many other forestry uses of simulation could be mentioned, (i.e., mill yard inventory and allowable cut calculations) I will conclude my brief presentation by discussing the application of simulation to forest management problems. The first application of simulation in this area was the Harvard Forest Simulator[9,26]. Although this simulator has been criticized as being unrealistically simple, it did open the door for further more refined models. This model was constructed to determine the long-range effects of a price insensitive (i.e., traditional regulation methodology) vs. a price sensitive harvest strategy. Simplifications in the model included: (a) only one species and product; (b) only one site index; (c) deterministic occurrence of catastrophic disturbances; (d) the lack of any spatial allocation of the cut; (e) the use of a normal yield table for obtaining yields; (f) the assumption of immediate regeneration of harvested acres and (g) the lack of any facility for handling silvicultural practices. A revised version of this simulator has removed many of these simplifications and has made the model much more realistic[10]. However, in my opinion, one deficiency that still remains is the lack of any spatial or geographic allocation of management activities.

A second example of a forest management simulator was that developed at the Rocky Mountain Forest and Range Experiment Station[20]. This model is similar to the Harvard simulator in scope but is more sophisticated than the original Harvard model. Like the Harvard simulator, this model does not allocate the cut to a geographically located compartment or stand. This simulator can be used to test many combinations of alternative timber management strategies over extended periods of time. Since it includes options for several silvicultural treatments it allows for a more realistic representation than the original Harvard model.

A third example of a forest management simulator was that developed at the University of Georgia[7,8]. This model is quite different from either of the two preceding models in that it identifies each individual stand and associates a particular management regime with each stand. Thus, for each stand the manager determines the feasible management alternatives. The simulator then computes the wood volumes and discounted values associated with each regime. As we saw this morning the output from this simulator is fed into a linear programming model where the objective is to maximize the discounted present value of harvested material subject to restrictions on the volume of wood harvested each year, and the number of acres regenerated each year. This particular model has been used extensively by the pulp and paper industry in the southern United States where it has been used to schedule over 15 million acres of pine land.

In addition to these published models, most of the large pulp and paper and lumber companies in the U.S. have developed simulation models for use in their timberland divisions. These models have proved to be very valuable planning tools and, further, they have stimulated the development of new concepts and procedures in the area of forest management.

MANAGEMENT GAMES

Before concluding my presentation I would like to spend a few minutes introducing the subject of business or managment games. Management games are actually a form of competitive simulation where several management teams compete against one another within the simulated environment created by the game. The distinguishing characteristic of management games is that human participants interact with the simulation model as it proceeds through time. Thus, feedback from earlier decisions is used to modify the actions and decisions of the participants during some later decision period[11].

The three most important advantages of management games over other existing educational techniques are: (a) the ability to compress the time horizon so that students may visualize the impact of past decisions and also so they may manage a firm or resource over an extended period of simulated time; (b) the emphasis of games on integrating knowledge of several subjects or disciplines within a decision - making environment and (c) the emphasis on the organization of reports and available information so that it can be used effectively to make the best possible decisions. Some management games give students experience in developing long-term strategies and policies while others stress the implementation of a strategy on a short-term basis with primary emphasis on short-term goals and objectives.

CLASSIFICATION OF GAMES

Management games may be classified according to several criteria. First, games may be interactive or non-interactive. A game is said to possess the interaction characteristic if the decisions of one team affect the decisions of another team. Otherwise it is non-interactive. Obviously, a whole continum of interactive games exist since some games are extremely interactive while others are only slightly interactive.

Management games may also be classified as either functional or top management oriented. While a top management game involves the simulation of a total enterprise with marketing decisions, production decisions, research and development decisions, etc., a functional game only involves decisions in one of these areas. Most of the current emphasis is on the development of this latter type of game. Examples of functional games are: (a) The Purdue Forest Management Game[5]; (b) The Purdue Farm Supply Management Game[4]; (c) The Harvard University Forest Simulator[9]; (d) The Penn State Pulpwood Procurement Game[6].

Management games may also be classified according to: (a) the number of products included; (b) the length of the planning horizon; (c) the number of students per team; (d) the number of teams per game and (e) whether the games include stochastic or deterministic elements.

FOREST MANAGEMENT GAMES

In the area of forest management there are only a limited number of management games currently available. The previously mentioned Harvard Forest simulator can be considered as a game. However, there is no interaction between teams so the student actually competes against nature rather than against an opponent in a business environment. The first forest management game designed expressively for educational purposes was the Purdue Forest Management Game[5]. This game will be described shortly, so further description will be deleted until then. A third management game which has recently been constructed is the Penn State Pulpwood Procurement Game[6]. While the Purdue game involves the production of pulpwood from company owned lands, the Penn State game is only concerned with the purchase of wood from outside sources. The possibility of linking these two games together to form a single complete game has been discussed and may be attempted this year. The only other forest management game I am aware of is the Forest Industries Management Game developed at the University of Oregon[30].

This game is not involved with actual forest management activities but is more concerned with the decisions surrounding the manufacturing of logs into various types of forest products. Therefore, this game will not be described in any further detail.

This concludes my brief introduction to simulation and its application in forest management. As can be seen, simulation has proved to be a very valuable planning tool for both forest managers and researchers. It will probably continue to gain popularity as the technique becomes more widely understood. Ultimately, a new approach to forest management may imerge with simulation being the basic planning tool.

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