An Empirical Evaluation of Spatial Restrictions in Industrial Harvest Scheduling: The SFI Planning Problem

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ABSTRACT: *Member companies of the American Forest and Paper Association have adopted common operating principles called the Sustainable Forestry Initiative^{SM} (SFI) that call for marked reductions in the size of clearcut harvest areas, greenup intervals and proximity restrictions on the harvest of adjacent areas. A commercially available hierarchical planning software suite is used to analyze the impact of the adjacency and harvest size objectives within SFI on a representative forest of the U.S. Southeast. Ten alternative, spatially feasible tactical schedules were developed for a 15 yr planning horizon and achieved 73.4 to 75.6% of the harvest volume predicted by the nonspatial strategic harvest schedule. Spatially feasible harvest levels were negatively affected by increasingly restrictive spatial parameters: the cost of increasing the greenup interval by 1 yr was at least 5% of the strategic harvest volume, and reducing the maximum allowable block size from 180 ac to 60 ac yielded a 10% reduction in harvest. The planning software has been implemented at Champion International Corporation, providing planners with a valuable tool for strategic and tactical forest planning. South. J. Appl. For. 25(2):60–68.*

Key Words: Spatial planning, spatial restrictions, harvest scheduling, adjacency, SFI.

In October 1994, the American Forest & Paper Association (AF&PA) drafted a set of principles called the Sustainable Forestry Initiative^{SM} (SFI) to guide forest management activities on the lands of member companies. These guidelines included objectives concerning maximum clearcut size, minimum buffer widths between harvest openings, minimum time intervals between harvests of adjacent areas (greenup intervals) and other restrictions on forest operations. These guidelines required a large change in the operations of most member companies, and in the planning methods used to estimate sustainable harvest levels. However, to date there has been little research effort applied to the creation of decision support tools that can handle the spatial planning problems inherent to the SFI objectives and requirements, and we are aware of none reported in the literature that tackle the problem directly. This article describes some of those objectives and requirements and discusses a software solution that has been implemented with good success by several AF&PA members, including Champion International Corporation.

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The SFI Planning Problem

Champion International is a large integrated forest-products company with land holdings throughout the United States, including significant acreage throughout the southeastern United States. Like most other industrial forestland owners in the region, the bulk of these forestlands are managed as southern pine plantations. These plantations are typically large (several hundred to upwards of several thousand acres) and have been harvested multiple times with rotations ranging from 15 to 35 or more years, depending on growth rates. Harvest scheduling has typically been stand-level oriented, based on maximization of present net worth and land expectation value. Concentration of harvesting operations to minimize the cost of moving harvesting equipment has been used extensively. The resulting landscape is generally one of overwhelming uniformity, with large tracts of the same species and very similar age in close proximity to one another.

Southern pines are shade-intolerant, fire-adapted species, and so the preferred method of regeneration harvesting is clearcutting, which best mimics their natural process of regeneration after catastrophic fire. However, public perception of large clearcut areas has been largely negative, and so guidelines that limit the size of clearcut areas have been adopted by most public and private forestry agencies. The SFI guidelines impose opening-size and adjacency restrictions only on harvesting practices that remove the entire canopy during harvesting, such as clearcutting. Harvesting practices such as commercial thinning or selection harvesting are not restricted and may occur next to clearcut harvest operations without contributing to the opening-size limits.

As one of the principals in developing the Sustainable Forestry Initiative, Champion has established operating procedures that fully comply with SFI guidelines. For example, Champion limits clearcut harvesting to areas no greater than 120 ac, unless extraordinary circumstances warrant it (such as insect infestation or forest fire salvage). Clearcut harvest areas are considered *contemporary* if they are established within a fixed number of years of one another, and until better estimates of regeneration response are known, Champion has conservatively set the greenup period at 4 or 5 yr in most regions. Clearcutting will not be permitted within 300 ft of a contemporary clearcut harvest area unless a watercourse that requires more restrictive riparian zone management separates the two.

Champion is not unique with its operating guidelines; continued membership in AF&PA is contingent on adoption of sustainable forestry principles, and all member companies must draft and adopt similar operating principles that are at least as rigorous as those set out by the SFI guidelines. However, the majority of forest companies that have developed these types of operating guidelines face similar difficulties in implementing them: they require some method of determining spatial harvest schedules in a timely manner, and they have to contend with a major shift in harvesting logistics associated with smaller harvest areas dispersed over much wider areas. Since AF&PA members have agreed to abide by similar operating guidelines, the planning problem faced by them is similar, and we refer to it as the *SFI planning problem*.

Although it is quite easy to state that forest management planning as an activity is deciding what activities to implement, in what place and at what time, the actual process of making these determinations is far from easy. In years past, locating a harvest activity had little consequence elsewhere in the forest or in future years, except for the fact that the harvested timber was no longer readily available and that regeneration costs would be incurred. In the SFI planning problem, the location of a single harvest block requires that neighboring areas of the forest be unavailable for harvest for several years, and inevitably these new operating principles come with a cost in terms of harvest availability and present net value. Since the effects are cumulative over space and time, a poor choice in locating a harvest block can severely limit options for the future, with concomitant heavy costs.

The Remsoft Spatial Forest Planning System

Remsoft Inc. is a Canadian company that develops software products for wildland fire management, integrated resource planning and forest management. Remsoft has developed two software packages, Woodstock and Stanley, as an integrated spatial forest planning system. The system is based on the hierarchical planning approach of distinct but linked models, described by Jamnick and Walters (1993). First, a conventional strategic harvest schedule is used to estimate long-term harvest levels and to identify forest classes suitable for harvesting in each planning period. Next, the initial planning periods of the strategic harvest schedule are allocated to specific forest stands to form a tactical harvest schedule that complies with spatial restrictions. For the process to work, a number of data preparation steps must be followed but these steps are largely automated by the Woodstock and Stanley software.

A stratum-based forest classification scheme is developed, based on stand-types of similar age and developmental characteristics. If individual stands are larger than maximum allowable block size allowed by regulation they are usually subdivided using a geographic information system into smaller polygons. Each of the polygons in the forest map database is assigned a unique identification number and the stand-type stratum to which it belongs. A conventional stratum-based, strategic forest management schedule is then developed.

Because the GIS database identifies polygons by their associated strata, the strategic harvest schedule can easily be disaggregated into lists of polygons eligible for each of the treatments chosen in the schedule. If an entire stratum is harvested in a planning period then all of the associated polygons in the stratum should similarly be harvested. However, if the stratum is harvested over two or more periods, or if more than one harvest treatment is selected for the same stratum, then there is some flexibility in how the individual polygons can be allocated. Since strata are assumed to be uniform regardless of geographic location, any polygon in a stratum may be freely substituted for another in the same stratum without affecting the strategic harvest schedule, as long as the areas treated are equal.

The Jamnick-Walters approach is founded on two key assumptions. First, only the strata scheduled for harvest in the initial planning periods of the strategic plan are eligible for allocation in the tactical planning process. This greatly reduces the magnitude of the tactical planning problem because fewer periods and fewer strata are considered within it. Partitioning the tactical planning horizon also prevents the inadvertent exploitation of strata (in the near term) that are needed to maintain harvest levels in future periods. Without this partitioning, spatial scheduling in the short term may well be enhanced but at the cost of increasingly difficult spatial scheduling in the future (Feunekes and Cogswell 1997).

Second, the approach generally retains in the tactical plan the goals and constraints of the long-term forest management plan by preserving the basic timing choices of the strategic harvest schedule. Although variations from the strategic timing choices are usually necessary to meet spatial restrictions, the strata that are scheduled for harvest early in the strategic planning horizon are similarly scheduled early in the tactical planning horizon. If the strata are relatively homogeneous with respect to growth and yield, it can be reasonably assumed that the output flows of the tactical plan will be very similar to the strategic plan if the timing choices in the tactical plan closely approximate the timing choices in the strategic plan.

Woodstock is Remsoft's strategic forest management modeling system, and most users employ the generalized

Model II linear programming (LP) formulation described in Johnson and Scheurman (1977). A detailed description of Woodstock and its features is given in Walters (1996). Stanley is the tactical planning software component of Remsoft's spatial planning system. It attempts to implement a spatial forest management schedule by assigning management activities to eligible forest polygons. Rather than deal with conflicting resource and output constraints directly, as is done in Woodstock, Stanley is primarily concerned with minimizing deviations in the timing of harvest activities and maintaining the same levels of output flows that characterized the strategic schedule. Any output that was constrained or optimized in the strategic harvest schedule may be used as a controlling variable to guide the harvest blocking process. A detailed description of Stanley and its features is given in Remsoft Inc. (1996).

A harvest block in Stanley is composed of one or more forest polygons that belong to the forest classes scheduled for harvest in the corresponding planning periods of the strategic model. If a single polygon is too small to harvest alone, it may be combined with other neighboring polygons that are eligible for harvest in the same planning period to form a feasible harvest block. Because adjacent polygons may be harvested simultaneously, Stanley must keep track of the polygons that belong to each harvest block and must ensure that other adjacent blocks are not harvested within the greenup interval. As a result, the Stanley algorithm determines the final harvest block configuration simultaneously with the block schedule. The common approach used by most companies is to delineate harvest blocks *before* scheduling, and without detailed consideration of the potential for adjacency conflicts or disruptions in harvest flow that arise when spatial restrictions are applied.

Since most of the management objectives and constraints are dealt with in the strategic harvest schedule, the blocking and scheduling process in Stanley requires relatively little input other than parameters to guide the blocking process under spatial restrictions. The user chooses a constrained output from the Woodstock strategic harvest schedule to act as a controlling variable in Stanley and then specifies the length of the tactical planning horizon, the minimum and maximum size limits on harvest blocks, the minimum distance required between contemporary blocks (proximity distance), the length of the greenup interval, and how much deviation from the strategic timing choices is allowed when harvest units are being generated. The user can run Stanley for a fixed amount of time or a fixed number or iterations, or may let the program run continuously until manually stopped.

Woodstock and Stanley are complementary software tools. Stanley can be used to perform the forest classification process, and it will process the GIS data to generate the initial stratum areas file for a Woodstock model. During matrix generation, Woodstock generates a *choices file*, a database representation of the decision variables used in the linear program (LP) and their objective function coefficients, the basis, and the reduced costs for nonbasic variables. Stanley reads this file to help choose appropriate alternatives when it must deviate from the timing choices that were selected in the strategic harvest schedule. Together, Woodstock and Stanley help to streamline the spatial planning process by automating the steps in the forest management modeling process, and by maintaining the linkages between strategic and tactical decisions that are necessary for a workable system (Covington et al. 1988; Jamnick and Walters 1993).

Case Study

A hypothetical forest-planning problem was developed for land in the southeast Atlantic Coastal Plain. The forest is composed primarily of plantations of slash pine (*Pinus elliottii* Engelm.) and loblolly pine (*P. taeda* L.), cypress (*Taxodium distichum* [L.] Rich.) ponds, and bottomland hardwoods, totaling about 88,000 ac in 3,690 stands and plantations. The species and age structure of this forest is a representative example of southern pine plantation management practiced by forest companies operating throughout the U.S. Southeast, including Champion International.

There were 160 polygons greater than 120 ac in size, but these comprised more than 40% of the total forest area. Because Stanley allocates polygons on an all-or-nothing basis, subdivision of these oversized polygons was necessary to prevent exceeding the maximum opening-size limit. Geographic overlay of a 15 ac square grid was employed to subdivide polygons larger than 15 ac into smaller allocation units for spatial harvest scheduling purposes. In general, Stanley yields better solutions using smaller polygons but at the cost of increased processing time. The choice of the 15 ac grid was arbitrary, but it allowed for sufficient flexibility in allocating the 15 yr harvest schedule while keeping run-times sufficiently short. The resulting forest of 12,803 polygons had an average polygon size of 4.93 ac. No attempt was made to remove sliver polygons because the Stanley algorithm can combine multiple polygons into a single harvest block, and once final blocks have been determined, a dissolve procedure can be used to eliminate polygon fragments, if desired.

Existing cutovers were identified by year of establishment, and Stanley was used to identify polygons that were initially unavailable for harvest due to adjacency restrictions. Any polygon having a boundary point within 300 ft of an existing cutover boundary that was harvested within the previous 5 yr was marked as ineligible for harvest for the appropriate number of planning periods in the Woodstock model. Once the greenup interval expired in the strategic planning model, the affected polygons were eligible for the same treatments as other polygons within their development type classes. Changing the greenup interval and/or the proximity distance results in different polygons being marked as ineligible and so the strategic harvest schedules for the various runs exhibited minor variations in discounted net revenue (less than 0.5%).

Methods

Default SFI guidelines

A strategic forest plan was developed with Woodstock using 1 yr planning periods, a planning horizon of 50 yr, and a management emphasis based on clearcut harvesting and artificial regeneration. The objective function maximized discounted net revenue (DNR) subject to nondeclining yield (NDY) flow constraints on harvest volume and nondeclining inventory constraints during the latter half of the planning horizon. A 6% discount rate was used, calculated from the end of each period. The costs and revenues used in the analysis included silviculture costs (site preparation, planting, competition abatement, fertilization, etc.) and stumpage prices, but excluded fixed costs such as administration and taxes, as well as variable harvesting costs.

Fixed costs do not change the decisions to harvest and artificially regenerate stands for an ongoing forestry enterprise, and it can be argued that membership in AF&PA requires a company to absorb increased harvest costs as a cost of doing business. Commercial thinning was not included in this simple case study to emphasize the impact of spatial restrictions on clearcut harvesting. However, commercial thinning may be an important component of an overall management strategy under SFI because it is not subject to block size and adjacency restrictions.

The forest has been managed for well over 50 yr, and harvesting has been conducted in recent years. There are 7,674 ac of forest adjacent to the recent cutovers that were unavailable for harvest until the fourth planning period, to comply with greenup restrictions. Although this comprises almost 10% of the land base, some of this area is immature timber and ineligible for harvesting. However, a significant proportion is at rotation age or beyond.

Harvest blocks were constrained to be no smaller than 10 ac and no larger than 120 ac. The greenup interval was set at 5 yr and the proximity distance for contemporary harvest blocks was set at 300 ft. Relative harvest flow fluctuations were constrained to be less than 2.5% across all periods to approximate the flow constraints of the strategic harvest schedule. Alternative tactical plans were developed using Stanley, based on the first 15 periods of the strategic forest plan, while imposing spatial restrictions based on SFI guidelines. A common tactical planning horizon among forestry companies is 10 yr. By extending the tactical planning horizon to 15 yr, the effects of a 5 yr greenup interval are applied equally to the first 10 yr. With periodic replanning and blocking for additional periods beyond the usual tactical planning horizon, the potential for disruptions due to end-of-planning-horizon effects is minimized. A total of 10 Stanley runs were completed, each running for 32,000 iterations.

Using the block configuration of the best solution found by Stanley, a mixed-integer programming (MIP) harvest-scheduling model was constructed and solved using the IBM OSL library. The objective function was to maximize the minimum periodic volume over the 15 yr planning horizon, subject to pairwise adjacency constraints among harvest blocks, and constraints on harvest flows that kept periodic volume fluctuations within 2.5%. The rationale for this MIP formulation is to assess Stanley's scheduling abilities relative to an accepted methodology used widely in the literature. One could argue that the MIP solution is limited by the block configuration that was provided from the Stanley solution, but this same limitation exists for all of the analyses reported in the literature where block configurations are established before scheduling.

Effects of Spatial Parameters on Harvest Levels

An additional number of runs were conducted to approximately determine the marginal costs of different spatial and blocking parameters. These parameters included (1) length of greenup interval, (2) proximity distance to contemporary blocks, (3) maximum opening size of clearcut harvest blocks, and (4) minimum opening size of clearcut harvest blocks. Five new solutions were generated for each scenario, and Stanley was allowed to run for 32,000 iterations for each of these runs. Since the strategic objectives did not change from run to run, there was no need to alter the Woodstock model for the allowable block size restrictions series. However, proximity distance and greenup intervals affect how much of the initial inventory is subject to greenup restrictions by preexisting harvest blocks, so new initial inventory files had to be generated for each proximity distance and greenup interval scenario. The Woodstock model was then re-solved for each of these scenarios before running Stanley. Table 1 lists the various scenarios tested and their associated spatial parameters. Note in column 5 how varying the length of the greenup interval or the proximity distance affects the area precluded from harvest by greenup requirements.

Results

The strategic harvest schedule exhibits increases in harvest over the planning horizon from an initial level of about 42,000 cunits/yr to more than 55,000 cunits/yr in period 30. Figure 1 shows the periodic harvest levels from the strategic harvest schedule, and indicates the periods that will be blocked out in the tactical plan. Clearly, the harvest flow profile is a result of the nondeclining flow constraints used in the strategic model. Stanley does not require NDY or strict evenflow, but it does attempt to match the basic shape of the strategic flow profile in the tactical solution. The NDY constraints were chosen only because they are easy to inter-

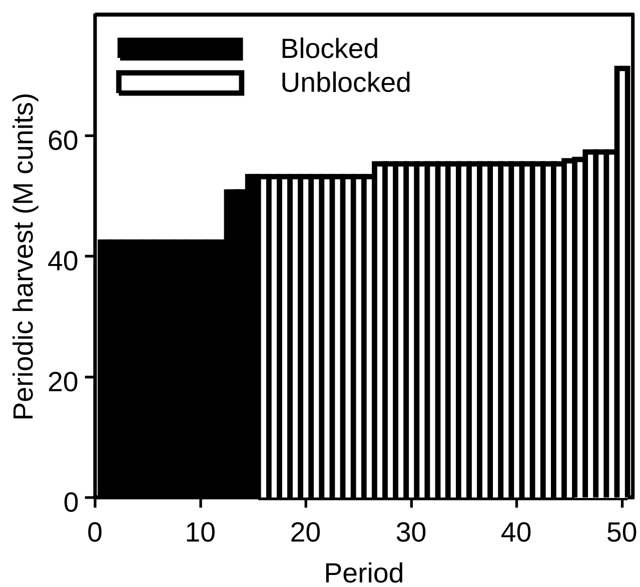

Figure 1. Periodic harvest levels of the strategic harvest schedule developed using Woodstock.

Table 1. Characteristics of the spatial harvest schedules developed using Stanley. Greenup interval, allowable block size and proximity distance are specified by the user and guide the development of harvest blocks and schedules in a Stanley run.

Problem definition	Greenup interval (yr)	Maximum/minimum block size (ac)	Proximity distance (ft)	Initial area in greenup buffer (ac)	Solutions generated
SFI standard	5	120/10	300	7,986	10
Greenup interval series	2	120/10	300	0	5
	3	120/10	300	4,890	5
	4	120/10	300	7,674	5
	5	120/10	300	7,986	5
	6	120/10	300	8,359	5
	7	120/10	300	10,848	5
Minimum opening-size series	5	120/5	300	7,986	5
	5	120/10	300	7,986	5
	5	120/15	300	7,986	5
	5	120/20	300	7,986	5
Maximum opening-size series	5	60/10	300	7,986	5
	5	90/10	300	7,986	5
	5	120/10	300	7,986	5
	5	150/10	300	7,986	5
	5	180/10	300	7,986	5
	5	210/10	300	7,986	5
	5	240/10	300	7,986	5
	5	360/10	300	7,986	5
	5	480/10	300	7,986	5
	5	600/10	300	7,986	5
Proximity distance series	5	120/10	0	4,526	5
	5	120/10	75	5,622	5
	5	120/10	150	6,445	5
	5	120/10	225	7,254	5
	5	120/10	300	7,986	5
	5	120/10	375	8,601	5
	5	120/10	450	9,381	5
	5	120/10	525	9,883	5
	5	120/10	600	10,532	5

pret in both the strategic and tactical solutions; they do not reflect Champion policy.

Each of the ten Stanley runs took about 20 minutes to complete on a Pentium II processor running Windows NT 4.0 with 256MB of system memory. The solutions yielded between 73.4% and 75.6% of the strategic harvest volumes forecasted in the first 15 periods of the Woodstock strategic schedule, with an average harvest volume achievement of 74.5%. The discounted net revenue from the best of the Stanley solutions equaled 81.6% of the discounted net revenue during the first 15 periods of the strategic harvest schedule.

There are four ways to mitigate adjacency conflicts in a spatial harvest schedule. First, one can change the harvest period of one of the conflicting blocks to another period that does not conflict. Second, the two conflicting blocks can be combined into a single harvest block if the maximum allowable block size is not exceeded. Third, if the blocks are very large, it may be possible to reduce the size of one of the conflicting blocks by dropping component polygons so that the minimum proximity distance separates the conflicting blocks. Finally, one of the conflicting blocks can be left unharvested. In general, Stanley favors the second approach in this forest because the harvest volume is maximized with minimal change to the timing choices assigned to harvested forest classes. Smaller blocks are used to separate larger blocks from each other and are better suited for balancing flows because of their incremental impacts. This results in a skewed distribution of block sizes, with nearly 50% in the largest size class and an approximately uniform distribution of blocks in the smaller size classes (Figure 2).

The impact of spatial restrictions in this study may seem rather severe to some readers and they may question how well the Stanley algorithm is performing. Reductions in harvest volume of more than 25% due to simultaneous constraints on flow and adjacency are not common, but they have been reported in the literature (Daust and Nelson 1993, Carter et al. 1997). Cox and Sullivan (1995) reported reductions in harvest level due to spatial constraints upwards of 12%. Other published reports showed lesser impacts due to spatial restrictions (Barrett et al. 1998; Boston and Bettinger 1999) but the definition of adjacency in these papers was less restrictive than SFI guidelines require.

Much of the cost of spatial restrictions in this study can be attributed to past southern pine management practices: establishment of large uniform plantations and concentration of harvest activities. The resulting forest structure is exactly the

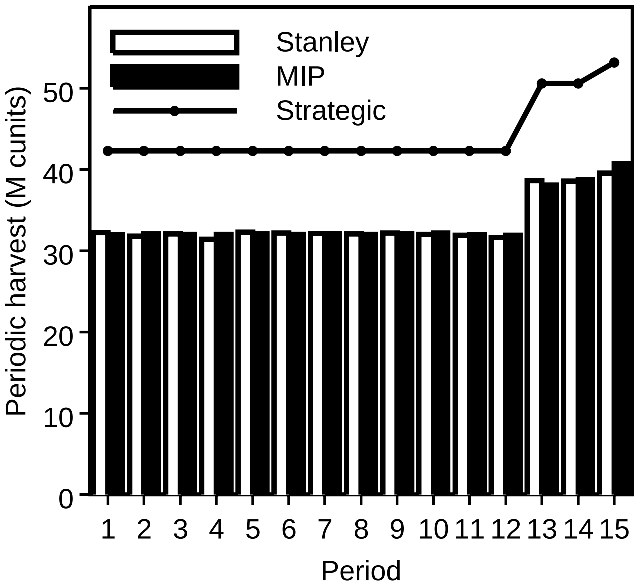

Figure 2. Block size distribution and cumulative frequency of block sizes from the best Stanley solution. Standard SFI guidelines were used to develop the spatial harvest schedule.

opposite of what SFI guidelines are designed to do: harvesting on smaller scales and harvests dispersed throughout the forest. Given that it took many years to achieve the age-class and spatial structure of the existing forest, it is reasonable to assume it will also take many years before the effects of past practices are minimized.

Using the block configuration of the best Stanley solution, a mixed-integer programming formulation of the block harvest-scheduling problem was developed. After 30 hr of processing, the best feasible solution achieved 75.8% of the strategic harvest volumes forecasted in the Woodstock strategic schedule. Figure 3 compares the harvest levels found using the MIP formulation to the corresponding harvest levels from the best of the Stanley solutions and the first 15 years of the strategic harvest schedule. In the MIP solution, six of the harvest blocks chosen by Stanley were left unharvested, and the flow variation was about half that of the Stanley solution (1.3%) suggesting some inefficiencies in allocation by the Stanley algorithms. However, the Stanley algorithm performed well, attaining 99.7% of the MIP harvest volume level in less than one-tenth the computation time of the OSL branch-and-bound algorithm.

Effects of Spatial Parameters

Champion's SFI guidelines call for conservative greenup intervals of 4 or 5 yr, proximity distances of 300 ft, and a maximum allowable block size limit of 120 ac. Other forest products companies have adopted similar, and perhaps more restrictive, operating procedures. Thus, it is desirable to know what relationship exists between these spatial parameters and achievable harvest levels under spatial restrictions. As expected, increasing the greenup interval reduces harvest levels, but the impact becomes increasingly more severe as the interval becomes longer (Figure 4). This suggests that the SFI planning problem is very sensitive to the length of the greenup interval, and a significant difference in harvest levels can arise by changing the length of the interval by just 1 yr.

In general, larger proximity distances yield reduced harvest levels, but over the range of 225 ft to 375 ft, the solution values are relatively stable (Figure 5). Outside of this range, increasing proximity distance leads to much sharper decreases in solution value. Champion's SFI requirement of a 300 ft proximity distance lies in the middle of this range, and moderate increases or decreases would not be expected to change solution values significantly in this particular forest. However, should conditions change (either by adjusting the other spatial parameters or applying the same parameters to another forest), the shape of the response curve could be quite different.

In order to maximize harvest volume attainment, the ideal maximum allowable block size for this forest (using a 300 ft proximity distance and 5 yr greenup interval) is between 420

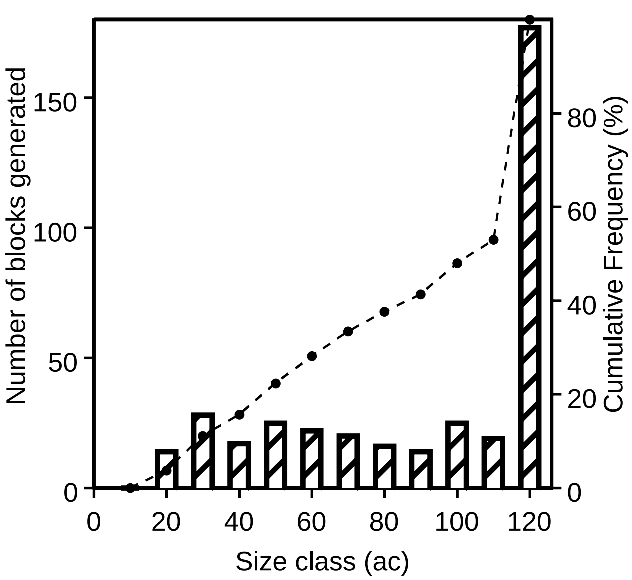

Figure 3. A Stanley harvest schedule compared to one developed using mixed integer programming. The same harvest block configuration was used in both solutions.

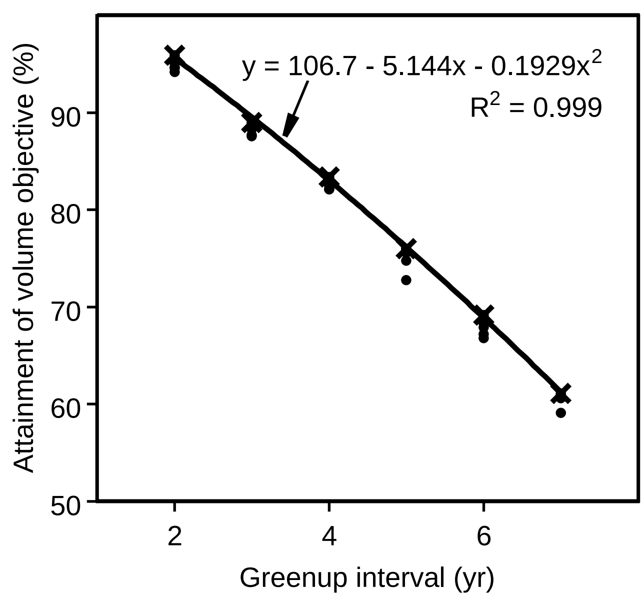

Figure 4. Effect of greenup interval on attainment of 15 yr harvest volume objective. The trend line was developed by regression of the highest attainment values found.

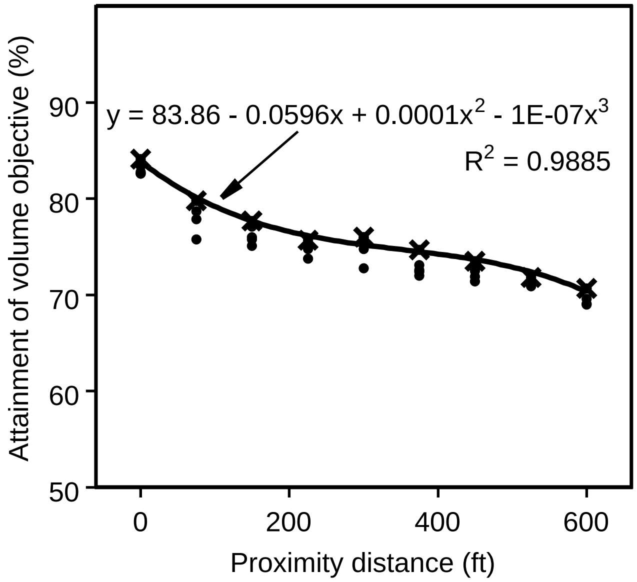

Figure 5. Effect of proximity distance on attainment of 15 yr harvest volume objective. The trend line was developed by regression of the highest attainment values found.

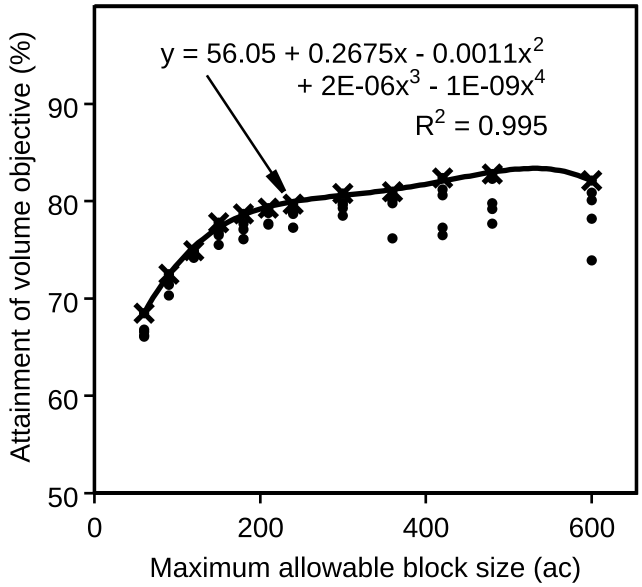

Figure 6. Effect of maximum allowable block size on attainment of 15 yr harvest volume objective. The trend line was developed by regression of the highest attainment values found.

and 480 ac (Figure 6). These upper limits are significantly larger than Champion's guidelines allow, but the average block sizes produced are not much larger than the maximum permitted average of 120 ac called for by the SFI guidelines. For example, the average block size was no more than 143 ac when the block size parameter was set to a maximum of 300 ac and no more than 154 ac when the size parameter was set to a maximum of 420 ac. Changing the maximum block size parameters has an impact on average block size, and on this forest one could set the maximum block size parameter as high as 200 ac, achieve higher harvest volumes, and still not violate the SFI requirement that average block size be no more than 120 ac (Figure 7).

Increasing the maximum allowable block size yields rapid improvements in harvest levels up to 180 ac, but the improvement slows markedly, peaking at 480 ac and decreasing thereafter. Although allowing larger blocks can be helpful in mitigating adjacency conflicts, large blocks ultimately become problematic since they tend to have a greater number of neighboring blocks that increase the potential for conflicts. Large blocks also make it more difficult for the Stanley algorithm to balance harvest flows within tight bounds while adjacency restrictions are in place.

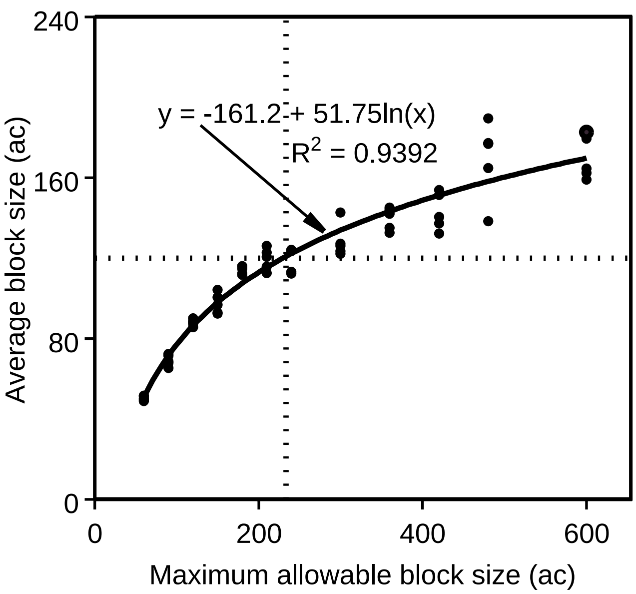

Figure 7. Growth in average block size with maximum allowable block size. The trend line was developed by regression of all values.

When an analyst delineates harvest blocks manually, he or she observes an implicit lower bound on area that constitutes a minimally feasible harvest block. In most manually delineated harvest block designs, blocks are configured to be similar in both shape and size, and they tend to approach the maximum size limit allowed by regulations. The smallest block in one of these designs is probably a good deal larger than the actual minimally feasible block. However, Stanley requires that the users specify a lower bound for allowable block size, and this lower limit has a large impact on solution values (Figure 8). For example, doubling the minimum allowable block size from 5 ac to 10 ac yields a 4% decrease in harvest level attainment and doubling it again yields a further 5% decrease.

The minimum block size directly affects how much of the forest is impossible for Stanley to block for a given set of spatial parameters. These "impossible areas" are small stands or pockets of timber left unharvested by previous operations that are basically islands of potentially harvestable timber surrounded by immature timber. Alone they are smaller than the minimum feasible block size and since there is nothing with which they can be combined to form a feasible harvest block, Stanley flags them as *impossible*. Although it is generally true that small blocks are economically inefficient to harvest on their own, there is a trade-off between the cost of harvesting small blocks now and the cost of leaving merchantable timber unharvested until the neighboring areas are ready to harvest as part of a larger harvest block.

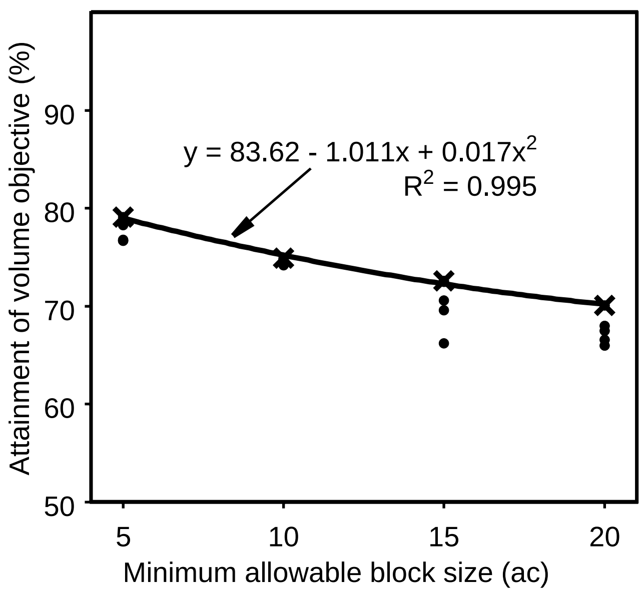

Figure 8. Effect of minimum allowable block size on attainment of 15 yr harvest volume objective. The trend line was developed by regression of the highest attainment values found.

Harvest volume attainment in the tactical schedules was generally lower than the corresponding attainment in discounted net revenue (roughly 73–76% versus 77–80%). Because Stanley is unable to allocate all of the area scheduled for harvest in the tactical plan, this creates some slack for blocking purposes. By targeting the higher volume stands for blocking and leaving the lower volume stands unharvested, the Stanley algorithm maximizes volume attainment by harvesting fewer acres, and in turn reduces the expenses associated with regeneration. This translates into lower discounted costs relative to the strategic harvest schedule; thus, the attainment ratio for discounted net revenue in the tactical schedules is higher than for harvest volume.

Three product categories were tracked in the strategic harvest schedule but total harvest volume was chosen as the control variable in Stanley. In the strategic harvest schedule, the relative contributions of pulp, logs, and chip&saw products were roughly 60%, 30% and 10%. In the tactical schedules, the proportion of log material was about 11.5%. Given that logs have the highest value of the three products, it would appear that some losses in DNR due to delayed harvest are offset somewhat by material growing into larger (and more valuable) product categories.

Obviously, other factors beyond harvest levels and discounted net revenues are considered in developing spatial operating guidelines: visual quality and wildlife habitats are both significantly affected by harvesting operations. However, it is still important to know the effects of a given policy since the impacts of even small changes can be very great.

A number of issues related to management under SFI were not addressed in this article. For example, the impact on harvesting and silvicultural costs arising from smaller harvest blocks dispersed throughout the forest was not examined. However, to a large extent, these increases cannot be avoided if a company is to abide by SFI. Woodstock and Stanley can be used to help mitigate cost increases, but clearly, they cannot eliminate them completely. Similarly, the impacts on water quality and wildlife habitat are ignored in this analysis. It is assumed that best management practices are established and implemented to protect water quality and wildlife habitat. However, a great deal about the long-term effects of management under SFI remains unknown with many opportunities for further analysis and study. This article simply attempts to draw attention to a few of the many ramifications of forest management under SFI.

Champion's Experience with Woodstock and Stanley

In 1993, Champion began investigating new harvest scheduling technologies to replace the various in-house systems developed and used in its U.S. operating regions. In 1995, Champion acquired two copies of Woodstock for testing in its eastern Florida region to determine whether it was suitable for use company-wide. In 1997, the company began testing Stanley as a tactical blocking tool. Champion is now nearing completion of a new unified forest information system that can fully support Woodstock and Stanley. A standardized procedure of data flows was developed that maintains the integrity of the geographic and tabular information across the strategic, tactical, and operational levels. Implementation of these procedures is ongoing, as is development of new growth and yield models that link stand-level inventory information directly to Woodstock through dynamic link libraries, rather than classical yield tables.

Champion is fully committed to the AF&PA Sustainable Forestry Initiative[SM], including independent third-party verification of all forestlands and forest management practices. This commitment to SFI requires Champion personnel to plan more thoroughly and more strategically than they ever have before. Champion's internal business goals also require a forest planning process that is unprecedented in its depth and accountability within the corporation. The use of Woodstock and Stanley for developing strategic and tactical forest plans is necessary for Champion to meet these objectives. To that end, Champion began the "operational" use of Woodstock in 1999 by successfully completing several internal projects from Maine to Florida to Washington. Champion's goal is to fully incorporate Woodstock and Stanley into the forest management planning process during the year 2000. All year 2001 operating plans will be based on the results of Woodstock and Stanley.

What has made Stanley well accepted by its users is the fact that the program quickly generates solutions that, largely, make intuitive sense. Some users have reported that approximately 60–70% of the harvest blocks selected by the Stanley algorithm are acceptable as is. To adjust the remaining 30–40%, foresters can override choices made by the Stanley algorithms by imposing operational decisions directly. Through an iterative process, an operational management plan is developed that reflects professional judgment and operational reality: initial algorithmic solutions are incrementally adjusted until a spatially feasible, operational harvest schedule results. Stanley provides a tremendous advantage by giving foresters a head start on a solution rather than starting from scratch.

Conclusions

In this article, we have presented results from a hypothetical industrial forest being managed under spatial guidelines compliant with the Sustainable Forestry Initiative^{SM} (SFI) of the American Forest and Paper Association, an organization that counts as members most of the larger forest products companies of the United States. Although each member company may implement slightly different guidelines, in general they face a similar planning situation that we term "the SFI planning problem."

A strategic harvest schedule covering a 50 yr planning horizon was developed to maximize discounted net revenue subject to constraints on harvest flow. In turn, alternative tactical harvest schedules were developed, based on this strategic harvest schedule, that comply with allowable block size limits, proximity distance requirements, and greenup interval requirements of Champion International's SFI guidelines. Two results of this analysis stand out. First, the spatial restrictions imposed under SFI guidelines can yield significant reductions in harvest levels and discounted net revenue. Clearcut harvesting, large plantations, and low spatial diversity of age classes have been characteristic of southern pine management, but the SFI guidelines are at odds with that system because they require small clearcut areas dispersed throughout the forest. As such, the structure of the forest can impose severe constraints on available timber because of adjacency restrictions. For example, in the best tactical solution found, nearly one-fourth of the harvest volume projected in the strategic harvest schedule could not be harvested under default SFI guidelines. These results are case specific, but the forest was chosen to be representative of pine plantation management in the Southeast, and so similar results could be expected elsewhere.

Given the latitude afforded by the SFI requirements, member companies can adopt operating guidelines that are compliant yet minimize the negative impacts of spatial restrictions. In the case study, it was found that harvest levels were sensitive to all spatial parameters, but some parameters exhibited ranges where harvest levels remained relatively stable. Ideally, operating guidelines should avoid setting limits outside of these ranges. For example, Champion's SFI guidelines use a proximity distance of 300 ft, which falls well within the range of stability. Although the stable range for maximum allowable block size was larger than current guidelines allow, the analysis did indicate that some significantly larger blocks could be allowed without violating the SFI requirement that the average block size be no greater than 120 ac. The length of the greenup interval is probably the most critical in terms of impact on harvest level attainment. In the case study, the marginal change in harvest volume attainment due to a change in the greenup interval was more than 5%—a 5 yr greenup interval yielded a 13% reduction in attainable harvest level relative to a 3 yr greenup interval. Efforts that can shorten the greenup interval such as fertilization and competition abatement may be even more important under SFI guidelines than they have been in the past. Moreover, the benefits of such activities may be underestimated in a strategic harvest schedule where spatial restrictions cannot be modeled directly. Overall, the findings strongly suggest that arbitrary decisions regarding parameter values for operating guidelines should be avoided at all costs; the impact of even a small change in a parameter can be very great.

Second, the case study demonstrated that the Remsoft planning software provides a practical means of addressing the SFI planning problem. A nontrivial case study was developed for a forest that had over 12,000 polygons, and more than 100,000 adjacency and proximity relationships. A 50-period strategic plan and alternative 15-period tactical plans were developed for this forest. The solutions generated by Stanley were comparable to a mixed-integer programming formulation of the spatial scheduling problem: the best Stanley solution yielded a minimum harvest level that came within 1% of the MIP solution, indicating that the software provides very good solutions to a difficult planning problem.

One of the strengths of the Woodstock/Stanley approach is that the strong linkages between the GIS database and the planning models prevent important information from being hidden from or overlooked by planners. Analysis will quickly alert a forest planner to small but important details that might otherwise be blurred by the scope of a forest comprised of hundreds of thousands of acres. Such attention to detail is what makes it possible for Champion to rigorously comply with SFI guidelines. Woodstock/Stanley provides a good framework for empowering management decisions: planning allows foresters to anticipate potential problems in the future, and by testing alternatives they make sound business decisions that improve the company's profitability and competitive advantage.

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