AN EXPERT SYSTEM FOR ESTIMATING PRODUCTION RATES AND COSTS FOR HARDWOOD GROUP-SELECTION HARVESTS

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ABSTRACT.—As forest managers shift their focus from stands to entire ecosystems alternative harvesting methods such as group selection are being used increasingly. Results of several field time and motion studies and simulation runs were incorporated into an expert system for estimating production rates and costs associated with harvests of group-selection units of various size by cable logging. This system also is useful for estimating production rates/costs for combinations of stand condition and unit size.

Public concern about clearcutting has resulted in the increased use of group-selection harvests. The small openings created by this technique allow landowners to harvest timber without impairing the visual quality of the site. Managers interested in containing logging costs also are concerned about the potential loss of production and profit in choosing group selection over conventional harvesting methods. The challenge for managers is to determine the harvesting cost associated with group-selection units of various size.

Group-selection entails harvesting small groups or clumps of trees in a somewhat random pattern across a stand. The goal is to capture financially mature trees as well as dead stems and those damaged by insects and disease, and to regenerate the stand. Major advantages of group selection over single-tree selection are that:

1) older mature trees can be harvested more economically and with less damage to the residual stand;
2) managers gain greater flexibility in increasing environmental conditions that favor successful reproduction; and
3) reproduction develops in well-defined, even-aged aggregations.

The latter is particularly important for the development of good tree form, especially among hardwood species (Smith 1981).

The openings or gaps created in the forest canopy by group selection increase the amount of desirable habitat for wildlife. Many wildlife species benefit from the combination of environmental conditions within and along the boundaries between the young reproduction and older adjacent trees. A wide array of protective cover is available in proximity to various food plants that may be created by various microclimatic conditions between the edges and the centers of the young groups.

The economic success of group-selection harvests of eastern hardwoods is dependent on product markets, tree species and quality, and logging costs (Bell 1989; Boucher and Hall 1989; Brummel 1992; Erickson and others 1992; LeDoux and others 1991, 1993; Hassler and others 2000). Several studies have attempted to define group-selection harvests and when they can be used (Roach 1974). Total harvesting costs generally increase as the size of the opening decreases. Results suggest that costs might be prohibitive when groups smaller than 0.50 acre are harvested by cable logging systems (LeDoux and others 1991).

Regeneration studies have shown that species composition can be affected by group selection (Walters and Nyland 1989, Dale and others 1995). Marquis (1965) found that the surrounding forest affects a greater amount of the total area of

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smaller than larger clearcuts. The increased competition for water and nutrients that results from these edge effects influences tree growth (Minckler and others 1973, Smith 1986, Dale and others 1995). Reductions in total height and merchantable growth of new regeneration were reported near the opening edge for 10 to 30 years following small group-selection cuts (Minckler and Woerheide 1965, Sander and Clark 1971, Willison 1981, Hilt 1985, Dale and others 1995).

LeDoux (1999) used regeneration data from Dale and others (1995) and harvesting data from LeDoux and others (1991) to determine the size of group-selection openings that would maximize financial yields for upland oak forests in the central hardwood region. Although the optimal size of opening should be 1.5 acres or larger to maximize financial yields (LeDoux 1999), managers find it necessary to use units of various size to meet a variety of objectives. In this paper, we describe an expert system that was developed for estimating production rates/costs associated with harvesting hardwood group-selection units of various size by cable logging.

METHODS

Time and motion and stand data from field studies (LeDoux and others 1991) were input into the THIN-PC (LeDoux and Butler 1981) simulation model to develop cost estimates for combinations of group-selection units of different size and stand and operating conditions. THIN-PC also can be used to simulate the harvests by cable logging systems. Specifically, the model evaluates how different diameter classes, stand densities, yarding efficiencies, external and lateral yarding distances, spatial log distributions, and prebunch-and-swing strategies affect production rates and related direct costs of harvesting group selection units of various size.

THIN-PC was run for more than 5,000 combinations of group-selection units of 0.25, 0.50, 1.00, 1.50, 2.00, 2.50, and 3.00 acre along with varying values for average diameter at breast height (DBH) of the cut stand, log length, average log size, average slope yarding distance, and log parameters resulting in alternative volumes removed per acre. The stand attributes, average log length and slope yarding distances, and volumes removed per acre for observed stands are shown in table 1. The results from these runs were stored in a database that formed the observed domain of the expert system.

Additional stand data from forest-model plots was used to develop a broader range for DBH and volume removed per acre (table 2). The average cut stand DBH ranged from 7.2 to 24 inches. Log lengths were 16 and 32 feet and tree length. Average log size ranged from 9.6 to 89.12 ft^3. Average slope yarding distance ranged

Table 1.—*Stand attributes, average log length, average slope yarding distance, and volume removed per acre for observed stands*

Average DBH	Average log length: 16 feet	Average log length: 32 feet	Average log length: Tree length	Average slope yarding distance	Volume removed per acre
Inches	Ft^3	Ft^3	Ft^3	Feet	Ft^3
9.57	8.0	12.6	22.4	50-950	817
11.02	10.6	16.5	32.5	50-950	1,327
11.23	11.0	17.3	31.3	50-950	1,223
11.90	12.4	19.4	38.0	50-950	1,493
12.16	12.9	20.2	37.0	50-950	1,614
12.44	13.5	20.8	39.1	50-950	2,711
12.48	13.6	21.3	41.8	50-950	1,493
12.67	14.0	21.6	40.5	50-950	2,699
12.93	14.6	22.9	43.0	50-950	2,008
13.20	15.2	23.5	43.9	50-950	2,728
13.87	16.8	30.0	48.9	50-950	2,852
13.92	16.9	26.6	50.0	50-950	2,519
14.48	18.3	28.2	54.5	50-950	2,776
14.50	18.4	29.4	57.1	50-950	1,556
17.82	27.7	44.9	89.8	50-950	3,052
17.91	28.0	44.6	89.2	50-950	3,390

Table 2.—*Stand data for forest model plots A2, B10, C8, D14, E13, F4, G4M, and H4M*

Forest-model plot	Average DBH	Merchantable volume
	Inches	Ft^3/acre
A2	7.2	2652
B10	8.1	2528
C8	9.1	3556
D14	11.6	3124
E13	12.7	4922
F4	16.8	6315
G4M	20.4	6466
H4M	24.0	6871

from 50 to 950 feet in increments of 100 feet. Simulated volumes cut per acre ranged from 600 to 6,300 ft^3. The results from these runs were stored in a database that formed the continuous domain of the expert system. These data and data from the observed stands were used to develop the interpolation equations that formed the knowledge base used in the second of four user-access modules.

EXPERT SYSTEM DESIGN

The expert system was designed to handle all possible combinations by dividing the system into four modules and linking them using VP-EXPERT (Sawyer 1989), a commercially available expert system development software shell. The shell uses the backward chaining method of inferencing and a production rule-based system of knowledge representation. The expert systems are fairly generic, extracting data from the databases as necessary.

Module 1

The primary purpose of Module 1 is to exploit the discrete observed database domain generated. It helps the user to query the system database and obtain production rates/costs for the observed stands. There are two database domains within the expert system, an existing observed database domain and a runtime database domain. The latter is the database developed during the execution of the third module. Module 3 is used to generate a database at runtime (LeDoux and Butler 1981). Executing THIN-PC for different combinations of input parameters creates this runtime database.

Results from THIN-PC are stored automatically in a new runtime database. The various data fields are filled using the output generated by executing THIN-PC. The production rate is used to calculate the cost using an equation provided by LeDoux and others (1991). The equation (for the Christy cable yarder) is of the form:

$$\text{Cost } (\$/ft^3) = ((((V_{oac} * AC)/PR) + 3.92) * MR)/(V_{oac} * AC),$$

where V_{oac} = the volume per acre in ft^3; AC = the unit size in acres; PR = simulated production rate in ft^3/hour; MR = machine rate/hour; and 3.92 = constant for setup, road and landing changes, and delays in hours.

Module 2

The primary objective of Module 2 is to use statistical relations to determine the production rates/costs for a variety of unit sizes and stand variables. For example, the database domain developed in Module 1 was for discrete levels of DBH (e.g., 9.57, 11.02, 11.23, etc.) and other stand variables. Module 2 uses statistical relationships to develop production rates/costs for continuous levels of input variables such as DBH of 9.57, 9.58, 9.59, etc.

Variables of interest included DBH, log length, average log size, unit size, slope yarding distance, and volume per acre. Suitable interpolation equations were developed for calculating the production rate based on the input parameters volume per acre, slope yarding distances, etc. Thirty different interpolation equations were developed to conduct the interpolations; these equations form the knowledge base for Module 2.

Module 3

The primary objective of Module 3 is to enable the user to execute THIN-PC within the expert-system environment and to create input files for executing THIN-PC. Another objective is to automate the process of database creation. The database domain created is called a discrete runtime database domain, which is exploited in Module 1. Another computer program retrieves the relevant data from the output file created by executing THIN-PC. The system then appends these values along with the output data obtained from executing THIN-PC onto the discrete runtime database. The system appends 10 records to the runtime database for each execution of the model. In this way, the runtime database is developed and various executable programs are executed within the expert-system environment.

Module 4

The primary objective of Module 4 is to allow the user to query the database for feasible operating conditions within a specified maximum affordable cost allowed. For example, users can search the database for all combinations of operating conditions that will result in a yarding cost of $0.15 or less per ft^3. Module 4 uses the graphical features and backward chaining mechanism of VP-Expert to locate all feasible scenarios. It allows the user to obtain multiple sets of conditions as the result of a query based on maximum affordable cost.

Figures 1 and 2 show the sets of conditions that would result in a maximum yarding cost of $0.15/$ft^3$ or less. Figure 1 shows a stand with an average DBH of 12.44 inches and a volume removed of 2,711 ft^3/acre. Group-selection units of 1.0 acre can be used only if the wood is yarded tree length and slope yarding distances are not more than 350 feet. Figure 2 shows a similar stand with an average DBH of 12.48 inches and volume removed of 1,493 ft^3/acre. Group-selection units of 2.0 acres that are yarded with 32-foot logs will require short yarding distances (50 feet or less). If the same-size units are logged tree length, the slope yarding distance can be increased to 650 feet.

Generally, larger units results in more volume removed per entry, and larger logs are cheaper to harvest. Combinations that remove more volume/acre from larger units and that use tree-length yarding provide the largest set of feasible options. These combinations also allow the use of longer yarding distances. Another way to use this information is to fix the slope yarding distance at, say, 850 feet. The only feasible set in the 12.48 DBH stand would require units of 3 acres and that the wood be yarded tree length.

VALIDATION

The expert system was validated by comparing observed results (Module 1) with estimated results (Module 2) for numerous combinations. For comparison purposes, select combinations of observed values were input and Module 1 was used to develop estimates for discrete values. The same combinations of values were then entered into the system and Module 2 was used to develop estimates in a continuous mode. The results were comparable for all combinations tested. Table 3 is a sample listing of the validation tests. In every instance, the differences between observed and predicted values were within ±10 percent. On the basis of the results of these validation tests and the differences between observed and predicted values, we believe that the expert system can be used to develop cost and production information for group-selection harvests by cable-logging systems.

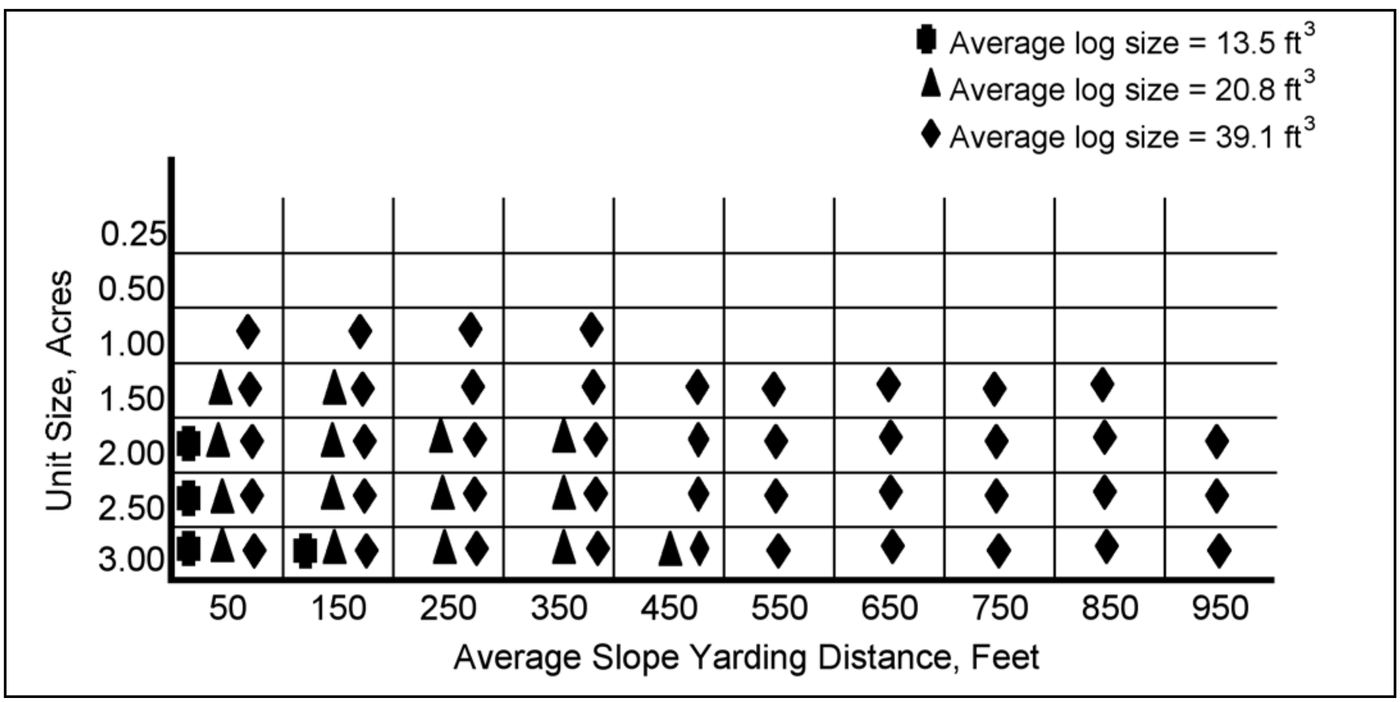

Figure 1.—*Set of combinations that would result in maximum yarding cost of $0.15/$ft^3$ (average DBH cut = 12.44 inches; volume removed = 2,711 ft^3).*

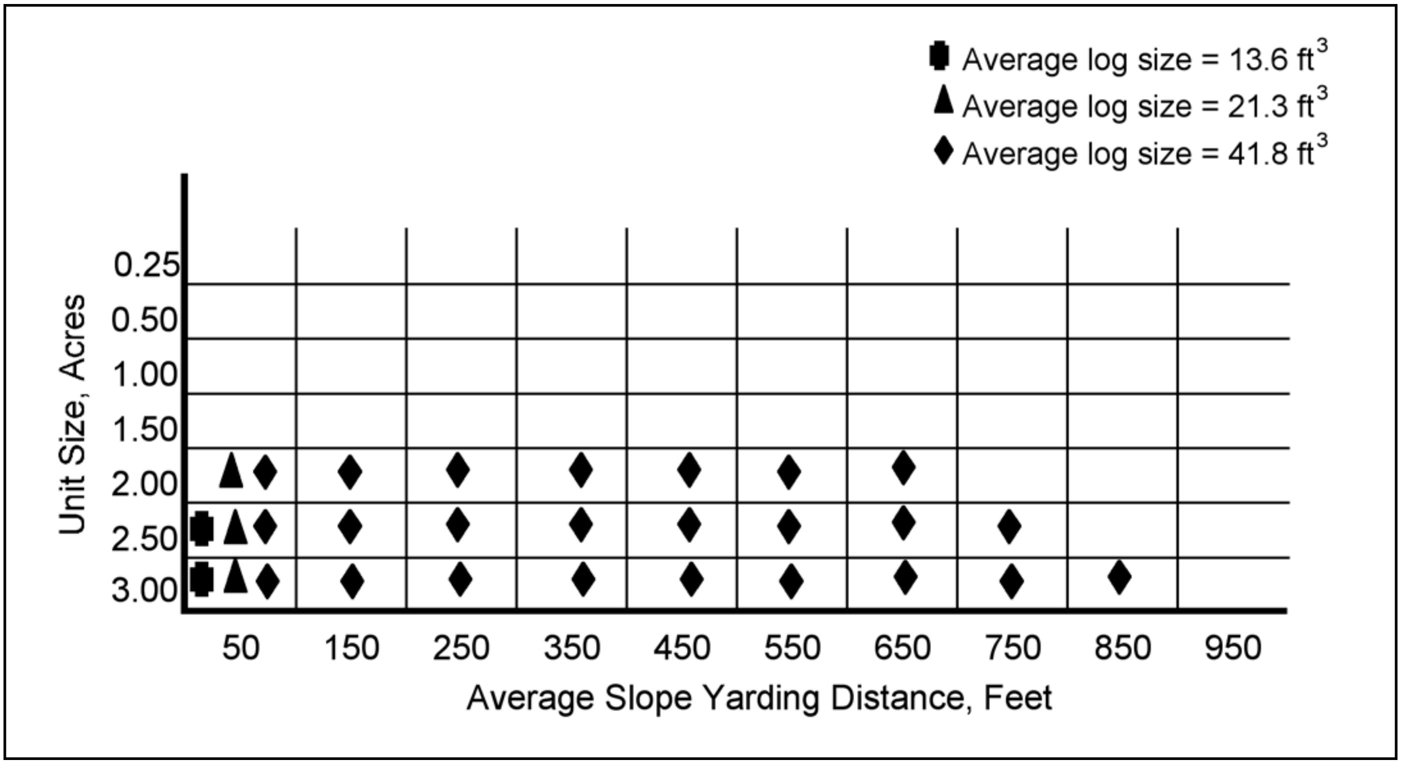

Figure 2.—*Set of combinations that would result in maximum yarding cost of \$0.15/ft^3 (average DBH cut = 12.48 inches; volume removed = 1,493 ft^3).*

Table 3.—*Results of validation tests between observed and estimated values*

Test number	Unit size	Average log length	Average slope yarding distance	Average DBH cut	Volume/acre removed
	Acres	Feet	Feet	Inches	ft^3/acre
1	0.25	32	350	9.57	817
2	0.25	32	350	11.02	1,327
3	0.50	32	650	11.02	1,327
4	1.50	16	750	14.48	2,776
5	3.00	16	950	17.91	3,390
6	3.00	Tree Length	550	17.91	3,390

Test number	Production rate and cost Module 1		Module 2		% difference	
	Ft^3 / hr	\$ / Ft^3	Ft^3 / hr	\$ / Ft^3	Ft^3 / hr	\$ / Ft^3
1	162.09	1.34	172.11	1.31	+6.18	-2.24
2	342.77	0.78	357.42	0.77	+4.27	-1.28
3	224.14	0.55	226.61	0.54	+1.10	-1.82
4	236.04	0.27	248.09	0.26	+5.11	-3.85
5	298.99	0.20	270.69	0.21	-9.47	+5.00
6	767.32	0.09	803.02	0.08	+4.65	-4.44

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