Forest Harvesting Decision Support for Sustainable Development

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Abstract The principles outlined here apply as much to other types of regional analysis, and not just forestry, although forestry applications show many of the complexities of the general problem. The objective is first to map the forests in some valid fashion, then to predict their growth in the future, and finally to schedule harvesting that both preserves the regeneration rate of the whole forest, preserves biodiversity, and allows sensible access and road construction programs. None of these three have obvious answers.

Traditional forest mapping has been performed by skilled air-photo interpreters outlining stand types according to the appropriate classification scheme. There are many difficulties with the identification of these boundaries, and with the verification of the interpretation on the ground. Some recently proposed alternatives include fuzzy boundary methods, and automated individual tree crown identification. Growth rate prediction of established forest is reasonably satisfactory using the yield-curve approach, but there has been little success in predicting the type of forest to expect after cutting - thus handicapping long-term sustainable-yield planning.

Most decision support systems for planning the forest harvesting have used classical optimization techniques, with the adjustment of various parameters to achieve an acceptable simulation of test data. Experience to date suggests that these systems are difficult to use in an operational context. Moreover, current methods do not usually take adequate account of the spatial distribution of the cut schedule. This means that the results must be drastically modified to accommodate the real- world engineering problems: especially those concerning access and road construction.

We are attempting to address these issues in several ways. Firstly, a North American workshop on harvest scheduling methods took place in March 1997, and the practical discussions may help us to re-orient future work. Secondly, new graph-theoretic algorithms may help to put the primary emphasis back on the spatial distribution of the cutting program by basing results on the existing or proposed road network. Thirdly, it appears that practical systems should be based more on the idea of a toolkit, rather than a program that provides final answers. This 'flight-simulator' approach both allows input from the forest manager, and provides manager training by indicating the consequences of his proposed actions.

Introduction

In this paper I would like to review some aspects of forest management in Canada, as well as some of the attempts to handle these problems.

Canada has an extremely large landmass. The southern parts are largely grasslands or aspen parkland in the prairies, rainforest on the west coast, and mixed hardwoods in the east. Between these and the northern tundra there is a broad band of boreal forest: largely coniferous softwoods, in part used for lumber, but mostly used for ulp and paper. These forests are a major economic resource, and their management is of great importance to the future of the country.

In earlier days the only issue was one of extracting the wood as economically as possible, but this is no longer the case. In some places close to inhabited areas the forest is already gone.

In other places it has been massively altered, frequently by selective cutting: if you take out all the trees of the kind you want, it is likely that the type you have left behind will take over.

For these and other reasons, the last decade or so has seen a large emphasis on 'sustainable development', where it has become important to take out less than is being grown, and with the same mixture of species that was there before. Part of this is due to the national and international environmental movements, who are putting pressure on forest companies to justify their actions. Part of this is due to a widespread realization that the old ways were destroying both livelihoods (jobs in forestry, pulp and paper making, lumber) and recreation (hunting, fishing, lakeside activities, tourism - which also mean jobs). Part of this is due to the economic realization that in the long run sustainable management pays for itself, both in me provision of wood for the future and the preservation of various land uses besides forestry alone. Part of this is due to the rights of the native peoples.

Today few people would deny these objectives, although there are still major conflicts in detail between those who want jobs (and profits) now, and those who want most cutting to stop. In practice this means that most forest planning requires both government (provincial Ministries of Forestry) and public (through public hearings) approval. While not perfect, and certainly noisy, in general this prevents the worst extremes from happening.

The greatest difficulty in putting such plans in place is our inability to model/ and predict the consequences of/ both natural and man-made forest changes.

Previous Work

As part of the work of the national committee, Green Plan, on decision support systems, we attempted to define the overall needs for computer tools for helping foresters to make decisions. There were a variety of categories: harvesting, wildlife conservation, recreation/ multiple use, pest management, etc. It was generally concluded that the input to each of these categories of requirements was very variable, with different regions and companies having different priorities.

Some general conclusions were reached after several years:

1) Support for decision making could be computer based, but need not be (e.g. mechanisms for determining public opinion);
2) The overall need was to generate various scenarios for evaluation according to any of a wide variety of criteria (e.g from the categories given above);
3) Scenarios could be generated by any mechanism: the forest manager's judgement, public feedback, computer simulation;
4) True optimization techniques were probably expensive and unnecessary, as the situation would change frequently, due to changing government regulations, forest fires, blowdowns, pests, etc.;
5) Scenarios, or forecasts, could be manually or automatically generated, and could attempt to predict the future state of the forest without human intervention, or as the result of harvesting, planting, etc.;
6) Most elaborate models were unsuccessful in that too many non-intuitive'parameters needed to be provided, and the systems were not readily transferrable to industrial users - indeed, often only the developer could use them!

7) A concept of a general software 'platform' with plug-in modules was developed, but not implemented.

Examples of earlier work are given in Baskent and Jordan (1991) and Moore and Lockwood (1990), among others.

The 'Flight Simulator' approach

Chen and Gold (1992) and Gold (1993) developed the 'flight simulator' concept to describe a system based on scenario evaluation rather than optimization. (A scenario may be defined as some current state, or else an action plan on that state, that is to be submitted for evaluation.) It was based on a simple concept of 'bandwidth': the capacity of the channel of communication between the computer (good at calculations) and the manager (good at judgements made with imprecise data). The computer data largely consisted of simple properties for large numbers of forest stands (e.g. wood volume, species, area) and simple rules (maximum allowable cut). The human data consisted of large quantities of imprecise information of a general nature (political and social consequences, terrain trafficability, practical rules for the management of men and machines). The problem was to take advantage of the strengths of each, and transfer information between the two in the most appropriate form. The conclusion for data transfer was the scenario, which could be understood by the manager in its global form, and evaluated by the computer in its details. This reduces to the simple process of the manager proposing a scenario, and the computer evaluating it.

The key question was the iterative sequence of scenario generation and evaluation. These could be modified as necessary for the particular context. For example, a manager could prepare a plan, involving a particular harvesting sequence for a proportion of the forest, and the computer could evaluate it for a variety of ecological, economic, social and wildlife criteria -whatever items were of interest, and for which reasonable models existed. (A good deal of wildlife modelling is devoted to providing habitat indices for a variety of indicator species. Thus a particular forest state at a particular time may be rated for habitat suitability for some species. This species is chosen as being either representative of a group of species - a guild - or as being particularly sensitive to change.)

This simple approach produces a good feedback loop: the manager proposes a plan, and this is evaluated for various criteria. He may then modify his plan to improve various indices, and re-submit it. The various criteria may be imagined as being shown on a set of gauges or dials on the screen, and the manager's objective is to keep all the needles out of the 'red' zones. We call this the Flight Simulator paradigm, as there are two objectives: to go from some original state to some final state as efficiently as possible (but above all without any catastrophic error!), and to train the operator by practical experience as to what actions are generally positive, and which are not.

Boreal Forest Management

The scenario developed above may be for a single time step, or for a sequence of time steps (often five years apart in the Canadian context). This clearly requires a growth model for the forest, supplied by standard growth and yield curves for the main forest types. These have been developed over many years, and are usually considered pretty good for the average (regional) case. Thus prediction of future states of the forest/ based on the past, is an attainable goal if there are no breaks in the growth. However, the Canadian boreal forest is very short lived, with trees reaching maturity after about 80 years. After that they start to die off, and if left alone the forest stand will disintegrate. At this stage the future state becomes unpredictable, as well as being particularly susceptible to disease, pests, fire etc. Unlike other forest regions, the boreal forest is naturally fragmented, showing the consequences of disease, fire, blow-down, etc. in the relatively recent past. Thus long-term modelling is particularly difficult without a good model of regeneration: a method of predicting what type of forest will arise in a region that has been laid low by natural, or man-made, events. Unfortunately this is difficult, and still needs extensive research before we can truly model long-term forest growth, and thus be confident of achieving our objectives of sustainable forest development.

In many circles the idea of 'clear-cutting' - of clearing all the trees from a moderate-sized area - is considered very bad. Like a forest fire, or the aftermath of a wind blowdown, clearcutting is visually unattractive. If done badly it can contribute to serious soil erosion. However, it does allow the possibility of preparing the land for another 'crop' of a predictable type, by scarifying, planting, and fertilizing. If done well, this may be good forest management, although the choice of species for regeneration must be made with care. The alternative -selective harvesting - is not only more expensive in many areas, but frequently ruins the species mix of the forest by removing the commercial species and allowing the remaining, unharvestable, species to take over completely. This has happened in some of the longer-inhabited regions of the Canadian boreal forest. Thus the task of harvest management that both provides economical wood extraction, and preserves the original mix of species, wildlife and habitat over the long term is an extremely complex problem. It is not obvious that even the best experts can make good estimates all the time, and it is certainly evident that it is beyond the ability of today's computer algorithms and the relatively simple data sets available. The task of the software developer must therefore be to extend the 'reach' of the manager, and to make his task easier, by automating the arithmetic operations that may be done well by the computer. The scenario evaluation approach seems to provide the most intuitive interface, following the flight simulator model. The simplest approach takes one time interval as input, and evaluates it according to the available criteria. The next approach . involves the simulation of growth over time, as well as the difficulties of simulating forest regeneration. Thus an initial forest state generates a series of snapshots of the forest, each of which can be evaluated for wood volume, species mix, wildlife habitat, etc.

We are still not yet successfully simulating a natural forest, as much of the boreal forest's fragmented nature is due to fire (caused by lightning strikes), pest destruction (especially the spruce budworm), blowdown due to wind storms, destruction due to freezing rain and consequent ice buildup, etc. While overall statistics might be possible, the location of these events is unpredictable, as is their size. Once we come to human activity, the first rule of forest resource extraction is to salvage trees being destroyed by the events mentioned above, as well as by over-maturity and natural degradation. (Even here there are constraints: many wildlife species thrive only in a forest with a reasonable percentage of dead wood. The human suppression of natural forest fires also causes environmental change, since some species are adept at taking advantage of this naturally-occurring opportunity.)

The main purpose of forest management, however, is to minimize man's impact while maximizing the economic value of the forest. Thus the main objective of decision support systems is to help the forest manager to plan his interventions in the forest (harvesting, road building, silviculture, etc.) to maximize the economic return (value minus cost) while minimizing the adverse long-term impact. Thus, in our scenario evaluation, the initial input is the current forest state plus the proposed harvesting plan. (These plans themselves are subject to a large number of regulatory constraints, such as not cutting too close to a river, restricting the size of the cut block, and not allowing adjacent blocks to be cut within some specified 'green-up' time period.) The economic considerations are not merely to grab the best wood first, but to make the best use of the economic resources available (men and machines) over the long term, which often means attempting to equalize the volume of wood, of each desirable species, going into the mill each year, and to extract this while using the same number of men, heavy equipment, logging trucks and road-building crews each year as well. Not an easy task! Our flight simulator thus has a series of dials for economic criteria, as well as environmental parameters, for each of the time periods being simulated.

Generating Multiple Scenarios

At this stage, instead of having a single scenario generated as input, we will need to generate a sequence of interventions that conform as far as possible to our economic criteria. The forest manager will thus specify a general plan, and the scenario generator will put together a sequence of scenarios, with varying parameters, that may be run through the computer-based evaluation system. An example of this is the evaluation of varying road construction schedules, where a particular annual budget must be assigned to the most appropriate road segment. (Appropriate here means that it makes accessible an appropriate portion of the forest, for current or future exploitation.) Algorithms may be developed to suggest plans based on varying budget levels. However, it is not feasible to develop automatic systems for such plans, as there are too many other factors, such as terrain trafficability, that are not yet capable of being removed from the realm of human judgement. Thus any such tools must then allow manual modification, followed by a further evaluation step.

Based on the philosophy described above, we have started work on the software. This is a stand-alone program capable of reading standard GIS polygon files and the associated databases, and displaying the results, primarily as a coloured polygon map. Simple analysis techniques, such as shortest-path analysis, have been written for demonstration purposes. The user may select particular polygons in order to specify road systems or to specify some scenario. We hope to add the forest growth module shortly, incorporating standard growth and yield curves, and thus be able to generate simulations over time. The next step would be to add various dials or gauges, showing the value of various indicators, thus allowing the flight indicator type of feedback. Later stages would allow the specification of various models for the harvesting operation.

Conflict Resolution

The reality of modern forest management, however, is that there are many different interest groups who need a say in the overall management plan. On the purely commercial side, there are often several companies, requiring different wood products, who share in a particular license area. On the non-commercial side, there are valid claims from those with lake cottages, the sports (hunting and fishing) communities, the native communities who have used the forests for many generations, as well as various environmental preservation groups. It is not possible, or desirable, to impose a single outside solution on all these legitimately interested parties. Much experience world-wide indicates that the local people are most attuned to the state of the land and forests, and a bureaucracy ignoring their input can create appalling damage. On the other hand, effective and economic management and use of the forest resources requires a bigger picture (and more financial resources) than is available locally. This inevitably produces multiple incompatible management criteria, even if all the problems of the simulation models had been worked out. Since these problems have not all been resolved, the output of any scenario must be examined with a sceptical eye by all parties, to detect any obvious absurdities in the results.

At this stage the flight simulator may be run based on the criteria desired by any interested party, and the results of this step (frequently a map or series of maps) presented to the appropriate committee or public hearing where all views are represented. It will often be found that some parts of the plan cause little conflict, in which case efforts can be made to reconcile the other parts. Manual modifications to the various plans may be submitted to the computer evaluation process, and over a period of time a workable plan may be derived.

What we see here is an extension of the flight simulator philosophy. When the pilot is sitting in the cockpit, his primary objective is not to crash. With practice he will both arrive at the destination by a reasonably efficient route, and also learn which manoeuvres are good, and which bad. The same approach is essential for forest management. There will be no perfect solution; the most to hope for is the avoidance of catastrophes, as defined by any reasonable interested party. For that reason it is essential that all those claiming some special knowledge of the land and forest be allowed to contribute to the general good.

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