Developing Optimal Commercial Thinning Prescriptions: A New Graphical Approach

KaDonna C. Randolph, USDA Forest Service Forest Inventory and Analysis, Knoxville, TN 37919; and Robert S. Seymour and Robert G. Wagner, Department of Forest Ecosystem Science, University of Maine, Orono, ME 04469.

ABSTRACT: We describe an alternative approach to the traditional stand-density management diagrams and stocking guides for determining optimum commercial thinning prescriptions. Predictions from a stand-growth simulator are incorporated into multiple nomograms that graphically display postthinning responses of various financial and biological response variables (mean annual increment, piece size, final harvest cost, total wood cost, and net present value). A customized ArcView GIS computer interface (ThinME) displays multiple nomograms and serves as a tool for forest managers to balance a variety of competing objectives when developing commercial thinning prescriptions. ThinME provides a means to evaluate simultaneously three key questions about commercial thinning: (1) When should thinning occur? (2) How much should be removed? and (3) When should the final harvest occur, to satisfy a given set of management objectives? North. J. Appl. For. 22(3):170–174.

Key Words: Nomogram, silvicultural system, financial analysis, FVS, simulation.

Careful regulation of stand density through thinning arguably distinguishes truly intensive management above all other silvicultural treatments (Smith et al. 1997), and in every important forest region, rigorously derived thinning schedules are crucial in meeting production objectives. Typically thinnings are prescribed using stocking guides or stand-density-management diagrams. Since the 1970s in the northeastern United States, stocking guides developed in the manner of Gingrich (1967) have dominated practice (Seymour 1995, 1999). These stocking guides are based on tree-area ratios that define an expected maximum density for a given forest type and use easily measured stand attributes such as basal area, quadratic mean diameter, and trees per unit area to assess stocking of a single stand at a particular point in time (Nyland 1996). Typically, the stocking guide charts are divided into zones of overstocking, full stocking, and understocking with the familiar A-, B-, and C-Lines, respectively.

A common alternative to Gingrich-style stocking guides is the stand-density management diagram (SDMD). Formulated initially by Reineke (1933), SDMDs were later developed by Japanese scientists in the 1960s and introduced to North America in the late 1970s (Drew and Flewelling 1979, Newton 1997a). SDMDs graphically depict the relationship between stand density and average tree size (either quadratic mean dbh or stemwood volume, and frequently supplementary isolines depicting tree height; Newton 1997b, Wilson et al. 1999). SDMDs are used to determine the specific stand density required to meet various production objectives, including minimizing time to operability and attaining specified mean diameters and log dimensions at the end of a rotation. Volume-based SDMDs are useful for predicting yields of various thinning regimes and even to evaluate their consequences on wildlife habitat (Newton 1997a).

Although stocking guides and SDMDs are very useful for prescribing thinnings, users must tacitly assume that the typical recommendations of researchers to maximize yields (e.g., thinning to the B-Line or 40% relative density) will automatically meet their objectives. More commonly, forest managers are interested in balancing maximum yields with financial and piece-size targets. Stocking guides and SDMDs are not designed to identify a specific residual density that simultaneously optimizes multiple objectives. For example, SDMDs do not include any financial information, and therefore net present value or internal rate of return must be calculated separately, a time-consuming and error-prone process.

Our objective was to develop an analytical framework that would facilitate the application of existing stocking
diagrams and stand-growth simulators in formulating density-management regimes that can achieve user-specified goals. Rather than deriving a single “optimum” strategy, we sought to develop a method or tool that could illustrate the trade-offs among multiple biological and financial response variables by using an interactive format that promotes flexibility by identifying the range of feasible strategies. This article outlines the conceptual approach of such an analytical tool and provides an example of how this strategy was incorporated into the customized ArcView GIS application called ThinME (short for Thin Maine) for developing commercial thinning prescriptions in Maine spruce-fir stands.

Figure 1. Steps in plotting simulation model output for producing a single nomogram. (A) Stand development is projected after three different thinning prescriptions (to residual densities of 400, 325, or 260 trees/ac) and the calculated effects on mean annual increment are plotted against residual stand density and stand age. (B) Isolines are drawn through the mean annual increment “heights” shown in (A) to yield a response surface.

Figure 2. Steps in applying nomograms to derive a commercial thinning prescription. (A) Unacceptable outcomes for two management-objective variables (mean annual increment and piece size) are shaded individually. (B) The individual nomograms of (A) are overlaid, yielding an unshaded area in which the two management objectives are met simultaneously. (C) The range of residual density and final harvest ages that meet the management objectives are read from the axes. Note: TPA reference lines slant slightly downward to reflect tree mortality simulated by the FVS model.
Conceptual Approach

If unlimited time and resources were available, one could use a stand growth simulator, along with appropriate financial postprocessors, to derive a “custom” thinning prescription for every stand to be treated. Of course, such an approach is impractical. Efficiently developing silvicultural prescriptions requires a method to synthesize results from numerous simulations in an easy-to-use, understandable manner. The many decision variables that forest managers must incorporate make it difficult to visualize the multidimensional space in which the management objective(s) must be optimized. To overcome this difficulty, Peterman (1975, 1977) developed a graphical technique (nomogram) to compress the outputs of simulation models into an understandable, two-dimensional format, while retaining all possible information.

The nomogram technique used by Peterman graphically depicts one response variable, a measure of system performance that a manager seeks to influence such as stand yield, as a function of two other input variables that are under the manager’s control such as stand density and rotation age. This format effectively captures a three-dimensional relationship in the form of a contour plot or response surface. Using the nomogram, a user can quickly and easily determine if certain levels of a response variable are attainable, distinguish trade-offs required to achieve certain goals, and examine alternative outcomes. We selected this method for analyzing commercial thinning prescriptions owing to its intuitive graphical nature: by overlaying alternative scenarios, nomograms can depict numerous management response variables simultaneously.

Individual Nomograms

The nomogram consists of two main axes and a response surface of a variable of interest relative to the main axes. For commercial thinning applications, the horizontal axis is age at the simulated final harvest and the vertical axis is residual stand density (trees per acre) after thinning. The variable of interest reflects a stand-management objective and could be average piece size, mean annual increment, net present value, or any other density-dependent variable that changes as a stand develops over time.

Generating nomograms requires several sequential steps. First, initial stand conditions are entered into the growth and yield model. After examining three different growth and yield models, we selected the USDA Forest Service’s Forest Vegetation Simulator NE-TWIGS variant (Bush 1995, Teck et al. 1996) for this application. Next, thinning prescriptions are repeatedly applied to the stand of interest with the goal of spanning the range of feasible densities and thinning methods. Stand development is projected, and the effect of the thinning prescription on the management variable(s) is recorded (in a spreadsheet) at successive ages and plotted (Figure 1A). Finally, to complete the nomogram, isolines

![Figure 3. Shadings for a set of management objectives result in different areas of acceptability when commercial thinning is implemented at three stand ages: (A) age 27; (B) age 32; and (C) age 37. Unshaded regions define the conditions in which final harvest piece size is less than 20 trees/cord and mean annual increment is at least 0.85 cords/ac/year; for clarity in illustration, other variables are not considered. Density of the simulated spruce-fir stand before simulated commercial thinning was 750 trees/ac; site index = 70.](image-url)
lines of equal value) are generated via mathematical interpolation to define “contours” of the management response variables (Figure 1B).

Once a nomogram is generated, users can “shade out” unacceptable outcomes in the nomograms to arrive at a target residual stand density and final harvest age (Figure 2A). When the nomograms for two response variables (mean annual increment and final-harvest piece size) are overlaid, the remaining unshaded zone represents the range of residual densities and final harvest ages that simultaneously meet both objectives (Figure 2B). This process can be repeated for as many response variables or nomograms as needed. Figure 2C illustrates that for any given residual density, there is a range of rotation ages at which the final harvest must occur: after the stand “grows” into the highlighted region and before the stand “grows” beyond it. For this reason, residual stand density and final harvest age should be read in tandem from the vertical and horizontal axes, respectively. In this example, the greatest flexibility in final harvest age (about 54–68 years) appears to result from thinning to 500 TPA.

Multiple Nomograms

Just as a stand can be thinned to various residual densities, a stand also can be thinned at different ages. Determining when to commercially thin is accomplished by evaluating nomograms generated from thinning prescriptions applied at different stand ages. In essence, the process illustrated in Figures 1 and 2 is repeated for the same hypothetical stand thinned once commercially at different ages. Figure 3 illustrates this approach for commercially thinning the same stand at 27, 32, or 37 years of age.

Using the same combination of five response variables (mean annual increment, piece size, final harvest cost, total wood cost, and net present value) for each thinning age, the nomograms in Figure 3 are shaded to show the combinations of residual density and final harvest age that simultaneously meet two objectives simultaneously: piece size at final harvest less than 20 trees per cord; and mean annual increment at least 0.85 cords/ac/year. Figure 3A is completely shaded, indicating that thinning at age 27 cannot meet these multiple objectives, regardless of the residual density or final harvest age. The objectives can be met,
however, if the stand is thinned at age 32 (Figure 3B) or 37 (Figure 3C). To determine which of these two ages is better, the size of the unshaded region is considered. Taller areas imply more flexibility in residual density, whereas wider areas imply more flexibility in final harvest age. In this example, we consider the third timing, age 37 (Figure 3C), to be the best option because it provides the most flexibility in setting the commercial thinning and final harvest prescriptions and, thus, the greatest robustness against unexpected pest outbreaks or abiotic stresses (Peterman 1977).

Application

When Peterman first suggested these methods, production of nomograms required tedious manual interpolation, plotting on transparent media, and shading of unacceptable outcomes, so it is no surprise that few applications ensued. Modern GIS automate these tasks and allow users to create a customized visual user-interface using ArcView GIS (Environmental Systems Research Institute 1997). By means of the customized interface (ThinME), the effects of different commercial thinning prescriptions on biological and financial variables are illustrated for a variety of stand conditions and thinning options applicable to Maine spruce-fir forests. ThinME is designed to distill a myriad of harvesting options into a more reasonable assemblage of alternatives by assisting the user in answering the three questions discussed here: (1) When should thinning occur? (2) How much should be removed?; and (3) When should the final harvest occur, to satisfy a given set of management objectives?

ThinME includes the following financial and biological stand-management objective variables: mean annual increment, piece size, final harvest cost, total wood cost, and net present value, all projected forward 50 years after the simulated commercial thinning entry. Spruce-fir stands with a history of precommercial thinning (PCT) and spruce-fir stands that have never been precommercially thinned (natural) both can be examined. Nomograms are available for different site indexes, three ages of thinning entry, three initial stand densities for PCT stands (1000, 750, and 500 trees/ha), and for natural stands, two thinning methods (low and crown).

ThinME automates the shading of unacceptable regions in the same way spatial queries are performed with geographic data. Slider bars allow the user to set acceptable limits for each management objective; on clicking an “okay” button, ArcView queries the nomogram and highlights the acceptable regions (Figure 4). Successively smaller adjustments in the response variables quickly allow the user to converge on the optimal thinning age, residual density, and final harvest age.

Conclusion

Our nomogram approach to assigning commercial thinning and final harvest prescriptions is an improvement over traditional stand-density-management diagrams and stock-liquid guides. By incorporating financial and biological variables into an easy-to-use graphical system, forest managers are able to more quickly and thoroughly explore a variety of commercial thinning prescriptions. The nomogram approach also allows forest managers to weigh the different outcomes and determine acceptable trade-offs among an array of specific management objectives.

ThinME is our first attempt to integrate postthinning growth responses and the formulation of silvicultural prescriptions using the nomogram methodology. We envision future versions of the model that will allow users to enter their own stand data and directly interface with existing stand simulators such as the USDA Forest Service Forest Vegetation Simulator. As data become available from ongoing commercial thinning studies in the region (Wagner et al. 2001), ThinME will be improved through the use of growth and yield models specifically calibrated to project postthinning growth responses.

Literature Cited


