A REVIEW OF COMPUTER SIMULATION IN FOREST MANAGEMENT AND A PRESENTATION OF A FOREST MANAGEMENT SIMULATION MODEL FOR DOUGLAS-FIR

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INTRODUCTION

Within the last ten years, the verb "to simulate" is a term that has come into wide use in forest management. O'Regan, Arvantis and Gould (1965, p.194) have termed simulation as the "new disciple", the approach to problems in a systems context;

> to break a problem down into simpler component parts, so that variables in a particular part, or sub-system, are more related to each other than to variables in other sub-systems; to identify restraints on possible solutions, to devise a model, and then to operate the model to obtain solutions.

The use of electronic digital computers for simulation in forest management is described by J.H.G. Smith (1967, p.4) as part of the "trend towards diagnostic rather than descriptive forestry research".

Greatly improved forest management can result from careful consideration of the potential results of decisions and appreciation of the full range of economic and biologic-ical factors as illustrated by computer simulations of stand growth and yield of forest products. The increased use of electronic digital computers for simulation has made it possible to "make an attack on some of the problems which underline our fundamental knowledge of forestry" (Jeffers, 1961, p.175), and to solve many forestry problems previously considered unmanageable (Lee, 1967).

It is the purpose of this paper to review the literature on computer simulation in forest management, and to present the adaptation of a stand model to Douglas-fir as part of the development of a forest management simulation model.

THE PLANNING SITUATION

In recent years, the rise of new social values and the changing raw material requirements resulting from technical innovations have brought about the need for more and better planning; "a process of continous planning to balance the use of forests ... to adjust the slow process of nature to the rapidly shifting demands of society" (Gould and O'Regan, 1965, p. 2).

Any attempt at a process of continuous planning must involve the prediction of future events (Clutter and Bamping, 1965). The use of these predictions in forest management is complicated by two principal difficulties. The first is the uncertainty associated with any prediction of future biological and economic conditions. As our experience and scientific knowledge increases, we are able to predict the future with less uncertainty, but it is probably fair to say that this problem will "always be with us in any kind of management planning" (Clutter and Bamping, 1965, p. 180).

The second problem arises from the conceptual and computational magnitude involved in defining the factors affecting the operation of the enterprise and in keeping track of them during some future planning period. This problem involves: defining appropriate mathematical models to describe the enterprise, providing input information required for calculations with the model, and actually carrying out the arithmetic involved in projecting the models foward through time.

In spite of the apparent simplicity of this problem, forest managers have been forced to use outmoded data and simplified rules-of-thumb, simply because it required too much work and money to use better, more detailed data and more sophisticated analyses. With the development of electronic digital computers in the early 1950's, computing equipment capable of dealing with this problem became available (Clutter and Bamping, 1965).

EARLY APPLICATIONS OF COMPUTERS

The first applications of electronic digital computers to forest management problems were primarily concerned with the speeding up of computations which were already being undertaken by other means (Jeffers, 1961); such as calculations involved in large scale forest enumerations in the construction of yield and volume tables and the mathematical analysis of designed experiments and surveys. The entire Dec. 13th, 1957 issue of The Timberman was concerned with this type of computer applications in forestry, citing the applications of computers by private industry and federal and state agencies for use in forest inventory, audit reports, fire reports, mailing lists and project costs.

In recent years this same type of computer application has been used in work such as the processing of sampling data for valuation of immature timber stands (Hunt and Bell, 1961); calculation of bare land value and optimum rotation of a stand using the Faustmann equation (Howard, 1965); and the calculation of annual allowable cuts by area-volume regulation (Chappelle, 1966a) and area regulation (Sassaman and Chappelle, 1967).

In all of these applications, little advantage was taken of computers except that of speed and the tireless recall of data from the computer's memory. The form of calculations differed only slightly from that which would have been used by more conventional computing aids (Jeffers, 1961).

SIMULATION

In the past ten years, it has become apparent that the most important characteristic of computers in forestry is their ability to be used for types of calculations that had never before been attempted; not merely because they would take too long, but also because they were too complex to be handled by conventional computing machines (Newnham, 1968). Included in these new types of calculations is the use of mathematical models to simulate practical problems.

This "simulation" of problems is not a new concept. Simulation is nothing more than the ancient art of model building which has been adapted to some extremely diverse forms of models ranging from Renaissance paintings and sculptures to scale models of jet planes (Naylor et al., 1966). Simulation of a system in this sense can be defined as the operation of a model which is a representation of the real system; the model being amenable to manipulations which would be impossible, too expensive or impractical to perform on the entity it portrays.

Although the concept of simulation is not new, the use of electronic digital computers for simulation is a relatively new technique. Without the use of a computer, simulation studies would have to be very simple and often less realistic, and most of the time impossible (Lee, 1967). In this context, simulation as defined by Naylor et al. (1966) 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 system over extended periods of time.

The main uses of simulation models are for demonstration or display, for testing, for teaching aids, and when sufficiently refined, as aids to decision making.

The advantages of simulation are many:

a) Simulation makes it possible to study and experiment with the complex internal interactions of a given system.

b) Through simulation one can study the effects of certain informational, organizational, and environmental changes on the operation of a system by making alterations in the model of a system and observing the effects of these alterations on the system's behavior.

c) Detailed observation of the system being simulated may lead to a better understanding of the system and to suggestions for improving it, which otherwise would not be obtainable.

d) Simulation can be used as a pedagogical device for teaching both students and practitioners basic skills in theoretical analysis, statistical analysis and decision making.

e) The experience of designing a computer simulation model may often be more valuable than the actual simulation itself.

f) Simulation of complex systems can yield valuable insight into which variables are more important than others in the system and how these variables interact.

g) Simulation can be used to experiment with new situations about which we have little or no information.

h) Simulation can be used to try out new policies and decision rules for operating a system before running the risk of experimenting on the real system.

i) Simulation affords a convenient way of breaking down a complicated system into sub-systems, each of which may then be modeled by an analyst or team which is an expert in that particular area.

j) Simulation makes generalists out of specialists. Analysts are forced into an appreciation and understanding of all facets of the system, with the result that conclusions are less apt to be unworkable within the system framework.

k) Simulation models are valuable in gaining enthusiasm and acceptance for proposed changes in an operational process.

l) Simulation models do not depend on mean, median or model values in describing a variable factor.

m) Simulation models are more maneuverable than conventional mathematical techniques in the hands of those lacking advanced mathematical skills.

Simulation models also have their disadvantages. Simulation models do not seek an optimum solution to any problem, although they could provide data to be subsequently used by other optimization techniques. It is generally not possible to estimate the accuracy of simulation models due to the lack of data or to their intricacy, which prevents objective statistical tests. However sophisticated these models are, they are still unable to portray the real world as it actually exists; they only "sketch in some of its essential features" (Newnham, 1968, p. 7).

In building models for simulation, a number of assumptions and simplifications must be made. Thus the mathematical models are no better than the assumptions made and the data used.

FORESTRY SIMULATION MODELS

SAMPLING MODELS

The first computerized simulation models for use in forestry were those developed for simulating sampling methods by Palley and O'Regan (1961; O'Regan and Palley, 1965) that compared the efficiency of point sampling with line sampling and circular plot sampling.

The computer technique developed was based on the concept that an alternate way to study forest sampling methods, other than by making inferences from the results of actual sampling trials, is to identify and study all the elements of the population from which samples may be composed. Working from a simple example of listing the entire population in random point sampling, Palley and O'Regan developed an IBM 701 computer program which approximated the conceptual population defined by point and line sampling in a forest containing a large number of trees.

The idea of putting forests in the memory of a computer and simulating the application of different rules of sampling has promise in relation to those problems of forest sampling which can best be approached in terms of a study of all possible samples (Palley and O'Regan, 1961).

These models developed by Palley and O'Regan were later extended to include detailed cost analysis (O'Regan and Arvanitis, 1966).

In working with their models, Palley and O'Regan emphasized that it is the method they have developed that is important; their results are only an example of its use and should not be accepted as generalizations.

A simulation study in sampling which used the same basic technique as Palley and O'Regan is that by Payandeh (1968). The relative efficiency of systematic, stratified and simple random sampling for crown area, tree frequency estimation, and the effect of spatial distribution of trees in five major forest types found in the Pacific Northwest were studied. The basic data in the study consisted of the location and size of each tree crown as obtained from crown maps which were constructed from large scale aerial photographs. These data were put into the memory of a CDC 3300 computer, and the entire analyses was executed through computer simulation.

The savings in time and money by putting the forest in a computer and letting the computer do the sampling are obvious. With the advent of faster computers with larger memories, "there is little doubt that these methods will be more widely used" (Newnham, 1968, p. 8).

MANAGEMENT MODELS

A computer simulation model in which the basic unit is the forest stand, or compartment, rather than the individual tree as used in sampling models, is the Harvard Forest Simulator developed by Gould and O'Regan (1965).

A collection of stands making up a hypothetical forest enterprise was loaded into the memory of an IBM 7090 computer and then used to test the effects of rotation length and allowable cut on the volume and value harvested. These stands were projected on the basis of a normal yield table developed from experience with white pime in the Petersham, Massachusetts area. Allowances were made for variations in stumpage rates. A number of options, such as the occurrence of natural hazards or catastrophes, were also built into the model. These could vary from small local losses by fires to wide-spread losses by storms and hurricanes which could affect stumpage prices.

In their study, Simulation: A step towards better forest planning, (Gould and O'Regan, 1965) sustained yield policies were tested against variable yield policies. "The model is still very simple and perhaps not too close to reality" (Newnham, 1968, p. 8). It main uses at the present are for instruction and for giving management personnel experience in decision and policy making.

A model similar in concept to the Harvard Forest Simulator but involving a considerably larger enterprise and a somewhat more sophisticated representation of the biological and economic factors involved has been developed by Clutter and Bamping (1965) for use on an IBM 7094 computer.

The model simulates the reactions, biologically and economically, of a 330,000 acre hypothetical forest to any specified regime of management.

HARVESTING MODELS

Newnham (1966a) developed a simulation model that imitates the passage of a harvesting machine through a pulpwood stand. The model was developed for the feller-buncher type of harvesting machine having a rotating boom which can reach out and harvest all trees within a certain distance.

The model was used to test the effect on harvesting time per cunit of pulpwood of different operating speeds, different minimum and maximum radii of sweep or boom reaches, different strip widths and the effects of varying spatial pattern and number of trees per acre.

STAND MODELS

Of particular interest to the present simulation study are the stand models developed by Newnham for Douglas-fir (Newnham, 1964) and lodgepole pine (Newnham and Smith, 1964) and Lee's revision of Newnham's lodgepole pine model (Lee, 1967). These stand models describe the growth of a stand of trees on an individual basis as opposed to other models which use yield tables based on stand averages. Stand models have numerous advantages over the use of stand averages in simulation models. With the increase in demands for forest products has naturally come more intensive forest management controlling stocking and stand density through planting, spacing control, and thinning; thus creating a demand for improved growth information. By using a stand model for the projection of growth, various spacings, natural mortality resulting primarly from competition, irregular mortality, and various thinning regimes can be studied as to their effects on the development of a stand. In the past, normal yield tables have been assumed to represent what fully stocked forest stands can produce for a given age and site index. "The normal yield concept is simple, but its use is limited today" (Lee, 1967, p. 155). In comparison, a stand model can simulate the development of a stand from an understocked condition to normal stocking, or from normal stocking to an overstocked condition, as well as from overstocked to a normal stocked condition.

Although growth of stands may appear to be just the summation of the growth of individual trees, it is actually different and more complex because of mortality and in-growth (Lee, 1967). The amount of wood produced annually from a given stand at a certain time depends upon stand structure,1/ species composition, site quality and climatic variations (Lee, 1967). Over any given growth period, all but stand structure remain fairly constant. This effect of changing stand structure can be studied by the use of simulation models based on individual tree growth.

In the development of the Douglas-fir model, as in the

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1 Stand structure as used in this paper means not only the constitution of a stand with respect to age, crown, diameter and tree classes, but also the spatial distribution of trees.

building of any simulation model, Newnham made a number of assumptions concerning the dynamic changes in the development of a stand. These assumptions are:

a) Fully open-grown trees have the greatest radial growth at breast height.

b) Stand density increases with age and has a tendency to achieve a stable level roughly similar to that of the normal yield tables.

c) The age at which the initially fully open-grown trees come into competition can be estimated from study of crown widths.

d) Competition can be measured by the proportion of the crown of each tree occupied by the crowns of surrounding trees.

e) When a tree is released from all competition, it resumes the rate of growth of an open-grown tree.

f) After initial mortality, all mortality that occurs in the stand is due to suppression.

g) The average d.b.h. of trees will vary directly with site quality.

h) The frequency distribution of d.b.h. can be used to indicate crown classes on an objective basis.

Newnham's Douglas-fir model is initiated with a matrix of 15 X 15 trees; the number of trees per acre varying from 4000 at a 3.3 X 3.3 feet spacing to 250 at a 13.2 X 13.2 feet spacing. The initial d.b.h. of each tree is specified and from a crown width on d.b.h. regression, the crown width of each tree is calculated. This calculated crown width is reduced by 40 per cent to give the "competitive" crown width. As competition sets in, the competitive crowns begin to overlap, this original 40 per cent reduction is systematically reduced. Taking one tree in the matrix at a time, the model was tested to see if any of the surrounding trees were competing by determing whether the competitive crowns overlapped. If overlap occurred, the angle subtended at the center of the crown by the two points of intersection of the competitive crown perimeters for each competitor was measured. This measurement was weighted in each case by the ratio of the crown width of the competitor to the crown width of the tree being studied, thus recognizing that the trees with the larger crowns usually had the added advantage of being taller. For each tree the sum of these angles was divided by 2π to give the proportion of the circumference of the competitive crown of the tree occupied by the crowns of its competitors. Thus a value for the competitive status of each tree was obtained which ranged from zero, if the tree was free from competitors, and one or more, if the crown was occupied by several overlapping crowns.

The five-year d.b.h. increment of each tree was then calculated using a d.b.h. on age regression assuming that the tree was open-grown. This increment was reduced by an amount which depended on the competitive status of each tree, varying from zero for trees with no competitive crown overlap to 100 per cent for trees whose competitive crowns were completely overlapped by surrounding competitors. If this reduced increment was not greater than an arbitrarily chosen percentage of the d.b.h. at the beginning of the five-year period, the tree was considered to have died. If it was greater, the new diameter of the tree was calculated and used as a basis for calculating the next five-year's growth of the stand with the process being repeated to age 100 years.

At the end of each of these five-year periods, from age ten to 100, the computer program prints out the following:

a) diameter and spatial distribution of live trees
b) diameter and spatial distribution of dead trees
c) total number of live and dead trees per acre
d) mean d.b.h. for live and dead trees
e) variance associated with mean diameter
f) standard deviation associated with mean diameter
g) basal area per acre for live and dead trees
h) periodic annual basal area increment in square feet
i) mean annual basal area increment in square feet

Having developed this model, Newnham then tested it for stands having varying amounts and distributions of mortality, for various site indices, and for various thinning regimes.

Two different distributions of mortality of varying percentages were tested: random mortality, described by a binomial distribution, and clumped mortality, described by an uniform distribution. The allocation of each distribution of mortality was achieved by dividing the basic matrix of 15 X 15 tree locations into square plots of nine tree locations each, with the number of trees in each plot determined by the density function for the appropriate distribution. The locations of trees within each plot were chosen randomly.

To test differences in site quality, each tree in the basic diameter matrix used to develop the model was multiplied by a constant which varied with the site index being tested.

For testing thinning regimes, Newnham used what he termed as an objective method which was to prescribe the removal of all trees within certain diameter limits; the limits depending upon the mean d.b.h. and its standard deviation. The three thinning regimes tested were:

a) moderate low thinning - removal of all trees less than the mean d.b.h. minus one standard deviation.

b) severe low thinning - removal of all trees between mean d.b.h. minus one standard deviation and mean d.b.h. minus one-half standard deviation.

c) crown thinning - removal of all trees between mean d.b.h. plus three-fourths of one standard deviation and mean d.b.h. plus one standard deviation.

The model developed by Newnham and Smith (1964) for lodgepole pine is basically the same as the model previously developed for Douglas-fir except that new constants, used in describing crown width and d.b.h. growth, were derived from lodgepole pine data. In addition, a fixed amount of two feet, instead of 40 per cent, was deducted from calculated crown width to get the competitive crown width. Height estimation of individual trees and total cubic-volume per acre were introduced into the model. Thus, to the information printed out be the Douglas-fir model at the end of each five-year period, the following were added:

a) mean height for live and dead trees.

b) total cubic-volume per acre for live and dead trees.

c) cubic-volume of trees six inches and over in diameter, per acre for live and dead trees.

Lee's model for lodgepole pine (Lee, 1967) is basically the same as Newnham's models except for the following:

a) enlargement of matrix to 30 X 30 tree locations at age fifteen.

b) new regression equation for crown width on d.b.h.

c) new regression equation for height on d.b.h., d.b.h.^{2}, and basal area per acre.

d) replacement of Newnham's two cubic-volume regression equations by a combined variable equation of cubic-volume - basal area ratio on height.

e) simplification of the portion of Newnham's FORTRAN program involved in "moving" from one tree location to another in determining competition.

In addition to developing the revised lodgepole pine model, Lee added to this model a computer program that calculates the yield of eight-foot logs and the ratios of section volume to tree volume in order to analyze the economic consequences of harvesting various kinds of products. This separate program can use as inputs either the output calculated by the stand model or conventional cruise data.

Stand models, such as Newnham's and Lee's can be used to illustrate consequences of alternative methods of management thus providing guidelines for improved stand management. Using a stand model such as Lee's, a forester can simulate in a few minutes the growth of stands from age 15 to 100, and thus study and evaluate, within a short period of time, problems that ordinarily would have taken decades to study.

PRESENT SIMULATION STUDY

The purpose of the present simulation study is to develop a computer simulation model that can be used to illustrate the consequences of various management policies and decisions in terms of the structure and yield of the forest to which these policies and decisions are applied.

The simulation model will utilize forest inventory data as the basic inputs; grow the forest described by the inventory data under specified management policies and decisions; and print out the total volume harvested from each timber type for each year in a projection period, the total volume harvested at the end of the projection period, and inventory data of the resulting forest at the end of the projection period. In the manner in which the forest is harvested and kept track of in the computer, the model being developed will be similar to the management models developed by Gould and O'Regan (1965) and Clutter and Bamping (1965). A major difference between the previously developed models and the present model is the projection of the growth of the forest. The previously developed models used yield tables based on stand averages, whereas the management model being developed will use a stand model such as those developed by Newnham (1964), Newnham and Smith (1964) and Lee (1967).

The use of a stand model for the projection of growth will make it possible for the model being developed to be used in considering not only the economic effects of various management policies and decisions, as done by the other models, but also the effects on the stand structure of the forest. The simulation model is initially being developed for Douglas-fir on the Siuslaw National Forest, a second growth forest, which has a timber management plan that includes thinnings in the allowable cut. Thus the projection of growth by a stand model will make it possible to use this management model to study the effects that various types and intensities of thinnings will have on the structure and yield of the forest.

The effects on stand structure from mortality due to insects, diseases, fires and windstorms can also be studied with the management model being developed. The decision to accept a particular allowable cut or cutting priority policy can be aided by being able to see the stand structure and yields that result from growing a forest under the specified policy.

The use of this management model will present the possibility of eliminating the present time consuming methods of calculating the allowable cut; such as the modified area-volume check method used on the Siuslaw National Forest. With this model, an allowable cut can be selected by growing the forest under a range of arbitrarily chosen cuts and from the resulting forests, selecting the cut which has given the desired stand structure and yields.

ADAPTATION OF THE STAND MODEL

The particular stand model used for the projection of growth in the simulation model being built is Lee's revision of Newnham and Smith's lodgepole pine model (Lee, 1967). As the present model is being developed to simulate growth on the Siuslaw National Forest, Lee's model has to be adapted to Douglas-fir.

The first step in the adaptation of Lee's model was to be able to compile the FORTRAN program for the model on the CDC 3300 computer being used for this study. The program was initially keypunched for an IBM computer and failed to compile on the IBM due to errors resulting from difficulty in reading the program listing given in Lee's thesis. With these errors corrected, the program also failed to compile on the CDC 3300 because of a difference in the way in which the Hollerith cards are punched to represent certain characteristics on the IBM and CDC computers. Thus a new card deck was keypunched for running on the CDC 3300 computer. With this new deck, three computer runs were necessary to get the program to compile due to a difference in the way some FORTRAN statements have to be written for the IBM and CDC computers.

After the program had been compiled, the next step was to be able to run the program and obtain output that would verify that the model was operating correctly. Initially this was to be done by using the values for the input variables specified by Lee and comparing the results to the output given in Lee's thesis.

Although Lee gave the range of values he used for the majority of the input variables in the program, it was difficult to determine which combination of the given values was used to obtain the given output. Thus it was decided that instead of making a direct comparison with Lee's output, any output that could be obtained that would indicate that the model was operating correctly would be sufficient.

In the competition portion of the stand model the 15 X 15 tree location matrix was divided into octants and two tables of values were utilized by the model. As these two tables, used in calculating the coordinates of competing trees within an octant and whether a tree is completely within an octant or not, were only partially illustrated by Lee (p. 207-209), they had to be reconstructed. These tables of values are given in Table I, page 27, and Table II, page 28.

For those input variables which Lee gave as a range, a value was arbitrarily chosen from the given range. For those input variables for which Lee did not give a value, values were taken from either Newnham and Smith's lodgepole pine model or Newnham's Douglas-fir model. The following is a list of the values used in the first computer runs for determining whether the model was operating correctly and where these values were obtained. It should be kept in mind that these specific values have no great significance in the simulation model being developed; they were used only in checking the operation of Lee's model. Definitions for the following variables are given in Appendix I.

1) NMAT = 30

Lee, page 205

2) MAT10 = 30

Lee, page 205

3) NDIST = 4

Lee, page 224

4) ASTART = 15

Lee, page 212

5) ASTOP = 100

Lee, page 212

6) FACRED = 1.0

Lee, page 174

7) REDINC = -0.00025

Lee, page 225

8) PD = 3.3, 6.6, 9.9 and 13.2

Lee, page 224

9) PS = .2250, .9000, 2.0250 and 3.6000

Lee, calculated; see Appendix II

10) A1C = 2.86

Lee, page 227

11) B1C = 1.6288

Lee, page 227

12) A1 = -1.641

Lee, page 166; used by Newnham and Smith

13) BAMAT = 24.0

Lee, calculated; see Appendix II

14) VOLMAT = 400

Arbitrarily chosen

15) DINC = a range from 5% to .1%

Newnham (1964, p. 61)

16) CW = 2.4

Lee, page 225

17) LOOKM = 91

Lee, page 210

18) LOOK = 20

Lee, page 210

19) NCOORD = Table I, page 27

Lee, reconstructed; see Appendix II

20) ECOORD = Table II, page 28

Lee, reconstructed; see Appendix II

21) FPLOT = 4000, 1000, 444 and 250

Lee, tables on pages 231-234, trees per acre at age 20

22) D10 = diameters given on page 330 in Lee's thesis

Using the above values for the input variables, six computer runs were made before any output was obtained. The first five runs aborted because of control card errors in trying to determine the amount of computer memory space to specify, the amount of time to allow for a computer run, and the number of lines to allow for printout. The output obtained from the sixth run was not satisfactory as mortality did not occur. An error in the keypunching of one of the data cards was found and a seventh run was made with this error corrected. As mortality was again lacking in this

TABLE I. NCOORD VALUES

ICOORD & JCOORD	TREE NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	1	2	2	2	3	3	3	4	4	3	4	4	5	5	5	4	5	6	6
2	0	1	0	1	2	0	1	2	0	1	3	2	3	0	1	2	4	3	0	1

	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
1	6	5	6	7	7	5	6	7	7	6	8	7	8	8	6	8	7
2	2	4	3	0	1	5	4	2	3	5	0	4	1	2	6	3	5

	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
1	8	9	9	9	7	8	9	9	7	10	8	10	10	9	10	8	10
2	4	0	1	2	6	5	3	4	7	0	6	1	2	5	3	7	4

	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
1	9	11	11	11	10	8	11	9	10	11	12	12	9	11	12	10	12
2	6	0	1	2	5	8	3	7	6	4	0	1	8	5	2	7	3

	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88
1	11	12	9	10	13	12	13	11	13	13	12	10	13	11	12	13	14
2	6	4	9	8	0	5	1	7	2	3	6	9	4	8	7	5	0

	89	90	91
1	14	14	10
2	1	2	10

TABLE II. ECOORD VALUES

TREE NUMBER

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
.5	.5	.5	1	.5	.5	1	1	.5	1	.5	1	1	.5	1	1	.5	1	.5	1
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	1	1	.5	1	.5	1	1	1	1	.5	1	1	1	.5	1	1	1	.5	1
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1	1	1	1	1	.5	.5	1	1	1	1	1	1	1	1	.5	1	1	1	.5
61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	1	1	1	.5	1	1	1	1	1	1	1	1	.5	1	.5	1	1	1	1
81	82	83	84	85	86	87	88	89	90	91									
1	1	1	1	1	1	1	.5	1	1	.5									

seventh run, the values for the variable DINC were changed to range from 20 per cent to 10 per cent and another run was made. In this eight run mortality did not occur until age 70 and then was complete over the entire matrix. Thus the values of DINC were again changed, increasing the values before 70 years and decreasing the values for age 70 and above, to a range of 8 to 60 per cent. The result of this ninth computer run was a distribution of mortality over the years in the projection period. Although some of the values in the output from these nine computer runs do not compare to those in Lee's output, the limited analysis that has been done at the present does indicate that the model is operating correctly. Further analysis of these and other computer runs will have to be made to be certain that the model is operating correctly and that the next step, using values for Douglas-fir on the Siuslaw, can be started.

SUGGESTIONS FOR THE CONTINUED ADAPTATION OF THE STAND MODEL

The analysis of future computer runs can result in two outcomes: that the model is operating correctly, or that the model is not operating correctly. If the model is shown to be operating correctly, then the step of using values for Douglas-fir for all of the input variables can be started. However, if the output does not indicate that the model is operating correctly, then the next step will be to contact Lee to obtain the specific values he used for the input variables and the corresponding output before substituting all Douglas-fir values.

Assuming that the model will eventually be operating correctly, the purpose of this part of the paper is to present suggestions for the step of substituting Douglas-fir values for all of the input variables.

The procedure to be used in this step of adapting the model to Douglas-fir will be the same general procedure used by Newnham (1964) and Lee (1967). This procedure is to make a number of computer runs, changing the various input values, until the results obtained by the model agree with published yield tables for Douglas-fir. In this particular study, the comparison of the model results should be made with Bulletin 201 and data from the Siuslaw National Forest.

In adapting the model to Douglas-fir, a number of basic changes will be required. These are:

a) a new initial diameter matrix

b) a new d.b.h. on age regression equation

c) a new crown width on d.b.h. regression equation

d) a new height on d.b.h., d.b.h.^{2} and basal area per acre regression equation

e) a new volume-basal area ratio on height regression equation

Since the stand model being used is initiated at age 15 and Newnham's model is initiated at age ten, this eliminates the possibility of using Newnham's initial diameter matrix. Thus the diameters used in the initial matrix of 900 trees will have to be obtained from data from the Siuslaw National

Forest or data from other comparable areas.

For the d.b.h. on age equation, a possibility other than calculating an equation from data from the Siuslaw, would be to use the equation given by Newnham for his Douglas-fir model (Newnham, 1964, p. 50). This equation is:

$$5yr^{R}g = 0.06338 - 0.07223D_i + 0.4237D_{10} + 0.0196Age - 0.00005029Age^2$$

The use of this equation would require additional input values to be specified for the additional regression coefficients in the equation.

The crown width on d.b.h. equation can also be taken from Newnham's Douglas-fir model (p. 47). However, as Newnham uses two crown width on d.b.h. equations, one for trees less than three inches in diameter and one for trees equal to or greater than three inches in diameter, Lee's stand model would have to be adjusted for the use of the equations. These equations are:

trees < 3 ins. d.b.h. $CW = 2.270 + 2.399D$

trees ≥ 3 ins. d.b.h. $Cw = 5.031 + 1.423D$

Again, as with the d.b.h. on age and crown width on d.b.h. equations, the equation for calculating height can be taken from Newnham's Douglas-fir model (p. 156). This equation is:

$H = -11.083 + 8.27095D + 0.160482B - 0.154019D^2$ where H is the total height of the tree in feet, D is the d.b.h.o.b. in inches and B is the basal area of the stand in square feet per acre.

For the calculation of volume, the values for the volume-basal area ratio on height will have to be determined from data for the Siuslaw National Forest or data from a comparable area as the calculation of volume was not included in Newnham's model.

As with the above equations, the values for other input variables can be obtained from Newnham's Douglas-fir model; such as DINC which Newnham discusses on page 61 in his thesis and FACRED and REDINC on pages 74-76 of Newnham's thesis.

SUMMARY AND CONCLUSION

The rapid rise of new social values and the changing raw material requirements have brought about the need for better planning in the field of forest management. Within the last ten years, the technique of using electronic digital computers for simulation, the art of model building, has provided foresters with the means for improving management planning; for solving problems previously considered unmanageable. Computer simulation models have been developed for simulating a wide range of activities in forestry; from sampling methods, use of harvesting machines, the effects of fires and windstorms to the economic and biologic effects of harvesting policies.

Computers will undoubtedly continue to become larger and faster with the result of larger and more sophisticated simulation models. Although the advantages of simulation are many, it should be stressed that these simulation models do have their limitations; that they are no better than the assumptions made and the data used.

A forest management simulation model is presently being developed to illustrate the consequences of various management policies and decisions in terms of the stand structure and yield of a forest. The projection of growth in this management model will be done by the use of a stand model which has numberous advantages over the use of yield tables as used in previously developed management models.

The stand model being used, Lee's lodgepole pine model, has been compiled on a CDC 3300 computer and a number of computer runs have been made. Although the preliminary analysis of the output from these first runs tends to indicate that the stand model is operating correctly, more complete analysis of these and future runs will be necessary.

In substituting values in the model to have it simulate the growth of Douglas-fir on the Siuslaw National Forest, Newnham's Douglas-fir model will be used to a considerable extent.

The use of this management model will present numerous possibilities for improving management planning, but it should again be stressed that this model, as any other simulation model, will have its limitations. The model will be only as good as the basic assumptions that were made in its development and the data used in its operation.

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APPENDICES

APPENDIX I.

1. A list of the more important variables in the program with their meanings.

A	Age in years
ASTART	Age at beginning of the program
ASTOP	Age at which program stops
A1	Constant term in radial growth regression
A1C	Constant term in crown width regression
BAMAT	Basal area of input matrix
B1C	Regression coefficient in the crown width regression
CW	Reduction constant from calculated crown width
D	D.b.h.o.b. at beginning of each five-year period
DAP5	D.b.h.o.b. at the end of each five-year period
DINC	Minimum percentage five-year diameter growth for survival
D10	D.b.h.o.b. of trees in input matrix
ECOORD	Value denotes whether competitor is a full tree or half tree
FACRED	Beginning REDFAC
FLAST	Number of trees per acre at beginning of each five-year period
FN	Number of trees at end of each five-year period
FPLOT	Number of live trees in matrix at age 15
I	Row number in matrix
J	Column number in matrix

I,J	Coordinates for competing tree
K	In octants 1,2,5 and 6 this is the number of tree locations up or down a competitor is from the competing tree (I,J). In octants 3,4,7 and 8 this is the number of locations across to the left or right.
L	In octants 1,2,5 and 6 this is the number of tree locations across to the left or right a competitor is from the competing tree (I,J). In octants 3,4,7 and 8 this is the number of locations up or down.
K,L	Coordinates for competitors
LOOK	Number of tree locations in which the operator wishes the computer to carry out checks on crown spread at each run.
LOOKM	Maximum number of tree locations within each octant
MAT10	Number of trees per row and column in input matrix
NCOORD	Values for coordinates of tree locations of competitors in each octant
NDIST	Number of planting distances (initial spacings)
NMAT	Number of trees per row and per column in working matrix
NOCT	Number of octant
NT	Number of trees per acre in input matrix
PD	Planting distance
PS	Plot size in acres of working matrix
REDFAC	Reduction factor to reduce calculated crown width to competitive crown width
REDINC	Increment for REDFAC
S(M)	Distance the competing tree is from the tree being studied
SOC(I,J)	Proportion of circumference of the crown in the I,Jth position occupied by competitors

THETA	Angle subtended at the center of the crown by the two points of intersection of the competitive crowns divided by two
VOLMAT	Volume of the input matrix

2. FORTRAN SOURCE LIST FOR LEE'S MODEL

```
      PROGRAM MAIN
      DIMENSION PD(5),PS(5),NT(5)          ,DINC(40),D(40,40),D10(40,40),NDB
     1(30)
      DIMENSION DAP5(40,40),SOC(40,40),S(100),NNDB(30),DIST(100)
      DIMENSION NCOORD(2,100),ECOORD(100),ISIGNS(8),JSIGN(8)
      COMMON/DATA/ISIGNS,JSIGN
      DATA(ISIGNS=1,1,1,-1,-1,-1,-1,1)
      DATA(JSIGN=-1,1,1,1,1,-1,-1,-1)
      COMMON REDFAC,A1C,B1C,I,J,K,L,M,NMAT,S,THETA,D
      READ(5,1) NMAT,MAT10,NDIST,ASTART,ASTOP,FACRED,REDINC
      FORMAT(3I3,3F6.0,F7.0)
      READ(5,2) (PD(I),I=1,NDIST),(PS(I),I=1,NDIST)
      FORMAT(10F6.0)
      READ(5,5) A1C,B1C,A1,BAMAT,VOLMAT
      FORMAT(5F10.0)
      READ(5,6) (DINC(LA),LA=2,19)
      FORMAT(18F4.3)
      READ(5,5555) CW
      FORMAT(F10.0)
      DINC(1)=0.
      DINC(20)=0.
      READ(5,1) LOOKM,LOOK
      READ(5,1202)((NCOORD(I,J),I=1,2),J=1,LOOKM)
      FORMAT (24I3)
      READ(5,1203)(ECOORD(I),I=1,LOOKM)
      FORMAT(24F3.0)
OOP TO CALCULATE THE DISTANCE BETWEEN COMPETING TREE AND COMPETITORS
      DO 1200 I=1,LOOK
      DIST(I)=SQRT(FLOAT(NCOORD(1,I)**2+NCOORD(2,I)**2))
      READ(5,3) FPLOT,(NT(I),I=1,NDIST)
      FORMAT(F6.0,5I6)
ASIC MATRIX
      READ(5,1201)
     0FORMAT(30X,42H                                          /30X,25H
     1                         )
      DO 7 I=1,MAT10
      READ(5,8) (D10(I,J),J=1,MAT10)
      FORMAT(15F3.1)
      DO 10 IF=1,NMAT,20
RINT OUT BASIC MATRIX OF DIAMETERS
      WRITE(6,9)
     0FORMAT(1H1,51X,15HSTAND MODEL    /1H0,32HORIGINAL D.B.H.O.B. OF EA
     1CH TREE/)
      WRITE(6,1201)
      NMATF=MIN0(IF+19,NMAT)
      DO 10 I=1,NMAT
      WRITE(6,11) (D10(I,J),J=IF,NMATF)
      FORMAT(1H0,F4.1,19F5.1)
```

```
OOP FOR EACH PLANTING DISTANCE

 DO 130 II=1,NDIST
 WRITE(6,12)NT(II),PS(II),PD(II),MAT10,FACRED,REDINC
OFORMAT(1H1,51X,15HSTAND MODEL     ///47X,22HNO. OF TREES PER AC. =I
15//49X,11HPLOT SIZE =F8.5,4H AC.//46X,19HPLANTING DISTANCE =F5.1,4
2H FT.////10X,8HMATRIX =I3,8H SQUARE,,9H REDFAC =F6.3,9H REDINC =F7
3.4)

OOP TO CALCULATE THE DISTANCE OF EACH POSSIBLE COMPETITOR FROM THE
TUDY TREE

 X=PD(II)
 DO 1210 I=1,LOOK
 S(I)=DIST(I)*X
 BAST=BAMAT/PS(II)
 VOLST=VOLMAT/PS(II)
 REDFAC=FACRED
 FLAST=FPLOT
 A=ASTART
 ACOMP=0.
 DO 14 I=1,NMAT
 DO 14 J=1,NMAT
 D(I,J)=D10(I,J)
 PI=3.14159

OOP TO CALCULATE 5-YEAR PERIODIC DBH GROWTH

 DO 93 I=1,NMAT
 DO 93 J=1,NMAT
 SOC(I,J)=0.
 IF(D(I,J)) 92,92,16

OOP TO CALCULATE THE COMPETITIVE STATUS, SOC, OF EACH TREE BY OCTANTS

 DO 91 NOCT=1,8
 ICOORD=1
 JCOORD=2
 ISEE=(NOCT-3)*(NOCT-4)*(NOCT-7)*(NOCT-8)
 IF(ISEE.NE.0) 20,19
 ICOORD=2
 JCOORD=1
 DO 85 NEXT=1,LOOK
 K=KFIND(I+ISIGNS(NOCT)*NCOORD(ICOORD,NEXT))
 L=KFIND(J+JSIGN(NOCT)*NCOORD(JCOORD,NEXT))

EST TO SEE IF THERE IS A LIVE TREE IN THIS POSITION

 IF(D(K,L).LE.0.) 85,84
 M=NEXT

F A LIVE TREE IS PRESENT IN THIS POSITION THE SUBROUTINE CROWN IS
ALLED AND THETA IS CALCULATED

 CALL CROWN (CW)

ALCULATE THE COMPETITIVE STATUS OF THE TREE

 SOC(I,J)=SOC(I,J)+ECOORD(NEXT)*(THETA/PI)
 GO TO 91
 CONTINUE
```

```
 CONTINUE
LCULATE THE DBH OF EACH TREE AT THE END OF EACH 5-YEAR PERIOD (DAP5)
 DAP5(I,J)=D(I,J)+5.*(D(I,J)-A1)/A*(1.-SOC(I,J))
 GO TO 93
 D(I,J) IS LESS THAN OR EQUAL TO ZERO, DAP5(I,J) IS SET EQUAL TO
RO
 DAP5(I,J)=0.
 CONTINUE
 LA=.2*A+.5
 A=A+5.
 DO 97 I=1,NMAT
 DO 97 J=1,NMAT
 IF(DAP5(I,J)) 95,95,94
EST FOR MORTALITY
 IF((DAP5(I,J)-D(I,J))/D(I,J)-DINC(LA)) 96,95,95
ET D(I,J) EQUAL TO DAP5(I,J) FOR ALL LIVE TREES
 D(I,J)=DAP5(I,J)
 GO TO 97
ET D(I,J) EQUAL TO - DAP5(I,J) FOR ALL TREES THAT HAVE DIED DURING
HE CURRENT 5-YEAR PERIOD
 D(I,J)=-DAP5(I,J)
 CONTINUE
HE NEW DBH MATRIX IS PRINTED OUT FOR AGES 20, 40, 60, 80 AND 100
 MA=A
 MMA=A*.05+.1
 MMA=MMA*20
 IF(MA-MMA) 102,98,102
 DO 1010 IF=1,NMAT,16
 WRITE(6,99) MA
 FORMAT(1H1,57X,5HAGE =I3/1H0,17HD.B.H.O.B. MATRIX)
 NMATF=MIN0(IF+15,NMAT)
 DO 100 I=1,NMAT
 WRITE(6,101) (D(I,J),J=IF,NMATF)
 FORMAT(1H0,F6.2,15F7.2)
 WRITE(6,1015)
 FORMAT(1H0,19H(DEAD TREES ARE - ))
 DO 103 I3=1,30
 NNDB(I3)=0
 NDB(I3)=0
 SD=0.
 SDD=0.
 NNOW=0
 SND=0.
 SNDD=0.
OOP TO CALCULATE THE NUMBER OF TREES THAT HAVE DIED IN EACH ONE-
NCH DBH CLASS IN THE PAST FIVE YEARS
 NDEAD=0
```

```
 DO 112 I=1,NMAT
 DO 112 J=1,NMAT
 IF(D(I,J)) 104,112,108
 DN=-D(I,J)
 NDEAD=NDEAD+1
 SND=SND+DN
 SNDD=SNDD+DN*DN
 I3=1
 TI3=I3
 TI3=TI3+.5
 IF(DN-TI3) 107,106,106
 I3=I3+1
 IF(I3-30) 105,107,107
 NNDB(I3)=NNDB(I3)+1
 GO TO 112

OOP TO CALCULATE THE NUMBER OF LIVE TREES IN EACH ONE-INCH DBH CLASS

 NNOW=NNOW+1
 SD=SD+D(I,J)
 SDD=SDD+D(I,J)*D(I,J)
 I3=1
 TI3=I3
 TI3=TI3+.5
 IF(D(I,J)-TI3) 111,110,110
 I3=I3+1
 IF(I3-30) 109,111,111
 NDB(I3)=NDB(I3)+1
 CONTINUE
 IF(NNOW+NDEAD) 130,130,113
 IF(NDEAD) 115,115,114

ALCULATE MEANS,STANDARD DEVIATION,BASAL AREA, P.A.I., (BASAL AREA),
.A.I. (BASAL AREA)

DEAD = NDEAD = TOTAL 5-YEAR MORTALITY IN PLOT

 FDEAD=NDEAD

EAN DBH OF DEAD TREES

 DBARN=SND/FDEAD

OTAL 5-YEAR MORTALITY PER ARCE

 FDA=FDEAD/PS(II)

ASAL AREA PER ACRE (DEAD TREES)

 BAN=PI*SNDD/(576.*PS(II))
 GO TO 1151
 DBARN=0.
 FDEAD=0.
 FDA=0.
 BAN=0.
 IF(NNOW) 116,116,1152

UMBER OF LIVE TREES IN PLOT

 FN=NNOW
```

```
EAN DBH OF LIVE TREES
  DBAR=SD/FN
ARIANCE OF DBH OF LIVE TREES
  VAR=(SDD-SD*SD/FN)/(FN-1.)
TANDARD DEVIATION OF DBH OF LIVE TREES
  SIGMA=SQRT(VAR)
REE OF MEAN BASAL AREA
  D2BAR=SQRT(SDD/FN)
ASAL AREA PER ACRE (LIVE TREES)
  BA=PI*SDD/(576.*PS(II))
  BBA=0.0384*BA
.A.I. (BASAL AREA)
  AVAI=BA/A
.A.I. (BASAL AREA)
  CAI=(BA-BAST)*.2
  BAST=BA
OTAL NUMBER OF LIVE TREES PER ARCE
  FNTA=FN/PS(II)
RINT OUT DIAMETER FREQUENCY DISTRIBUTION TABLE
  MMA=A*.1+.1
  MMA=MMA*10
  IF(MA-MMA) 1251,1161,1251
  WRITE(6,117) MA
0FORMAT(1H1,57X,5HAGE =I3/1H0,39HD.B.H.O.B. FREQUENCY DISTRIBUTION
1TABLE/1H0,12X,60HD.B.H.  NO. OF  NO. OF TREES  5YR. MORTALITY  5YR
2. MORTALITY,9X, 6HHEIGHT/
3            1H ,12X,25HCLASS   TREES    PER AC.,25X,7HPER AC.//)
  DO 125 I3=1,30
  X=I3
  H=-10.0000+BBA+X*(10.4911-0.2439*X)
  IF(NDB(I3)+NNDB(I3)) 125,125,118
  IF(NDB(I3)) 120,120,119
  FNDB=NDB(I3)
  FNDAC=FNDB/PS(II)
  FNNDAC=0.
  GO TO 121
  FNDAC=0.
  IF(NNDB(I3)) 123,123,122
  FNNDB=NNDB(I3)
  FNNDAC=FNNDB/PS(II)
  WRITE(6,124) I3,NDB(I3),FNDAC,NNDB(I3),FNNDAC,H
  FORMAT(1H ,12X,I4,I9,F12.1,I14,F18.1,F17.1)
  CONTINUE
  GO TO 1253
```

```
 WRITE(6,1252) MA
 FORMAT(1H1,57X,5HAGE =I3/)
OWRITE(6,126) NNOW,FNTA,NDEAD,FDA,DBAR,DBARN,VAR,SIGMA,D2BAR,BA,BAN
1,CAI,AVAI
OFORMAT(1H0,13X,7HTOTAL =I5,F12.1,I14,F18.1/1H0,14X,6HMEAN =F6.2,5H
1 INS.,15X,F6.2,5H INS./1H0,10X,10HVARIANCE =F9.4/1H0,20HSTANDARD D
2EVIATION =F6.2/1H0,20H TREE OF MEAN B.A. =F6.2/1H0,20HBASAL AREA P
3ER AC. =F7.1,8H SQ. FT.,11X,F7.1,8H SQ. FT./1H0,20HP.A.I.(BASAL AR
4EA* =F7.1/1H0,20HM.A.I.(BASAL AREA) =F7.1///)

ALCULATE P.A.I.(VOLUME), M.A.I.(VOLUME), TOTAL VOLUME PER ACRE (LIVE
REES), TOTAL VOLUME PER ACRE (DEAD TREES), VOLUME (LIVE TREES 6 IN.
), VOLUME (DEAD TREES 6 IN. +), MEAN HEIGHT (LIVE TREES), AND MEAN
EIGHT (DEAD TREES)

  HTOT=0.
  VOL=0.
  VOLP6=0.
  HDTOT=0.
  VOLD=0.
  VOLDP6=0.
  DO 1270 I=1,NMAT
  DO 1270 J=1,NMAT
  X=D(I,J)
  IF(X) 1265,1270,1260
  H=-10.0000+BBA+X*(10.4911-0.2439*X)
  HTOT=HTOT+H
  V=0.0024036436*X*X*H
  VOL=VOL+V
  IF(X-6.) 1270,1264,1264
  VOLP6=VOLP6+V
  GO TO 1270
  X=-X
  H=-10.0000+BBA+X*(10.4911-0.2439*X)
  HDTOT=HDTOT+H
  V=0.0024036436*X*X*H
  VOLD=VOLD+V
  IF(X-6.) 1270,1269,1269
  VOLDP6=VOLDP6+V
  CONTINUE
  HBAR=HTOT/FN
  HDBAR=HDTOT/FDEAD
  Z=1./PS(II)

OTAL VOLUME PER ACRE (LIVE TREES)

  VOL=VOL*Z

OTAL VOLUME PER ACRE (DEAD TREES)

  VOLD=VOLD*Z

OLUME (LIVE TREES 6 IN. +)

  VOLP6=VOLP6*Z

OLUME (DEAD TREES 6 IN. +)

  VOLDP6=VOLDP6*Z

.A.I. (VOLUME)
```

```
 VOLMAI=VOL/A

.A.I. (VOLUME)

 VOLPAI=(VOL-VOLST)*.2

RINT OUT VOLUME AND MEAN HEIGHT

 WRITE(6,1275) VOLPAI, VOLMAI
0FORMAT(1H0,20HP.A.I.(   VOLUME   ) =F7.1/
1        1H0,20HM.A.I.(   VOLUME   ) =F7.1//)
 WRITE(6,1273) VOL,VOLD,VOLP6,VOLDP6,HBAR,HDBAR
0FORMAT(7X,14HTOTAL VOLUME =F8.1,8H CU. FT.,10X,F8.1,8H CU. FT./1H0
1,20HVOL.(TREES 6INS.+) =F8.1,18X,F8.1/1H0,7X,13HMEAN HEIGHT =F6.1,
24H FT.,16X,F6.1,4H FT.//)

EST TO SEE IF MORTALITY HAS OCCURRED BEFORE THE CURRENT PERIOD

COMP = AGE AT THE BEGINNING OF THE PERIOD IN WHICH MORTALITY FIRST
       OCCURS

 IF(ACOMP) 127,127,1272

EST TO SEE IF MORTALITY HAS STARTED IN THE CURRENT PERIOD

 IF(FLAST-FN) 128,128,1271

F MORTALITY HAS OCCURRED DURING THE CURRENT PERIOD, ACOMP IS SET
QUAL TO THE AGE AT THE START OF THE PERIOD

 ACOMP=A-5.

F MORTALITY HAS OCCURRED, EITHER BEFORE OR DURING THE CURRENT PERIOD,
EDFAC IS MODIFIED

 X=A-ACOMP
 Y=X-20.
 REDFAC=REDFAC+REDINC*(X+.01*Y*ABS(Y))
 WRITE(6,129) REDFAC
 FORMAT(1H ,8HREDFAC =F7.4)
 VOLST=VOL
 FLAST=FN

EST FOR END OF RUN

 IF(A-ASTOP) 15,130,130
 CONTINUE
 GO TO 200
 END

 FUNCTION KFIND(KM)

/HEN DETERMINING THE POSITION OF COMPETITORS IN THE MATRIX THIS
SUBPROGRAM ENSURES THAT THE MAIN LINE PROGRAM DOES NOT BRANCH OUT
)F THE MATRIX

 DIMENSION S(100),D(40,40)
 COMMON REDFAC,A1C,B1C,I,J,K,L,M,NMAT,S,THETA,D
 IF(KM) 1,1,2
 KFIND=KM+NMAT
```

```
 RETURN                                                              KFINDG06
 IF(KM-NMAT) 4,4,3                                                   KFINDG07
 KFIND=KM-NMAT                                                       KFINDG08
 RETURN                                                              KFINDG09
 KFIND=KM                                                            KFINDG10
 RETURN                                                              KFINDG11
 END                                                                 KFINDG12

 SUBROUTINE CROWN (CW)                                               CROWNG01

ALCULATE THE VALUE OF THETA, THE ANGLE SUBTENDED AT THE CENTER OF
HE CROWN BY THE INTERSECTION OF THE CROWN PERIMETERS DIVIDED BY TWO

 DIMENSION S(100),D(40,40)                                           CROWNG02
 COMMON REDFAC,A1C,B1C,I,J,K,L,M,NMAT,S,THETA,D                      CROWNG03
 R=.5*REDFAC                                                         CROWNG04

ALCULATE THE COMPETITIVE CROWN RADIUS OF THE TREE BEING STUDIED
R1)

 R1=(A1C+B1C*D(I,J))*R-CW                                            CROWNG05

ALCULATE THE COMPETITIVE CROWN RADIUS OF THE POTENTIAL COMPETITOR
R2)

 R2=(A1C+B1C*D(K,L))*R-CW                                            CROWNG06
 IF(R2) 8,8,1                                                        CROWNG07
 IF(R1) 2,2,6                                                        CROWNG08
 IF(R2-S(M)) 8,10,10                                                 CROWNG09

EST TO SEE IF THE COMPETITITVE CROWNS OVERLAP

 IF(R1+R2-S(M)) 8,8,7                                                CROWNG10

EST TO SEE IF THE CROWN OF THE TREE BEING STUDIED (THE I,JTH)
OMPLETELY OVERLAPS THAT OF THE COMPETITOR (THE K,LTH)

 IF(R1-R2-S(M)) 9,8,8                                                CROWNG11

HETA IS SET EQUAL TO ZERO AND CONTROL IS RETURNED TO THE MAIN PROGRAM

 THETA=0.                                                            CROWNG12
 GO TO 50                                                            CROWNG13

EST TO SEE IF THE CROWN OF THE COMPETITOR OVERLAPS THAT OF THE TREE
EING STUDIED

 IF(R2-R1-S(M)) 11,10,10                                             CROWNG14

HETA IS SET EQUAL TO PI (3.14159)

 THETA=3.14159                                                       CROWNG15
 GO TO 50                                                            CROWNG16

ALCULATE THE ORINATES OF THE POINT OF INTERSECTION (IN THE FIRST
UARDRANT) OF THE COMPETITIVE CROWNS

 K=(R1*R1-R2*R2+S(M))/(2.*S(M))                                      CROWNG17
 Y=SQRT(R1*R1-X*X)                                                   CROWNG18
```

```
EST TO SEE IF THETA IS GREATER THAN, EQUAL TO OR LESS THAN PI/2

  IF(X) 12,13,14                                                    CROWNG19

HETA IS CALCULATED ACCORDINGLY AND CONTROL RETURNED TO THE MAIN
ROGRAM
  X=-X                                                              CROWNG20
  THETA=(1.57080+ATAN(X/Y))*R2/R1                                   CROWNG21
  GO TO 50                                                          CROWNG22
  THETA=1.57080*R2/R1                                               CROWNG23
  GO TO 50                                                          CROWNG24
  THETA=ATAN(Y/X)*R2/R1                                             CROWNG25
  RETURN                                                            CROWNG26
  END                                                               CROWNG27
```

3. AN EXAMPLE OF THE DATA CARDS

```
IABLES NMAT,MAT10,NDIST,ASTART,ASTOP,FACRED, AND REDINC
 4    15   100      1-.00025

IABLES PD AND PS
   6.6    9.9   13.2  .2250  .90002.02503.6000

IABLES A1C,B1C,A1,BAMAT, AND VOLMAT
2.86      1.6288     -1.641      24.00      400.0

IABLE DINC
000450040003500300025002000150010001000100010000500050005000

IABLE CW
 2.4

IABLES LOOKM AND LOOK


UES FOR NCOORD (8 CARDS)
00200200200300300300400400300400400500500500400500600600600500600
0060070070060080070080080060080070080090090090070080090090070100
0090100080100090110110110100080110090100110120120090110120100120
01001301201301101301301201001301101201301401401401
000010020000100200000100300200300000100200400300000100200400300
0040020030050000040010020060030050040000010020060050030040070000
005003007004006000001002005008003007006004000001008005002007003
008000005001007002003006009004008007005000001002010

UES FOR ECOORD (4 CARDS)
0.51.00.50.51.01.00.51.00.51.01.00.51.01.00.51.00.51.01.01.01.00.5
1.01.01.01.00.51.01.01.00.51.01.01.00.51.01.01.01.01.01.00.50.51.0
1.01.01.01.01.00.51.01.01.00.51.01.01.01.00.51.01.01.01.01.01.01.0
1.00.51.01.01.01.01.01.01.01.01.01.01.00.51.01.00.5

IABLE FPLOT
  4000  1000    444    250

D STATEMENT NO. 200
                          +++++++++++++++++++++A HEADING++++++++++++
                          ++++++A HEADING++++++++++

TIAL DIAMETERS (60 CARDS)
1.21.41.51.31.61.51.11.40.61.31.21.30.6
1.21.41.51.31.61.51.11.40.61.31.21.30.6
1.41.81.00.90.91.11.41.51.61.71.41.11.2
2.21.51.41.70.51.50.71.70.90.41.10.81.0
0.71.11.10.61.41.51.20.81.31.00.81.51.2
0.91.81.31.40.70.80.21.71.31.20.71.41.9
0.71.11.10.61.41.51.20.81.31.00.81.51.2
1.41.81.00.90.91.11.41.51.61.71.41.11.2
2.21.51.41.70.51.50.71.70.90.41.10.81.0
2.21.51.41.70.51.50.71.70.90.41.10.81.0
1.10.61.41.20.11.30.81.31.21.61.11.01.5
1.21.41.51.31.61.51.11.40.61.31.21.30.6
1.41.81.00.90.91.11.41.51.61.71.41.11.2
```

0.91.81.31.40.70.80.21.71.31.20.71.41.9
0.51.42.31.40.80.81.71.30.91.81.31.71.8
1.01.11.20.31.90.90.71.12.01.90.81.11.8
0.91.81.31.40.70.80.21.71.31.20.71.41.9
0.51.42.31.40.80.81.71.30.91.81.31.71.8
1.10.81.01.10.81.01.60.91.51.12.10.91.9
0.51.42.31.40.80.81.71.30.91.81.31.71.8
1.41.81.00.90.91.11.41.51.61.71.41.11.2
0.91.81.31.40.70.80.21.71.31.20.71.41.9
0.51.42.31.40.80.81.71.30.91.81.31.71.8
1.41.81.00.90.91.11.41.51.61.71.41.11.2
1.21.41.51.31.61.51.11.40.61.31.21.30.6
1.01.11.20.31.90.90.71.12.01.90.81.11.8
0.91.81.31.40.70.80.21.71.31.20.71.41.9
1.01.11.20.31.90.90.71.12.01.90.81.11.8
1.41.81.00.90.91.11.41.51.61.71.41.11.2
1.61.11.11.41.31.31.41.80.41.01.20.51.4
1.61.11.11.41.31.31.41.80.41.01.20.51.4
0.50.91.61.10.71.80.30.81.20.80.41.20.5
1.01.11.20.31.90.90.71.12.01.90.81.11.8
1.01.11.20.31.90.90.71.12.01.90.81.11.8
2.21.51.41.70.51.50.71.70.90.41.10.81.0
1.21.41.51.31.61.51.11.40.61.31.21.30.6
1.21.41.51.31.61.51.11.40.61.31.21.30.6
1.21.41.51.31.61.51.11.40.61.31.21.30.6
1.21.41.51.31.61.51.11.40.61.31.21.30.6
0.51.42.31.40.80.81.71.30.91.81.31.71.8
0.51.42.31.40.80.81.71.30.91.81.31.71.8
0.71.11.10.61.41.51.20.81.31.00.81.51.2
1.01.11.20.31.90.90.71.12.01.90.81.11.8
1.01.11.20.31.90.90.71.12.01.90.81.11.8
0.50.91.61.10.71.80.30.81.20.80.41.20.5
0.71.11.10.61.41.51.20.81.31.00.81.51.2
1.21.41.51.31.61.51.11.40.61.31.21.30.6
1.01.11.20.31.90.90.71.12.01.90.81.11.8
1.10.81.01.10.81.01.60.91.51.12.10.91.9
0.91.81.31.40.70.80.21.71.31.20.71.41.9
0.51.42.31.40.80.81.71.30.91.81.31.71.8
1.10.81.01.10.81.01.60.91.51.12.10.91.9
0.71.11.10.61.41.51.20.81.31.00.81.51.2
1.10.61.41.20.11.30.81.31.21.61.11.01.5
0.71.11.10.61.41.51.20.81.31.00.81.51.2
1.61.11.11.41.31.31.41.80.41.01.20.51.4
0.71.11.10.61.41.51.20.81.31.00.81.51.2
0.71.11.10.61.41.51.20.81.31.00.81.51.2
0.71.11.10.61.41.51.20.81.31.00.81.51.2
0.71.11.10.61.41.51.20.81.31.00.81.51.2

4. CONTROL CARDS FOR MASTER

```
,DANECHEW,70067,075,6,2000
ED,CORE=43,SCR=3
(L,X)
```

FORTRAN PROGRAM

```
      FINIS
E,5=INP
E,6=OUT
,LGO
```

DATA CARDS

5. CONTROL CARDS FOR OS3

```
,70067,DANE
EL/SAVE FOR CHEW
E=360
LKS=500
IP,5=60
IP,6=61
TRAN,L,R
```

FORTRAN PROGRAM

```
      FINIS
```

DATA CARDS

```
E
```

APPENDIX II.

1. Calculation of PS - plot size

This calculation of plot size was initially done by multipling the spacing distance by the number of spacings on a side of the square matrix, 29; squaring this distance to get the area in square feet covered by the matrix of 30 X 30 tree locations; and dividing this by 43,560 square feet per acre to get the area covered by the matrix in acres.

As the number of trees per acre based upon this calculated area of the matrix did not agree with Lee's figures, the area in acres was recalculated by another method.

The number of trees per acre for each spacing at age 20, before mortality occurred, was taken from Lee's tables on pages 231-234. The number of trees in the input matrix, 900, was then divided by the number of trees per acre as given for each spacing in the tables, giving the area in acres of the matrix for each planting distance.

<u>3.3 X 3.3 feet</u>

900 / 4000 = 0.2250 acres

<u>6.6 X 6.6 feet</u>

900 / 1000 = 0.9000 acres

<u>9.9 X 9.9 feet</u>

900 / 444 = 2.0250 acres

13.2 X 13.2 feet

900 / 250 = 3.6000 acres

2. Calculation of BAMAT - basal area of input matrix

A reasonable figure to use for this variable was calculated from the basal area per acre of the stand at age 20 as given by Lee in tables 33-36 on pages 231-234. These basal areas given by Lee were multiplied by the area in acres of the matrix for each spacing distance. As the resulting basal areas for the four spacings varied slightly, an average of the values was taken.

3.3 X 3.3 feet

150.6 sq. ft. X 0.2250 acres = 23.76 sq. ft. per acre

6.6 X 6.6 feet

26.7 sq. ft. X 0.9000 acres = 24.03 sq. ft. per acre

9.9 X 9.9 feet

11.9 sq. ft. X 2.0250 acres = 24.12 sq. ft. per acre

13.2 X 13.2 feet

6.7 sq. ft. X 3.6000 acres = 24.12 sq. ft. per acre

Average = 24.00 sq. ft. per acre

3. Reconstruction of table of NCOORD values

The table of NCOORD values was reconstructed based on the information given on pages 207-209 and Figure 34 on page 211 in Lee's thesis. These values are the number of tree locations up or down and across a competitor is from the tree being studied. These number of tree locations for each competitor can be counted directly from Figure 34 on page 211.

As discussed on pages 207-209, in octants 1,2,5 and 6, the up and down units are referred to as K units and the across units as L units. In octants 3,4,7 and 8 this system of reference is reversed; the up and down units are L, and the across units are K. This shift in the reference of units is accounted for in the program by having the variables ICOORD, used in determining K units, and JCOORD, used in determining L units, take the value of either one or two.

The table for NCOORD values, page 27, was constructed such that the value for each tree in row one is the up or down units and the values in row two are the units across to the left or right.

Thus if the model is operating in octants 1,2,5 and 6, ICOORD is equal to one, reading up and down units as K; and JCOORD is equal to two, reading across units as L. If the model is in octants 3,4,7 and 8, ICOORD is two, reading across values for K; and JCOORD is one, reading up and down values for L.

4. Reconstruction of table of ECOORD values

This table, page 28, as the table for NCOORD values was reconstructed from information on pages 207-209 and Figure 34 on page 211.

By examining Figure 34, if a tree was on a line between two octants, it was given a value of 0.5. If the tree was completely within an octant, it was given a value of 1.0.