Spatial Scheduling of Forest Management Activities using a Dynamic Deterministic Harvest Block Aggregation Process

Pete Bettinger and K. Norman Johnson

Japan Society of Forest Planning
Spatial Scheduling of Forest Management Activities using a Dynamic Deterministic Harvest Block Aggregation Process

Pete Bettinger*1 and K. Norman Johnson*2

ABSTRACT

A dynamic, deterministic process for aggregating individual forest management units into larger harvest blocks was developed to allow a simulation of management behavior in support of the development of reasonable portrayals of forest policies in western Oregon, USA. The method described here dynamically aggregates individual management units into harvest blocks (a tactical goal), and the blocks are then fit to a variable (user-defined) clearcut size distribution (a strategic goal). One important objective with this work is that management behavior (the method for aggregation and the size distribution of recent clearcuts) is modeled or simulated, not optimized, for policy analysis purposes. Management units are selected for clearcut harvest and included in harvest blocks based on a valuation of the timber resource, and a determination of whether the size of the block is consistent with a clearcut size distribution. A close representation of management behavior facilitates a process whereby policy makers and landowners can evaluate alternatives to current policies, and begin to “think through” forest policies prior to implementing them.

Keywords: forest planning, forest policy analysis, simulation, harvest scheduling, area restriction model

INTRODUCTION

Forest policy analysis is increasingly relying on quantitative forest planning to provide an estimate of the spatial distribution of harvest activities over time under different policies, particularly to help understand the implications of different levels of forest management on the protection of biodiversity. A large-scale project to simulate the ecological, economic, and social aspects of forests of the Coast Range of Oregon (Coastal Landscape Analysis and Modeling Study 2002) for the next 100 years was developed with this policy process in mind. It requires a projection of the spatial nature of harvest activity. Future harvests in the Coast Range will likely occur largely through clearcutting of industrial and non-industrial private lands. To simulate the forest harvesting activities, the analysis process relies on a definition of individual land management units of similar characteristics as the building blocks for stand growth and yield. These, in turn, are aggregated into larger harvest blocks to emulate current management behavior. A dynamic, deterministic process for aggregating management units into these larger blocks, guided by a specified clearcut size distribution, was developed to facilitate this process. This process is part of the LAMPS (Bettinger and Lennette, 2002) simulation model. While Bettinger and Lennette (2002) provide a description of how to use LAMPS, they do not provide a detailed description of how newly developed processes within LAMPS, such as this, actually operate. Therefore the focus of this paper is on the description of a process (a dynamic, deterministic process for aggregating individual forest management units into larger harvest blocks) used to assist in the analysis of management behavior across broad areas and long time frames.

Strategic planning is generally characterized by processes that examine impacts and production over long time frames and large areas, with few spatial considerations recognized. Tactical planning is generally characterized by processes that examine impacts and production over short time frames and smaller areas, and addresses the spatial challenges involved in the development of a plan of activities. Public policy analysis is increasingly seeking a recognition of the characteristics of both approaches. As computer technology advances, the reasons for utilizing two separate approaches diminish, and as forest policy debates evolve, policy makers increasingly want

*1 Warnell School of Forest Resources, University of Georgia, Athens, GA 30602 USA; 706-542-1187, PBettinger@smokey.forestry.uga.edu
*2 Department of Forest Resources, Oregon State University, Corvallis, OR 97331 USA; 541-737-2377, K.Norman.Johnson@orst.edu
to see impacts of proposed strategic policies depicted on maps of the landscape. The policy analysis example we use throughout this paper relates to the examination of forest policies across large areas, multiple ownerships, and long time frames. One group of landowners (industrial) have indicated that emulating their management behavior is important in the policy analysis debate. One behavioral aspect we emphasize with this paper is that the blocking process used by industrial landowners is not necessarily optimal. While they tend to center harvest blocks on high valued timber stands, they may also harvest nearby adjacent stands of lower value, in an effort to minimize the costs associated with harvesting the lower valued stands. Another behavioral aspect is that land managers install on the landscape clearcuts of a variety of sizes, and (either consciously or unconsciously) may avoid making all clearcuts as large as the maximum size allowed. These two aspects of their behavior are important if one were to adequately evaluate, over time and space, the policies (regulatory and organizational) currently in place. Thus an important objective of the research presented here is that management behavior is being modeled, or simulated, not optimized.

Our intent throughout this research has been to merge strategic and tactical considerations into a simulation model designed for public policy analysis. Modeling the objectives of long-range strategic plans and the important characteristics associated with tactical planning efforts can facilitate various facets of policy analysis, since the placement of management activities on a landscape affects where future activities can be located, which may in turn affect commodity production values, cumulative watershed effects, wildlife habitat arrangements, and aesthetics (Jones et al., 1991; Snyder and Revelle, 1997).

One particular characteristic associated with tactical planning is the physical location of timber harvests. The size of clearcuts is increasingly becoming controlled by state or organizational policy, leaving forest managers to design clearcuts within a range of sizes. Early efforts in tactical planning centered on maintaining separation between individual management unit harvests, which are assumed to be internally homogenous and spatially stable over time (Holmgren and Thuresson, 1997). However, since individual management units are usually smaller (e.g., 15-20ha) than the maximum size defined in a policy (e.g. 50ha), such separation may come with a loss of flexibility in planning (Sessions and Sessions, 1991). Building harvest blocks within a forest planning process by aggregating adjacent management units, would alleviate some of this loss of flexibility, and allow the process to emulate actual management behavior.

The goal of the process described in this paper is similar to goals described by others (Clements et al., 1990; Lockwood and Moore, 1993; Wightman and Baskent, 1994), yet is different in several respects. First, previous efforts (Clements et al., 1990; Wightman and Baskent, 1994) defined harvest blocks a priori, whereas the process we describe allows block sizes to be changed as the harvest-scheduling considerations change. Second, Clements et al. (1990) chose the blocks for harvest randomly; our process uses a deterministic method for both building the blocks and scheduling harvest. Anderson and Marshall (1999) described a blocking process by which disturbance theory is used to randomly choose pixels (25-m grid cells) in the development of blocks of various shapes, sizes, and frequencies. This is similar, in theory, to our approach, except that the method by which pieces of land are chosen for inclusion in larger blocks is random (ours is deterministic), and the treatment of management units as continuous variables (ours are integer variables). Lockwood and Moore (1993) employed an approach to recursively examine changes in harvest block size and membership with integer variables, effectively creating and modifying (building upon, splitting, or reducing the size of) blocks during a binary-search process. In contrast to their approach of iteratively modifying harvest blocks, our process builds blocks to certain specifications, then leaves them alone. If the binary-search parameters are changed, all blocks are effectively eliminated and the process begins anew.

Still another approach is that developed by Holmgren and Thuresson (1997), which assigns priorities to raster grid cells, based on harvest entry costs and sub-optimality losses, for units that could be added to or removed from harvest blocks. This value-driven approach differs from most other approaches, which emphasize spatial constraints as the main reason for adding or removing units from harvest blocks. Our approach is also value-driven, but it is based on potential revenue, not cost. Another difference is that our approach treats management units as integer variables, whereas Holmgren and Thuresson (1997) disaggregate management units into smaller pieces (grid cells), which may lead to the development of unharvested pieces of management units that cannot be efficiently harvested in the future.

The work presented here is relevant for three reasons. First, the geographic location of activities is important for biologists and economists who collaborate in strategic planning and policy analysis efforts, and desire to associate ecological or socio-economic models (which typically use spatial information) with the projected landscape conditions to estimate the effects of current and alternative policies. Second, replicating a historical distribution of patch sizes is important to closely represent the management behavior of certain landowners when simulating management activities, a goal of the Coastal Landscape Analysis and Modeling Study (2002). Finally, the results of policies which attempt to emulate management behavior have meaning for the stakeholders who evaluate the products (maps) of planning efforts and policy analyses. A close representation of actual management behavior facilitates a process whereby policy makers and landowners alike can "think through" current and alternative policies prior to implementing them. The more closely actual
management behaviors are modeled, the more realistic the results may be perceived.

**METHODS**

Management units, spatially-defined pieces of land perhaps with different age class structures and tended at different times with various methods, are typically aggregated when final harvests (clearcuts) are scheduled on forest industry land in western Oregon. Although there is a variety of ownerships (federal, state, forest industry, non-industrial private) in western Oregon, this research only pertains to the management behavior of forest industry landowners. The reasons for aggregating management units are heavily influenced by regulations and organizational policies regarding the maximum size permissible for harvested areas, economies of scale regarding logging systems, and the need to convert low-valued forestland to higher-valued plantations.

The pattern of clearcut harvesting sizes in western Oregon over the past decade indicates that the contiguous area covered by these harvests tends to approach the maximum permissible by State law (48ha), yet not in all cases (Table 1). It was determined, based on several discussions with managers of industrial land in the region, that modeling this historical distribution in any type of policy analysis (current and alternative policies) was important. In addition, these managers noted that blocking management units for harvest was more reflective of their actual day-to-day decisions based on the reasons noted above. Therefore it should be clear that what we will soon describe, the application of a blocking algorithm to model management behavior across long time frames and large areas, is to simulate the management behavior of forest industry landowners. While the industrial forest landowners communicate the desire to be modeled as if they manage land under a net revenue maximization objective, in reality a mixture of stand types are blocked together in an effort to spread the costs associated with road building, and moving equipment to lower-valued management units over a broader revenue base.

To set the context for the forthcoming discussion, the problem we are addressing is one where we are evaluating the activities on forest industry landowners in a 560,000 ha area of western Oregon. A binary search technique, embedded within a forest landscape planning model (LAMPS, described in BETTINGER and LENNETTE, 2002), is used to develop a schedule of activities over time. Binary search requires an initial harvest target level, a harvest level to use as an adjustment to the target level, and stopping criteria. For example, assume that the initial target level was 1,000,000 units per time period over a planning horizon, and that the adjustment factor was 100,000 units. If 1,000,000 units were successfully scheduled in each time period within a planning horizon, the target harvest level would be adjusted upward to 1,100,000 units. The binary search process would then clear from memory the schedule of activities, and attempt to meet the new volume target. If the target was not successfully met in any one time period, the target volume level is adjusted downward by the size of the adjustment factor (to 900,000 units), the binary search process would clear from memory the schedule of activities, and attempt to meet the new volume target. In addition, the adjustment factor is halved after each use. At some point, the adjustment factor will become quite small, and commonly a rule is used to stop the binary search process after it falls below some threshold value. In addition to the binary search process, the LAMPS model treats the scheduling of activities as an integer programming problem, thus the response surface is most likely irregular. Binary search may require some refinements to work efficiently under these conditions, an area of investigation we leave for future endeavors.

The LAMPS model allows users to modify a large number of parameters related to forest policy scenarios. To illustrate the harvest blocking process, we designed a LAMPS scenario to utilize some very basic assumptions: the time frame is 100 years (twenty 5-yr. time periods); the goal is to achieve the highest even-flow of timber harvest volume possible; harvest blocks will be designed to emulate a clearcut size distribution; and a minimum clearcut harvest age requirement (45 years) is imposed.

The ultimate objective of the scheduling process in LAMPS is to minimize the deviations of actual harvest levels from a target harvest level set during an iteration of binary search.

Table 1. Distribution of clearcut harvest-block sizes in the central Coast Range of Oregon, 1991-1995.5

<table>
<thead>
<tr>
<th>Block size (ha)</th>
<th>Percent of total clearcut area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-16</td>
<td>16.7</td>
</tr>
<tr>
<td>16.1-24</td>
<td>14.3</td>
</tr>
<tr>
<td>24.1-32</td>
<td>15.2</td>
</tr>
<tr>
<td>32.1-40</td>
<td>17.3</td>
</tr>
<tr>
<td>40.1-48</td>
<td>36.5</td>
</tr>
</tbody>
</table>

5Personal communication, Jonathan Brooks, Department of Forest Resources, Oregon State University, Corvallis, OR.
\[ t = \text{a time period} \]
\[ T = \text{total number of time periods} \]
\[ i = \text{a management unit} \]
\[ I = \text{total number of management units} \]
\[ k = \text{a forest product} \]
\[ K = \text{total number of forest products} \]
\[ x_n = \text{binary variable indicating whether (} x_n = 1 \text{) or not (} x_n = 0 \text{) management unit } i \text{ is harvested in period } t \]
\[ V_i = \text{area of unit } i \]
\[ V_{k,t} = \text{Volume (per unit area) of product } k \text{ during time period } t \text{ in unit } i \]

LAMPS, however, is a simulation model, and takes a slightly different approach to meeting this objective: the goals (target volume levels) are defined for each time period during a binary search iteration. The scheduling of activities during a time period continues until the targets have been exceeded, or no other units are available for harvest. The resulting harvest levels are therefore usually slightly above (less than 0.01%) the target volume levels, unless the harvest levels cannot be achieved. In this latter case, the harvest levels are adjusted and the binary search process continues.

The minimum harvest age constraint allows a management unit to be considered for clearcut harvest in a particular time period:

\[ \text{If } \text{Age} \geq \text{minimum harvest age} \quad x_n \in [0,1] \]
\[ \text{Else} \quad x_n = 0 \]

Where:
\[ \text{Age}_n = \text{average age of the trees in unit } i \text{ during time period } t \]

The remainder of this discussion of methods relates to the harvest block size constraint. Management units are selected for harvest based on their "value", and perhaps blocked together for simultaneous treatment. Harvest blocks of various sizes are created, and an attempt is made to fit the distribution of acres by block size to a historical distribution to emulate the current management behavior.

There are two general approaches to applying spatial restrictions in forest planning efforts. First, the application of a technique called the "Unit Restriction Model" (URM) makes it possible to restrict harvest activity in units neighboring a unit scheduled for clearcutting, disallowing neighboring units from being treated in the same time period (or near-time periods). The technique would be invoked, for example, to prevent clearcut harvest of two adjacent management units in the same time period.

Constraints such as
\[ x_n + x_j \leq 1 \quad \forall n, i, j \in N_i \]

where
\[ N_i = \text{set of all management units adjacent to unit } i \]

can be used to control URM problems (Murray, 1999). Management units are typically smaller than the maximum clearcut size restriction, and thus it may be important to schedule adjacent units for harvest to produce a feasible management plan containing "harvest blocks." In such cases, a second technique, called the "Area Restriction Model" (ARM), can be used to assign simultaneous treatments to adjacent planning units, as long as the total contiguous area does not exceed the maximum area limit (Murray, 1999). Here, we use the ARM technique to build harvest blocks to fit a clearcut size distribution. Recursive functions are generally used to evaluate the resulting spatially sprawling block of management units. To evaluate ARM problems, constraints such as
\[ x_{n} + \sum_{j \in S_n} x_{j} \leq A \]

where
\[ S_n = \text{subset of the total number of harvested units that contains all units adjacent to the neighbors of unit } i \text{ plus all units adjacent to the neighbors of the neighbors, etc.} \]
\[ A = \text{maximum permissible area of harvest block} \]

are used. The blocking process we report here uses an ARM technique to evaluate the size of harvest blocks, and a URM technique to prevent two clearcut harvest blocks from merging together if they are being developed for clearcut during the same time period.

Defining Harvest Block Size Goals

Harvest block size goals come in many forms, such as a simple maximum size (e.g., in Oregon it is 48ha), a minimum size, or perhaps a range of sizes. In this research we had the goal of matching, or fitting, a historical range of harvest block sizes. To do so, the land area of forest to be clearcut in each period is first estimated. This estimate is made by determining how much clearcut area would be required to meet the binary search harvest volume target if one were to harvest the highest valued management units first, with no regard to the spatial positioning of the harvests. Then maximum area limits are used to define each harvest block size strata. For this study, the percentages of clearcut area in certain size classes (the strata) over the period 1991-1995 were estimated (Table 1). The area represented by each block size stratum is then calculated by multiplying the estimated total clearcut area by these percentages. We then know that for each stratum (e.g., 1-16ha), only a certain amount of area should be clearcut (e.g., Table 2, clearcut 167ha using 1- to 16-ha blocks).

Since exact achievement of these goals may be difficult, given the infinite number of potential combinations of harvest
blocks and the desire to achieve an even-flow of timber harvest volume over time, minor deviations from these goals are allowed. The harvest-scheduling process builds the blocks and continuously sums the amount of area in each block-size stratum. In each binary search iteration, the largest block-size goal not yet met is the current maximum block size for blocks being built. Once the clearcut area for the largest block size has been surpassed, the next size available (that does not already comprise more area than is desired) becomes the maximum block-size goal.

Defining How Individual Management Units will be Chosen

Scheduling management units for harvest typically involves stand-level or forest-level optimization based on the contribution of the unit (e.g., net present value, timber volume, habitat characteristic) to the overall goals of the plan. To determine which management units to add to a harvest block, the units must be evaluated based on some shared attribute, and function of their current (and projected) condition. For example, "valuing" might mean the per-hectare timber value for each unit, minus logging and transportation costs. Valuing could, however, be based on other criteria, such as an ecological value (e.g., a habitat suitability index, or number of snags per hectare) or a socioeconomic value (e.g., recreation opportunity value), depending on the forest goals being addressed. For example, an ecological value (high or low) may be used to rank individual management units if we were to use this process to build habitat blocks.

Value, for this study, is represented in each time period $t$ of an analysis by the net revenue, per unit area, from potential clearcut harvests:

$$
\sum_{i} \left( \frac{P_{ik} - c_{ik}}{v_i} \right) \quad \forall k,t
$$

where

- $P_{ik}$ = Stumpage price for product $k$ during time period $t$
- $c_{ik}$ = Logging and transportation costs for product $k$ during time period $t$

This is a value per unit area, not a total net revenue. Negative or non-positively valued management units are not included in the blocking process. These units may include young plantations or other sparsely-stocked management units where the cost of harvesting outweighs the revenues that might be obtained. Therefore, the current version of the blocking algorithm only allows positively-valued units to be included in a clearcut harvest block.

Build and Schedule Harvest Blocks

Most scheduling techniques (particularly heuristics) typically use 1-opt or 2-opt moves to schedule harvest of either management units or pre-defined harvest blocks. 1-opt moves examine a change in a single characteristic of a single management unit to the objective function value of a forest plan. 2-opt moves examine a swap of a single characteristic among two management units (perhaps the clearcut harvest timing). The effect of these changes on a forest plan are subsequently assessed, and if some goals are violated, generally only the last change to the solution is reversed. In addition, these methods can consider changes to a forest plan across all time periods simultaneously. In contrast, a binary search technique generally schedules activities period-by-period, with no opportunity to simultaneously schedule activities across all time periods. With each change in binary-search harvest-scheduling criteria, all schedules for management units are removed from memory, harvest goals change, and new harvest blocks are formed. As mentioned earlier, an ARM technique is used to control the sizes of clearcut harvest blocks, and URM technique is used to prevent blocks from merging together. Our application of these spatial considerations differs from previous research in that (1) blocks are not defined a priori; (2) once blocks are formed, they are not adjusted incrementally; (3) blocks may change in size and shape from one time period to another; and (4) maximum block sizes may be adjusted as each successive block is built.

To schedule activities, net values are calculated for each management unit in each time period (Fig. 1). Harvest blocks

![Fig. 1. A flow chart of the management unit blocking process.](image-url)
were then built one at a time. The highest valued available management unit becomes the "seed" around which harvest blocks are developed. Other management units adjacent to the selected unit are then added to the harvest block until a size is reached where the total area does not exceed the maximum-size goal. Even if the block being developed closely approaches the block size goal, the blocking process continues to check all possible other additions (with a positive value) to see whether any more can be added to the block. It is only when all possible additions have been checked that the block is scheduled. Any additions that are added (temporarily) to the block and subsequently result in the block exceeding the size goal, are removed from the block, and removed from the list of additions. Then, the process proceeds to the next highest valued available management unit, not adjacent to a harvest block, and repeats.

A short example may help illustrate the process. Suppose we select a management unit (number 8 in Fig. 2(a)) as a seed. We then develop a list of adjacent units from which we select the highest valued (13) and add it to the block. Unit 13 can be added because the total block size remains under our maximum size, and the unit is not touching any other unit being cut this period (Fig. 2(b)). The list of adjacent units is then expanded to include those adjacent to unit 13. The highest-valued unit from the expanded list of adjacent units is then selected (number 18 in Fig. 2(c)), and so on, until the harvest block has been created. Units 3, 5, 11, 14, 17, and 18 are selected and rejected either because they touch another unit being clearcut during the current time period or because their addition to the block would make the block too large. No other adjacent unit to those in the block (2, 7, 9, 10, 16) has positive value, so the harvest block (units 6, 8, 12, and 13 in Fig. 2(d)) is scheduled for harvest.

This process continues, and harvest blocks are developed and scheduled, until predetermined criteria are met. In our case, the criterion is whether the target even-flow volume for the current period has been exceeded. If it has, we move to the next period and begin building harvest blocks for that period. If the target even-flow volume has not been met, we select another "seed" unit and begin a new harvest block. If the binary-search harvest-scheduling model changes the target even-flow volume, all harvest blocks are removed from memory, and the blocking process begins as if no blocks have been scheduled.

An additional level of complexity to the process is added when clearcut size distributions are considered. Fig. 1 alludes to the notion that a block size goal is selected before each harvest block is developed. Clearcut size distributions were described in an earlier section of this paper. The block size goal is a maximum size that an individual harvest block can become as each block is being developed. Areas clearcut for each block size strata (such as those noted in Table 2) are accumulated as each block is developed. The largest block size stratum where the area accumulated has not exceeded its

<table>
<thead>
<tr>
<th>Block size (ha)</th>
<th>Area in clearcuts (ha)</th>
<th>Number of blocks†</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-16</td>
<td>167</td>
<td>8</td>
</tr>
<tr>
<td>16.1-24</td>
<td>143</td>
<td>3</td>
</tr>
<tr>
<td>24.1-32</td>
<td>152</td>
<td>2</td>
</tr>
<tr>
<td>32.1-40</td>
<td>173</td>
<td>2</td>
</tr>
<tr>
<td>40.1-48</td>
<td>365</td>
<td>3</td>
</tr>
</tbody>
</table>

† (Area in clearcuts / mid-point of block size range), rounded up or down to the nearest whole block.

projected total becomes the maximum size goal. Once the accumulated area for a clearcut block size stratum has exceeded its goal, the next smallest block size with accumulated area below its goal becomes the maximum size goal, and so on. Obviously, as harvest blocks are being developed, the resulting harvest block size may be less than the maximum size goal, due to the constraints involved in aggregating management units for harvest. While the blocking algorithm attempts to make the harvest blocks as large as the goal allows, the resulting harvest blocks may actually contribute area to smaller block size strata. At some point, the smaller block size strata may actually exceed their projected totals as a result of this process. As we will see, the block size goals serve as guides to the achievement of clearcut size distributions. The maximum area (A) of an individual block is constrained, yet the total area of clearcuts within a block size strata may not match exactly the areas projected for each strata.

Application to a Landscape

The landscape over which the harvest blocking process was applied is 560,000ha on the Coast Range of Oregon, of which about 206,000ha is in forest industry ownership and described by 20,544 individual forest industry management units. Each management unit is described by a set of tree lists derived from remote sensing (Ohmann and Gregory, 2002), and geographic information system databases describing the ownership pattern, the stream system, and other spatial features were used to characterize the landscape (see Coastal Landscape Analysis and Modeling Study 2002). Within the planning system, timber volumes are projected for over 2,600 hardwood, mixed hardwood and conifer, and conifer management prescriptions typical for the major landowners in the Coast Range of Oregon. The binary-search harvest-scheduling model (Bettinger and Lennette, 2002) is programmed in the C programming language and operated on a Pentium III 500 MHz computer with 2 Gb of RAM.
Fig. 2. An example of individual units being blocked together to create harvest blocks, from initial selection of the seed unit (a), to adding (b) and rejecting (c) potential additions to the block, to final harvest block configuration (d).

RESULTS AND DISCUSSION

When used in conjunction with a binary-search scheduling routine, which is driven by a goal of even-flow of timber harvest volume, the blocking algorithm consistently formed harvest blocks that resembled recent historical data (Fig. 3). The average length of time it took to develop harvest blocks for a single time period was approximately 3 seconds. The dynamic nature of the algorithm can be seen in the location of harvest blocks over a 100-year period for a sample of the landscape (Fig. 4). Here, we can see that the location of clearcut harvests, hence the harvest blocks, changes during each time period of the binary search harvest scheduling process. The members of each harvest block change in response to the constraints involved in the blocking process, and to a lesser extent, the volume goals of the binary search scheduling process. The harvest blocking process is thus dynamic, since block sizes and membership are not fixed in a spatial manner through time, as with other harvest scheduling processes (e.g. Clements et al., 1990; Wightman and Baskent, 1994).

For the results shown, no single block-size category exceeded its target by more than 12 percent. The modeled percentages do not exactly match the target percentages for two major reasons. First, harvest-block formulation is sensitive to the spatial arrangement of forest conditions (Wightman and Baskent, 1994), as well as the temporal availability of a suitable condition (or value). Second, the maximum block size constraint equaled the largest block size that was available. As a result, smaller blocks were scheduled for harvest regardless of whether the maximum block size could be achieved. This, in turn, placed more area in the smaller block-size classes than the target allowed. As we mentioned earlier, once a block-size goal was achieved, the next available smaller block-size goal was evaluated; if this goal had already been achieved (and perhaps exceeded), the next smaller block-size goal was evaluated, and so on. Given the irregular shape of the management units and the fact that block-size goals could...

![First period of simulation (Year 5)](image1)

![Tenth period of simulation (Year 50)](image2)

![Twentieth period of simulation (Year 100)](image3)

Fig. 3. Percentage of clearcut area in various clearcut size blocks when fit to a historical (target) distribution of clearcut block sizes.

Fig. 4. Example of harvest block locations over time in a sample area of the 560,000ha landscape.
Spatial Scheduling of Forest Management Activities using a Dynamic Deterministic Harvest Block Aggregation Process

change within the binary-search harvest-scheduling routine, the process described here performed reasonably well.

One must recognize and acknowledge that utilization of these procedures results in an emulation of behavior, not an optimization of some management objectives. The solutions generated satisfy the constraints that are assumed under the quasi-objective function, within the simulation framework, to generate realistic solutions for forest managers and policymakers. To optimize harvest blocking solutions, one could define the harvesting order by comparing the value increment of a management unit to the opportunity cost of letting the unit continue to grow. An efficient solution (from an economic or ecological point of view) may also be achieved by optimizing the value of the blocks in association with the block-size goals using heuristic methods. However, a more detailed analysis of a large number of possible spatial and temporal combinations would be required. From a management behavior and policy analysis perspective, utilization of the procedures described in this paper does result in the production of realistic or acceptable solutions for the managers or policymakers (the problem currently being solved seeks to maximize even-flow subject to behavioral issues), and thus seems appropriate for strategic planning or policy analyses. Our feedback from stakeholder groups has affirmed this notion.

The discussion of management behavior, and whether it is optimal within the context of the management context in which it is applied, may cause some tension among members of stakeholder groups. Although it was not the intent of our research, some landowners may feel as if they are portrayed as sub-optimal managers. At the stand-level, management behavior probably has not been economically optimal given the forest-wide goals of each organization and the fact that human nature plays a role in the decision-making processes. In our efforts to develop reasonable alternatives to assist policy makers, our first and foremost goal was to produce results of a scenario where we assume that landowners will continue to manage their land in the future as they do today. This requires understanding how the forests are managed today. Some may argue that the purpose of planning is to find optimal ways of managing land, which may be true for individual organizations in their efforts to control costs and manage land in an efficient manner. However, how forest plans actually are implemented is what is important for public policy analysis. Thus our objective was first to model reasonably well current management behavior, then (in the future) to examine other ways of managing land that seek to benefit one or more other goals (economic, social, environmental) within the simulation framework.

A variety of planning approaches may be facilitated by the use of a blocking process such as the one described here, including the following alternatives which have arisen from discussions with stakeholder groups:

1. Use a blocking process to aggregate management units of lower value. An operable timber harvest area can be defined by a minimum harvest volume, perhaps of certain product types. Developing large blocks of lower-valued timber might provide a minimum harvest volume and sufficient revenue to exceed the costs of moving equipment in and around other logging sites. Conversion of low-valued, low-stocked forests to higher stocking might then be possible.

2. Set a single, large block-size goal. A block-size goal that is as large as possible, within regulatory and organization policies (i.e., 40-48ha), may address some of the economy of scale problems associated with smaller harvest blocks. It could also serve an ecological goal by reducing forest edge and maintaining a maximum amount of area in forest interior.

3. Develop large, yet compact blocks. Rather than using volume or economic value as the key criterion for including a management unit in a harvest block, an objective of minimizing the dispersion of management units within blocks might be useful. By minimizing the distances between the centers of the management units, the formation of long, narrow blocks would be discouraged.

4. Develop disjointed blocks. A “neighborhood” approach, rather than strict adjacency, could be used to define adjacency. In practice, units that are not physically adjacent, but that are separated by short distances, are sometimes scheduled for harvest together. Although geographic information systems (GIS) can recognize spatial distances other than strict adjacencies, doing so over large areas with varying degrees of “closeness” is difficult.

5. Build habitat blocks. This process is the inverse of the harvest-block process. Instead of developing harvest blocks of some maximum size, the algorithm could be used to identify habitat blocks of some minimum size. Similar processes have been described by Bettinger et al. (1997; 1999; 2002). Examples include the development of blocks greater than some minimum size (e.g., 16ha) and containing only a preferred forest type (e.g., "older forest"), and the creation of large blocks (e.g., 160+ ha) that contain a minimum percentage of a preferred forest type and a maximum percentage of less-preferred types.

CONCLUSIONS

As public policy analysis evolves to include multiple ownerships, large areas, and long time frames, spatial and tactical models will increasingly be used simultaneously to better reflect the goals of managers and policy makers alike. One of our goals was to produce the most reasonable and realistic simulation of forest management behavior across a vast landscape (200,000 - 600,000ha). We feel that the blocking
algorithm described here allows us to move ever closer to doing just that. While we did not directly compare the results from the use of this algorithm to those produce by simply scheduling activities based on maximization of economic criteria, we believe the process is beneficial because the stakeholders (industry representatives) associated with the study area have provided feedback that indicates that the process is consistent with current practice. It therefore meets our goal of emulating or simulation management behavior. In addition, the process will facilitate the evaluation of alternative policies, such as lowering (to reflect increasingly restrictive policies) or increasing (to emulate, to some extent, a natural disturbance regime) the minimum clearcut sizes.

The blocking algorithm we described is a dynamic one, in which forest harvest blocks are neither static nor defined a priori. The algorithm is also deterministic (not stochastic) and based on a valuation of the individual management units. Other considerations (both spatial and non-spatial) are used to identify potential additions to a harvest block; these too are deterministic, not random. This blocking algorithm differs from previous work in harvest scheduling, which mainly considered adjacency restrictions among individual management units. As a result, a process such as this may be of use to forest planners and analysts who are interested in modeling realistic management goals to support forest planning and policy analyses.

LITERATURE CITED


HÖMGRÖN, P. and THURESSON, T., (1997) : Applying objectively estimated and spatially continuous forest parameters in tactical planning to obtain dynamic treatment units. For. Sci. 33: 317-326


(Received 24 July 2002) (Accepted 9 December 2002)