THINEX - An Expert System for Estimating Forest Harvesting Productivity and Cost

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ABSTRACT

As the emphasis of forest stand management shifts towards implementing ecosystem management, managers are examining alternative methods to harvesting stands in order to accomplish multiple objectives by using techniques such as shelterwood harvests, thinnings, and group selection methods, thus leaving more residual trees to improve the visual quality of the harvested land. Contemporary harvesting practices require the creative use of existing cable and ground-based technology. Silvicultural operations such as group selection methods, shelterwood harvests, partial cuts and thinnings require substantial planning in order to realize a profitable logging endeavor. THIN-PC is a personal computer based version of the original THIN developed by Chris B. LeDoux and David A. Butler in 1981. THIN and THIN-PC are computer simulation models, which evaluate the single- stage pre-bunch and swing methods of cable yarding. THINEX, the expert system developed as a result of this research, uses the results from THIN -PC and allows planners, managers, loggers to evaluate, plan, and execute profitable harvesting practices and permit effective sensitivity analysis by linking the terrain data with the production system information. Using THINEX, the user will be able to analyze several kinds of scenarios pertaining to a stand of trees and their harvesting resulting in the acquisition of production rate and cost values.

Keywords: Expert systems, Artificial Intelligence, Knowledge Based Systems, Forestry, Harvesting Productivity and Cost, Forest Stand Simulation.

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1.INTRODUCTION

A Forest region can be defined as a broad geographic zone within which the composition of the vegetation is relatively uniform and the forest resources provided by nature are very limited[7]. The most recent Renewable Resources Assessment found that the United States does not have a large, unreserved volume of softwood saw timber to draw upon to meet the Nation's needs [1]. This calls for the use of forest resources efficiently which can be accomplished through proper Forest Stand Management.

Silviculture, a basic tool of forest management, is applied forest ecology. Silvicultural knowledge and techniques are applied to forestland through prescriptions, which are records of the examinations, diagnosis, and treatment regimes recommended for forest stands. Many Silvicultural prescriptions project treatments and their anticipated costs and returns through an entire rotation.

1.1 SILVICULTURAL SYSTEMS

A Silvicultural System is a program of treatments for a whole rotation. The following are the important systems:

a) Even-aged system: A stand is said to be an even aged system stand if it consists of the same or nearly the same age [7].

1. Clear-cutting Method: "Clear-Cutting" has also been commonly used to describe cutting operations in which only the utilizable trees are cut. In the Silvicultural sense, it usually refers to regeneration operations in which virtually all woody vegetation is removed from the site preparations to establishment of the new trees.[7]
2. Shelterwood Method: Establishment of a new, eventually even-aged, stand from the release typically in a series of cuttings of new trees started under the old stand. [7]
3. Irregular Shelterwood: Delays in clear-cutting, induces irregularity in height growth of the new stand, then this variation is called as Irregular shelter woodcutting. [7]

b) Uneven-aged Systems: This system consists of stands that are created or maintained which include three or more distinctly different age classes.[7]

c) Intermediate Cuttings: These are the treatments conducted to modify or guide the development of an existing crop of trees, but not to replace it with a new one. Intermediate Cuttings can be summarized as follows [7]:

Release cutting, Improvement cutting, Thinnings, Salvage cutting, Sanitation cutting

In this research, the Thinning method is given much focus and attention. Thinnings are partial cuttings in even-aged aggregation of trees designed to improve future growth by regulating stand density. Thinnings are also grouped according to the crown classes of trees [7]. They are:

Low thinning, Crown thinning, Selection thinning, Geometric or Mechanical thinning, Free thinning

In this research, work-thinning method is addressed as whole without delving into the types of thinnings as classified above. Harvested wood needs to be transported to the place where it is processed for use. This process is called as Logging. Transport to the roadside is commonly termed skidding if moved by animal or tractor; forwarding if transported in the back of an off-road vehicle; or yarding if moved by cable, balloon, or helicopter [7]. The problem of yarding small logs [averaging less than 26ft^3 (0.73 m^3) in volume and 20 inches (51 cm) in diameter] produced from thinning on steep, broken terrain is one that the timber industries have yet to address fully[2].

The efficient management of forest stand depends on thinning and Silviculture technology, current and future market demands and prices for hardwood products, stand growth and yield response, stand composition, transport vehicles, machine-hour rate and landowner's objective. THIN[3] and THIN-PC[3] are computer simulation models that evaluate the single-stage and prebunch-and-swing methods of cable yarding [3].

1.2 KNOWLEDGE BASED EXPERT SYSTEMS

Expert systems are computer-based tools, which are used to solve problems that require a significant amount of human expertise. It is a computer system that applies inference techniques to a knowledge base, with purpose of supporting human expertise. Like a human expert, an expert system gives advice by drawing upon its own store of knowledge and by requesting information specific to problem at hand. A formal definition of expert system can be stated as: "An expert system can be defined as a computer program which has been developed based on existing knowledge pertaining to a specific domain. incorporating reasoning techniques which a human expert would employ in analyzing any problem and

thus acts as an advisory tool". There are number of areas where the expert systems form best tool to handle the problems. These are successfully applied in the areas of engineering, agriculture, finance, business, computer systems, chemistry, electronic, medicine, military, science, law, manufacturing among others.

The major difference between expert systems and conventional computer programs are: A typical computer program runs on a complete set of data with the expectation of a unique solution to the problem. In contrast, an expert system frequently runs on an incomplete set of data and may well produce many solutions to a problem, with varying degrees of confidence. Also conventional programs are algorithmic in nature and require a complete set of data to produce a unique solution, an expert system is conceptual in nature, can function with an incomplete set of data, and may produce several solutions. Most expert systems include the facility of determining and displaying their confidence in the advice they offer. In conventional programs, this feature is generally neither present nor important.

1.3 NEED FOR RESEARCH

For effective utilization of forest resources simulation models were developed as a part of research by the Forest Stand Management researchers at USDA Forest Service, Northeastern Forest Experiment Station, West Virginia. The major research objectives of this research can be listed as follows:

1. Design and Development of an Expert System for Hardwood Group-selection and Shelterwood Harvests on Steep Terrain using THIN-PC [3] results.
2. Integrate THIN-PC [3] into the Expert system thus developed.
3. Validate the Expert System results with the previous run THIN-PC[3] results.

The main objective of this research is to develop THINEX, an expert system to enhance efficient estimation of Forest Harvesting Productivity and Costs. This expert system helps forest managers in computing values for the input parameters to get maximum production rate and cost.

The expert system developed uses a database, which was created by running the THIN-PC[3] for various combinations. The expert system was developed in different modules each addressing an issue of forest harvesting productivity and cost estimation. They are:

- Module 1: This module helps the user to select the values from the existing database domain.

- Module 2: This module gives the user the option to select or enter the values of choice, the results will be obtained using extrapolation and interpolation of the existing values in the database domain.
- Module 3: This module allows the user to execute the THIN-PC[3] program from within the expert system.
- Module 4: This module gives the user the flexibility to enter the minimum cost variable and Method, upon the input the system generates the probable input variables as result.

1.4 SYSTEM DIAGRAM

The system diagram for the expert system developed is shown in the figure 1.1. Essentially this diagram depicts the various components and features of the expert system. The user input consists of the silvicultural method, diameter breast height (DBH), log length, slope yarding distance, unit size in acres, and volume per acre generated. The standard database consists of dBase[4] files, which are related to a particular silvicultural method.

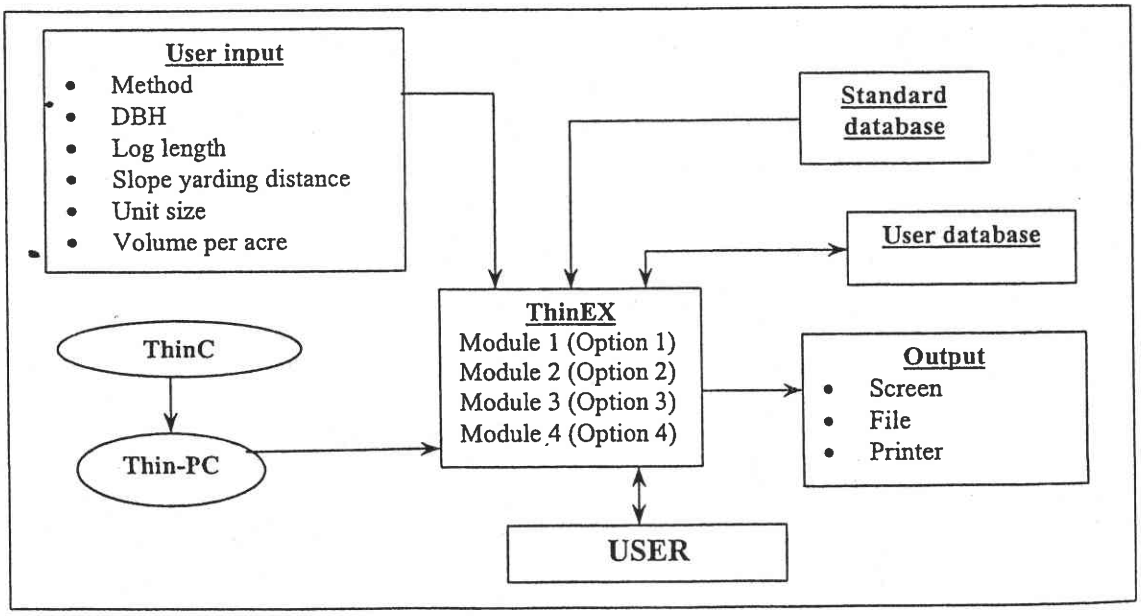

Figure 1.1 System diagram.

2. DETAILS OF THIN-PC

THIN-PC [3] is a package which was written in FORTRAN-IV to assist forest managers to obtain Production rates for different Silvicultural treatments on a particular Harvest site with applicable factors

which needs consideration. THIN-PC[3] is a personal computer based version of the original version of THIN[3] and THIN-PC[3] are computer simulation models that evaluate the single-stage and prebunch-and - swing methods of cable yarding. By combining data for both the single-stage and prebunch-and-swing yarding methods, the user is able to compare the output produced and estimate the most economical method of yarding a stand. THIN[3] was originally written in FORTRAN IV for execution on a Control Data Corporation CYBER 170 Model 720 using GASP IV[5] subroutines for gathering and reporting statistical results. It has been rewritten in Turbo Pascal version 6.0 and a user-friendly interface has been added. The GASP IV[5] subroutines used in the original have been rewritten in Turbo Pascal. Contents of THIN-PC[3] Package are:

1. THINPC.EXE - Executable file for THIN-PC[3]
2. INPUT.DAT - THIN-PC[3] data input file.
3. DEFAULTS.DFT -Data file, which specifies default input and output files.
4. INSTALL.BAT - Batch procedure to install THIN-PC[3].

2.1 THIN-PC EVALUATION

The amount of time THIN-PC[3] takes to execute is high. This is the case even on the powerful computers. The input file to run the THIN-PC[3] needs to be changed for each run, for different values. This is accomplished by changing the parameters in the input file using a text editor. Much care and understanding is required to manipulate the input file as it contains 37, 80-column records and some of which are simulation control parameter constants. The output file generated by THIN-PC[3]execution is huge and it contains lot of information, which demands profound knowledge and careful analysis.

2.2 DATA ACQUISITION USING THINC AND THIN-PC

The data that was used in creating the database files included the output from executing the THIN-PC for over 5000 combinations of input parameters. To eliminate the labor in creating the input file using text editors, a separate C program called as THINC was developed in Turbo C Version 5.0. This program essentially reduces the labor of opening the text editor and the creation of an input file needed for executing THIN-PC[3]. This program when executed asks the user to provide the input parameters, which are needed to run THIN-PC[3] with a different set of data. This program writes the input parameters along with other simulation control parameters onto a text file, which is used by THIN-PC [3] for successful execution.

Different Database files were created with respect to the different Silvicultural methods. The various runs were based on variation in input parameters like Silvicultural method, DBH, Unit size, Log length, Volume per acre. For one run successful run of the THIN-PC[3] yields the Production rate for 10 different Slope yarding distances for the same input parameter. The slope yarding distance ranges from 50 through 950 feet. The Production rate thus obtained is used to calculate the Cost incurred manually, using the equation available with the Northeastern Forest Experiment Station of the USDA, Morgantown, West Virginia. The different stand numbers are also derived from the same source as the Cost equations.

3.0 DESIGN OF THINEX EXPERT SYSTEM

THINEX, an expert system, is developed based on THIN[3], a-simulation model for forest stand management. THINEX has been design in a robust manner to handle all possible combinations. Different features of the expert system shell along with numerous tools were used to build an integrated system. VP-Experts compatibility with other software's like DBASE [4], ASCII text files, calling external programs etc. provided the much-needed tools to enhance the utility of the overall system. THINEX unique features include the explanation facility, handling of unknown and absurd values and directing the output to multiple destinations as may suit the desires of the user. It's additional advantages also involves its ease of interaction with databases and giving the user an option to append the database THINEX expert system is divided into four different modules. Each module helps the user to exploit its unique features.

3.1 MODULE 1

The main idea behind the design of this expert system module is to exploit the database domain generated. This system helps the user to query the system database, to obtain production rate and Cost. There are two database domains in the system, existing database domain and run-time database domain. Runtime database domain is the database developed during the execution of the Third module of this THINEX Expert System. Here a database is generated at runtime due to the execution of THINC and THIN-PC[3]. Executing the THIN-PC[3] for different combinations of input parameters had created this database. The various fields of database files are predetermined excepting fields for production rate and cost. The field value, which is mandatory, is the Diameter Breast Height. The various fields are filled using the output generated from executing THIN-PC[3]. The production rate is used to calculate the cost using the equations provided by USDA (United States Department of Agriculture) authorities of The Forest

Experiment Station, Morgantown, West Virginia. The equations are for the CHRISTY and the SHOP BUILT Yarder.

The Christy yarder is used for Group selection method and Shop Built yarder is used for Thinning, Conventional Shelterwood and for Irregular Shelterwood. The equation is of the form:

$$\text{Cost } (\$/Ft^3) = ((((V_{oac} * AC)/PR) + 3.92) * MR)/ (V_{oac} * Ac) \ldots(1)$$

Where

V_{oac} = the Volume per acre in Cubic Feet,

AC = the unit size in acres

PR = production rate in Cubic feet /hour.

MR = which is the Machine rate per hour.

3.2 MODULE 2

The main objective of this module is the use of statistical relations in determining the production rate and cost of different Silvicultural methods. The database domain developed in the module 1 is extensively used in arriving at proper statistical relations between different variables of interest. Statistical software was most widely used for developing different statistical relations.

The variables of interest included diameter breast height (DBH), log length, average log size, unit size, slope yarding distance and volume per acre. Suitable regression equations for calculating the Production rate based on the input parameters like volume per acre; slope yarding distances etc. were developed. For each Silvicultural method there needed to develop thirty different base equations were developed. These equations thus developed formed the knowledge base for this present module. These equations were used in the rule base of the expert system thus enabling the user to obtain the value of Production rate for different discrete input data sets.

3.3 MODULE 3

The main objective of this module is to enable the user to execute the THIN-PC[3], Within the THINEX environment. Also, execute THINC to create input file for executing THIN-PC[3]. The importance of THINC has already been discussed in detail in the discussion of background of Module1. The other primary objective of this module is to automate the process of database creation. The database domain

created is called as Run-time database domain, which is exploited in the module 1 of THINEX Expert System. The THINC program is used to create input for execution of THIN-PC[3]and THIN-PC[3] is executed within the THINEX environment. Another program called as PABBAC.C, written in Turbo C version 5.0 gets the relevant data from the output file created due to the execution of THIN-PC[3]. The system then appends these values along with the output data obtained from executing THIN-PC[3] onto the runtime database. For each execution of this module, the system appends ten records into the runtime database. In this way, the runtime database is developed and various executable programs are executed within the THINEX environment.

3.4 MODULE 4

The main objective of the present module is to give the user various input parameters based upon the query of maximum affordable cost and Silvicultural method. The present module extensively uses the graphical features and backward chaining mechanism of VP-Expert.[6] This module allows the user to get multiple record sets as a result of query based on maximum affordable cost and Silvicultural method. It also gives the user the flexibility to enter the maximum cost affordable in dollars/Cubic-Feet ($/Cu-ft). The module uses the values selected or given as input as the indices for querying the database and reports to the user the valid record sets that match the query. The user can experiment with this module for various cost parameters so that the valid input parameters are obtained.

4.0 CONSULTATION WITH THINEX

First VP-Expert should be loaded by using the command "vpx" at the DOS command prompt. The VP-Expert[6] main menu comes up, from which the proper "KBS" file should be loaded. Once the main menu of THINEX appears on the screen user has four options for selecting modules.

4.1 CONSULATION WITH MODULE 1

The user during the start of consultation with Module 1 or Option 1 is offered with two choices in the menu. Selecting choice one starts a help screen and it has information regarding the steps that are needed to follow for successful consultation. The system prompts for various inputs, some by giving the user an option to select from the menu and some by prompting to enter the relevant data. The input parameters that are necessary for successful consultation will be some or all of the following variables, : Database domain, Silvicultural method, Diameter Breast Height, Log length, Slope Yarding distance,

Volume per acre and Unit size (if applicable). In Module1, the user is given the flexibility to enter unknown for two variables Log length and Slope Yarding distance. Once the system gets the relevant and valid input from the user the Expert System provides three options for the user to select the mode of viewing the results, which include displaying on screen, saving them onto a ASCII text file or sending them to a printer.

4.2 CONSULTATION WITH MODULE 2

The second module or option uses extensively the statistical regression equations in projecting the Production rate (Cu-Ft/hour) and the Cost ($/hour) associated with it. The system prompts for various input parameters like Log length, Diameter Breast Height, Volume per acre and Unit size (if applicable). The system calculates Production rate and cost using the knowledge base.

4.3 CONSULTATION WITH MODULE 3

The main concept behind this option is to execute THINC and THIN-PC[3] within the THINEX environment. VP-Experts capability in calling external DOS programs or any other procedure oriented language's executables made this concept to put into action. The user needs to create an input file for executing THIN-PC[3]. This can be accomplished by first executing THINC, a program that automates the process of input file creation. After the creation of input files the system then executes THIN-PC[3] depending upon the users choice. Once the results due to execution of THIN-PC[3] are obtained the system then prompts for appending of the results to the runtime database. The system appends to the runtime database depending upon the user response. If the user responds to the appending of the database the system displays the record sets that are being appended to the runtime database domain.

4.4 CONSULTATION WITH MODULE 4

Module 4 generates various ways that a user can have the variable set for a given maximum affordable cost and Silvicultural method. In this module, the graphical features of VP-Expert[6] are very well exploited. The system prompts the user to select the Silvicultural method from a drop down menu and prompts the user to enter the maximum affordable cost in $/Cubic-feet and to select the Unit size, if applicable. The system then executes the query with the incomplete data sets and provides the user with various record sets as options that match the query. The system also displays the option number along with

the results. Thus depending upon the Cost and the Silvicultural method the user is provided with various other input parameters that the user needs to achieve the results under given constraints.

5.0 VALIDATION OF RESULTS

The accuracy and validity of the results given by the system determine the measures of success of developing a system. In developing, every care has been taken and every step has been developed in maintaining the accuracy of the results. The results that are obtained by either of the methods vary within the range of 5% to 10% or even less. This is because in the development of regression equations the data that was available was discontinuous. This played a major role in this variation. In general, THINEX is a good example of an intelligent system applied in the forestry decision-making domain.

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