A hierarchical approach to spatial planning: a report card

Karl R. Walters, Associate
Forest Management Systems
Remsoft Inc.,
332 Brunswick Street, Fredericton, NB
Canada   E3B 1H1
email: waltek@mindspring.com

Ugo Feunekes, Vice President
Remsoft Inc.,
332 Brunswick Street, Fredericton, NB
Canada   E3B 1H1
www.remsoft.com   email: mail@remsoft.com

Remsoft Inc.
332 Brunswick Street,
Fredericton, NB,
Canada E3B 1H1

1-800-792-9468 or
1-506-450-1511
www.remsoft.com

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Abstract

The hierarchical approach to forest management planning typically recognizes three stages of planning: strategic (multiple rotation planning horizon), tactical (multiple period planning horizon) and operational (a planning horizon of 1 to 10 years). Three existing forest management planning tools (Woodstock, Crystal, Block) were applied to the hierarchical planning structure of a New Brunswick Crown License, in a comparison to the current approach using FORMAN+1, for strategic planning followed by a manual process of harvest blocking and scheduling. Woodstock is a forest management modeling system that is ideal for strategic forest management scheduling, using either simulation or linear programming. Crystal is an allocation algorithm designed to allocate harvest prescriptions from a harvest schedule to individual stands to form harvest units. Block is a Monte-Carlo integer programming model designed to schedule the harvest of blocks (harvest units) under both product flow and spatial constraints.

The results from using each of the programs were quite good. The LP model developed with Woodstock yielded higher objective function values than corresponding FORMAN+1, despite the fact that numerous constraints were imposed in the model which could not be implemented using FORMAN+1. The Crystal algorithm was able to allocate roughly 86% of the area scheduled for harvest in the first 7 planning periods in minutes, rather than the hundreds of hours the process would take if done manually. Using the harvest units developed by Crystal, Block was able to determine a spatially feasible block harvest schedule that yielded an AAC marginally higher than the strategic level found using FORMAN+1. Furthermore, the average block size was virtually constant across all seven periods.

Crystal and Block are both prototype planning tools with a number of deficiencies. However, in the context of the case study planning problem, both yielded results at least as good as the manual processes they replaced, and did so in far less time. Thus, planning aids like Crystal and Block appear to have great potential, and the hierarchical approach used in the case study appears to be a valid method for forest management planning.

Keywords: *spatially constrained harvest scheduling, forest planning.*

Overview of the hierarchical planning approach

Virtually all of the forest management literature on the subject of integrated forest planning indicates that a hierarchical approach is really the only feasible means of tackling the problem at this time. Rather than attempt to create monolithic planning models that incorporate all aspects of the problem, the hierarchical approach advocates the use of separate, but linked, planning models incorporating appropriate levels of spatial and temporal resolution.

The first step in the process, strategic planning, is to determine the productive capability of the forest for the long term. At this stage of planning, the intent is to determine the kinds of silvicultural interventions needed over time to produce a desired mix of benefits and outputs from the forest. Details about specific locations of activities or operational details are unnecessary at this level of analysis.

At the tactical level of planning, the analyst must rationalize long term objectives and activity schedules with the physical realities of the forest. It is at this level of planning that geographic location of stands becomes important where silvicultural interventions are to be implemented, usually as blocks. Although the spatial resolution at the tactical level is more refined, temporal resolution generally remains unchanged from the strategic level (planning periods); however, the planning horizon for tactical planning is far shorter.

At the operational level of planning, spatial and temporal resolution become finer still. At this level of planning, details becomes important: average yields for stand types are often replaced with operational cruise information for individual stands, scheduling of activities goes from a periodic basis to a yearly or monthly basis, and the planning horizon is reduced still to a time frame of just a few years.

In order for this process of planning to work, there needs to be consistency across planning levels. Some assert that this can only be done in the context of a single planning model, but the forest management literature has largely refuted this approach. The alternative then, is a common planning database founded on GIS. Although the GIS is typically a repository for detailed stand information, there is no reason that the classification scheme cannot also contain information useful at more aggregated levels of planning. In this planning framework, the GIS then becomes a powerful database server to a variety of individual client forest planning tools which use information from the GIS as input and write solutions back to the GIS database, thus maintaining spatial integrity at all times.

The case study

New Brunswick provincial guidelines require Licensees to conduct a strategic harvest scheduling analysis with a planning horizon of 80 years, and to produce a management plan based on this analysis with a planning horizon of 25 years. Locations of proposed harvesting must be identified on map sheets for the entire 25 year planning horizon. Blocks must not exceed 100 ha in size, and stands adjacent to these blocks are subject to a minimum 10 year delay in harvesting following harvest of these blocks. In addition, areas of suitable habitat for fauna requiring mature/overmature softwood types were delineated across the License; at least as much area qualifying as habitat now must be maintained in these areas for the next 40 years.

Remsoft Inc. was contracted by the NB Forest Research Advisory Committee to undertake a study of three currently available planning tools, to evaluate their usefulness in the context of the management planning process required of NB Forest Management Agreement holders, and to compare these results with those of two Licensees who have recently completed their management plans. The three planning tools we evaluated were Woodstock (developed by Remsoft), Crystal and Block (both developed at UNB Faculty of Forestry).

Woodstock is a forest modeling system, capable of modeling a variety of forest planning problems including harvest scheduling. One of its key features is the ability to use simulation approaches or linear programming (LP) approaches to generate harvest schedules. For the purposes of this study, a LP formulation was used.

Crystal (Walters, 1991) was designed to allocate harvest prescriptions from a stratum-based harvest schedule to stands. Using stand adjacency information extracted from an ArcInfo coverage, Crystal uses a heuristic algorithm to form contiguous harvest units while minimizing deviations from the strategic harvest schedule. The user has control over parameters such as block size and magnitude of deviations, and one can preallocate blocks if desired. Crystal does not however attempt to comply with opening size or adjacency constraints.

Block (Dallain, 1989) is a tool designed to schedule the harvest of blocks or harvest units under flow constraints, maximum opening size constraints and adjacency delay constraints. Based on a Monte Carlo integer programming (MCIP) algorithm, Block determines spatially feasible block harvest schedules using volume maximization or cost minimization objectives.

Although two Licensees participated in the NB FRAC study, the study is not yet completed and so we will present results only from License 8, managed by Valley Forest Products Ltd. (VFP) on behalf of the Ste Anne-Nackawic pulp mill. License 8 encompasses about 126 000 ha of Crown land, much of it interspersed among small private woodlots resulting in a rather fragmented land base. The pulp mill uses almost no softwood, relying on mixed hardwood (maple, yellow birch, etc.), white birch and poplar to produce its various pulp products. However, the License must also provide numerous log material to various saw and veneer mills. Operating largely in mixed wood stands, VFP faces the difficult task of trying to generate required volumes of hardwood pulpwood and softwood log material without concomitantly generating surplus softwood pulpwood which is difficult to dispose of.

In order to represent all management requirements in their wood supply analyses, VFP subdivided their forest into different capability classes on the basis of product type (softwood or hardwood), operating restrictions (habitat vs. timber management) and management emphasis (evenaged or unevenaged management), resulting in 6 different FORMAN+1 models plus individual models for each deer wintering area on the License. Due to the complexity of the management problem, and the difficulties in balancing product flows across 6 different planning models, VFP staff were able to maintain balanced flows for just 5 of 16 planning periods.

Because we formulated the VFP management problem as a Woodstock LP model, constraints on product flows, silviculture levels, and wildlife habitat area could all be achieved in a single model, solved once.

Trying to do the same thing through harvest and silviculture rules would not only have taken far longer to accomplish, it is almost a certainty that the overall allowable cut would have been significantly lower, or at least one or more of the constraints would have been violated to sustain the cut (Jamnick, 1990).

Crystal was used to allocate the first seven periods of the management schedule generated by Woodstock. Although Licensees are required only to block out the first 5 planning periods for their management plans, we decided to use 7 periods to provide additional flexibility to Crystal when allocating stands in the later planning periods. Similarly, the harvest units generated by Crystal were scheduled in Block using the same 7 period planning horizon. Finally, to test long term sustainability, the block harvest schedule was run through the Woodstock simulator to verify that all constraints were indeed met.

Results

Because the data used in the case study was provided to us in confidence, we will present all results in graphical form or relative terms. Although graphs will not have y-axis coordinates, direct comparisons between the two approaches can be made since the minimum y-value in each graph is zero.

As expected, the LP model far outperformed its FORMAN+1 counterparts. For example, the VFP models only attempted approximate flow control on key products such as mixed hardwood and birch pulpwood, with either total spruce/pine/fir or total hardwood as primary controlling outputs. Therefore, no direct management control could be exerted on most outputs.

The LP model yielded significantly higher average softwood harvests than did the FORMAN+1 model; the FORMAN+1 models yielded higher average hardwood harvests than the LP model, but with considerably more variation period to period. The Woodstock model was constrained to maintain existing mature/overmature softwood habitat for 40 years, and to provide double that area forest-wide for the remaining planning periods; the FORMAN+1 models only attempted to maintain the same are over the entire planning horizon. Despite this more rigorous requirement, the Woodstock model still managed to yield better harvest levels for all products (see Figures 1 through 3).

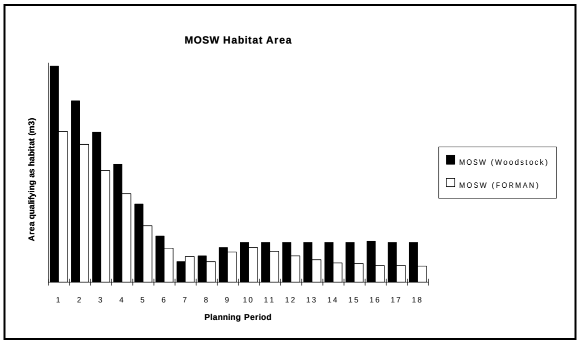

Figure 1. Mature/overmature softwood habitat profiles produced by FORMAN+1 and Woodstock..

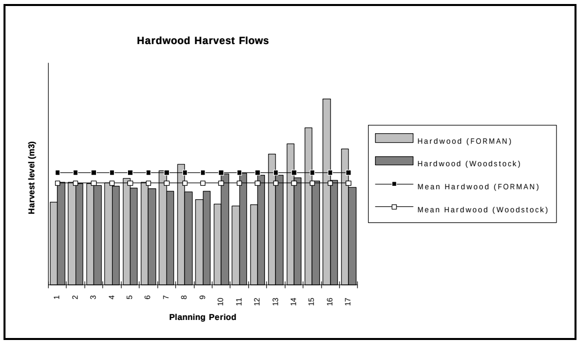

Figure 2. Hardwood harvest levels determined by FORMAN+1 and Woodstock.

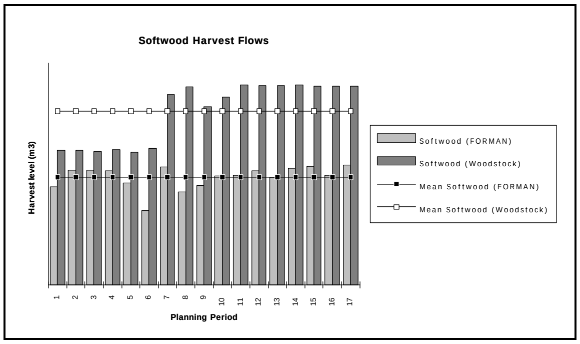

Figure 3. Softwood harvest levels determined by FORMAN+1 and Woodstock.

Processing the Woodstock harvest schedule through Crystal yielded a successful allocation of about 86% of the originally scheduled area for the first seven periods. As noted earlier, Crystal does not attempt to comply with opening size or adjacency constraints. Furthermore, because it only attempts to allocate area to silvicultural prescriptions, following the prescribed harvest period suggested by Crystal would not necessarily provide acceptable harvests in each period.

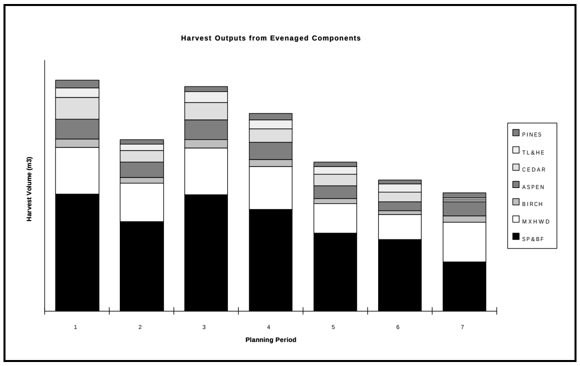

Figure 4. Harvest flows arising from following the harvest schedule generated by Crystal.

Figure 4 illustrates how the harvest levels need to be smoothed out by Block through deviations in timing choices. Note however, that since Crystal only considers stands scheduled for harvest in the first seven periods of the strategic harvest schedule, the allowable cut must be an underestimate.

Crystal assigns a suggested harvest period based on an average harvest period, weighted by the area of the component stands within each block. Based on the average yield for the block however, a different harvest timing choice could yield more wood. It is the weighted yield by block that is used in Block to determine final block harvest timing choices.

Because Block uses a MCIP algorithm to generate solutions, one needs to bound the decision space somewhat to improve the probability of finding superior solutions. Through a trial and error approach of setting minimum periodic harvest levels, we were able to find good, relatively consistent block harvest schedules, all of which met opening size and adjacency constraints. Running this block harvest schedule back through Woodstock yielded the following harvest profile for the first seven periods.

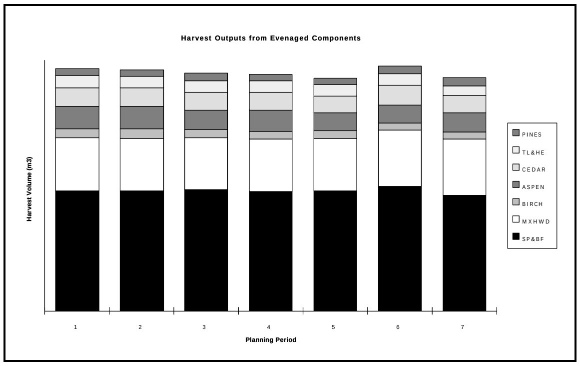

Figure 5. Harvest profile arising from block harvest schedule generated by Block.

There are three significant points arising from these results. First, there is a significant reduction in allowable cut from the strategic harvest schedule generated by Woodstock to the spatially feasible block harvest schedule generated by Block (about 32% in softwood and about 25% in mixed hardwood). Second, despite the rather large decreases attributable to spatial constraints, the AAC arising from the spatially feasible block harvest schedule was marginally higher than the AAC found by VFP using FORMAN+1, prior to blocking and spatial constraints. Third, the average block size remained essentially constant across all planning periods (Figure 6). Algorithms which allocate harvests sequentially typically exhibit rapid declines in average block size over the first few planning periods as unallocated stands are quickly used up; both Crystal and Block attempt to allocate all periods at the same time, to avoid this difficulty.

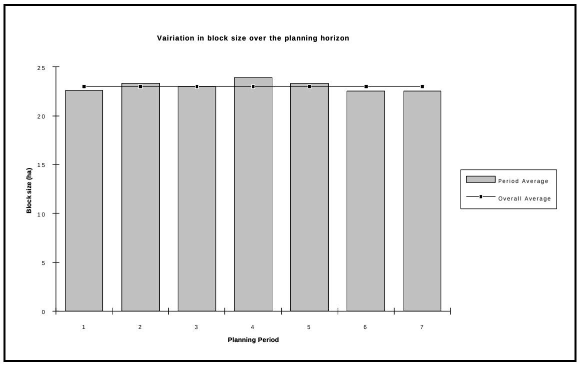

Figure 6. Variation in block sizes by period following scheduling by Block.

Discussion

Strategic planning models that are stratum-based are not necessarily aspatial. In the case study, we developed a stratum-based model based on a classification scheme embedded into the polygon attribute data. By summarizing the stand data, we were able to generate geo-referenced strata which could easily be linked back to individual stands. Furthermore, since the mature-overmature softwood habitat area was uniquely identified, our constraints to maintain this habitat were in effect, spatially oriented. In New Zealand, researchers have been studying linkages between short-term and long-term planning through a technique called variable resolution modeling (Manley, 1993). Using a stratum-based scheduling model, stands that are likely to be harvested in the near future are represented as individual strata, but younger stands that will not be harvested for some time are aggregated together into classical stand types. The approach allows one to incorporate specific detail for the early planning periods where needed, and to use forest-wide averages for later periods where spatial detail is not required.

We hold the opinion that spatial modeling of all planning periods at the strategic level is unnecessary – it is questionable whether one should be grouping stands together into harvest blocks far into the future where the uncertainty associated with growth and yield makes the likelihood of actually implementing such blocks unlikely. Our understanding of regeneration response in Canada is relatively poor; we are barely able to predict outcomes, and only then on the basis of forest-wide sample estimates. Even those who claim to do spatial modeling invariably avoid the regeneration issue by reducing planning horizons or by assuming a uniform regeneration response.

Linear programming models, used within the limitations imposed by the LP structure, are a much more efficient means to providing management control than simulation models. In addition to consistently higher objective function values, LP models permit simultaneous constraints on product flows, silviculture levels, age class distributions and wildlife habitat. Trying to accomplish the same thing through harvest and silviculture rules would not only take far longer to accomplish, it is doubtful that one could simultaneously meet all of the constraints, never mind match the objective function value.

Algorithms like the one used in Crystal appear to have promise as tactical planning aids: they are fast, consistent, and produce solutions at least as good as those generated by manual methods. Crystal needed only minor modifications for use on a large-scale forest planning problem. The difficulties with the algorithm used in Crystal lie in the allocation of intermediate harvests and alternative final harvest activities: in what order should the activities be scheduled, and, when a particular stand can be allocated to more than one activity, which activity takes precedence? Because the allocation process does not occur simultaneously, it is always possible that an earlier allocation may preempt an alternative allocation which would yield a better overall solution. Unfortunately, in its current form Crystal is capable of allocating only one type of prescription at a time. However, despite its faults, Crystal seems a far better alternative to the labour intensive, manual allocation approach used by Valley Forest Products.

Like Crystal, Block required only minor modifications for the case study. The block harvest schedule produced by Block was quite good: all spatial constraints on opening size and adjacency were met and the average harvest level was nominally better than the strategic allowable cut found using FORMAN+1 without spatial considerations. The MCIP algorithm generates feasible solutions very quickly, and by generating a sufficiently large sample, near optimal solutions can be found. However, Block has a number of shortcomings as well. The degree of control on flows of individual products is quite limited. With increasingly narrow bounds on harvest flows the algorithm tends to generate fewer and fewer feasible solutions, but without bounding the decision space there is too much variation in period to period flows. Furthermore, Block can only handle final harvest activities, and does not permit the user to bound output levels for specific periods. In the case study, commercial thin volumes had to be ignored, as did the increase in AAC permitted in period 7 of the strategic harvest schedule. But as with Crystal, Block remains a viable alternative to manual scheduling of harvest blocks.

None of these tools are workable without access to GIS data. Both Crystal and Block depend on adjacency information that can only be realistically produced from a digital database. By incorporating the classification scheme for the strategic model into the polygon attribute database, the development of strata is trivial and guarantees that stands are assigned only to a single stratum. Furthermore, the geo-referenced strata provide the basis for allocation decisions later on.

Conclusions

The approach we used to address spatial modeling is based on analytical tools that have been available for some time (Block was written in 1989) but have not been tested in an operational setting before. In general, they work quite well, and represent a viable alternative to all-in-one spatial modeling approaches such as GISFORMAN (Baskent, 1990). Although GIS data is used extensively, none of the programs used actually requires a GIS. Furthermore, all of the analysis was done using a relatively inexpensive DOS-based 486DX2-66 microcomputer.

Both Crystal and Block suffer from limitations due to the separation of block allocation from block scheduling. Because the configuration of harvest units is fixed by Crystal before Block is to schedule their harvest, one or more of these harvest units may need to be left unharvested to avoid opening size or adjacency constraint violations. If the configuration could be adjusted during the scheduling phase, the constraint violation(s) could be ameliorated without discarding the rest of the harvest units. We intend to address this issue with a new tool being developed at Remsoft, which will use simulated annealing to simultaneously allocate multiple harvest activities to stands under harvest flow and spatial constraints. In theory, combining the two processes into one should provide a better means to incorporating spatial requirements into strategic forest management objectives.

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Acknowledgments

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