A simulation model for a wide range of harvesting scenarios in boreal forest

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Abstract.

A spatial decision support system (SDSS) was designed to help forestry planners take into consideration aboriginal land uses in eastern Canada. This SDSS permits the comparison between different harvest scenarios based on four criteria: wood procurement, accessibility, wildlife habitat and land use. Each criterion is evaluated through a set of indicators calculated by mathematical models. The SDSS operates as ArcGis9.x extension and allows one to measure spatial parameters used to calculated economic and land use indicators.

An economic model is used to evaluate the operational cost of a given harvest scenario using productivity and cost functions for four sub models: planning, road, harvesting and transportation. The economic model takes into consideration harvest patterns, harvest systems (tree length or cut-to-length), equipment displacement, road classes, block sizes and seasonal effects.

The land use model generates information in regards to suitability habitat index (moose, marten and rabbit), area accessible from forest roads, forest cover changes, and the impacts on sensitive zones. These indicators were identified by the aboriginal community members as being important to assess the impacts of industrial forest management on their traditional way of life.

Finally, the indicators for each scenario are reported into a matrix. The matrix permits forestry planners and aboriginal community members to compare scenarios. Several case studies performed very well in the north of Quebec territory will be presented.

Keywords: GIS, forest operations, decision support, mosaic cutting, Business as usual cut, Clear cut. Partial cut, natural disturbance emulation, wood procurement cost, wildlife habitat. Forest planning, ArcGis extension.

INTRODUCTION

Several communities in Canada depend largely on forest companies to create local employment and generate economic activities. Native people may not have benefited as much from the activities of forest products companies as others, and forest harvesting can disturb their traditional activities. While confrontations have marked the issue of forest management in the past, forest products companies are now working with local groups to try to accommodate non-fibre-related uses of the forest. Recently, alternatives to current harvesting procedures have been sought in an effort to reduce the impacts of forest operations on non-fiber-related activities.

The Waswanipi Cree Model Forest (WCMF) in the Abitibi region has been using mosaic cutting (MOSAIC) as their preferred intervention procedure. The key to MOSAIC is harvesting the forest in patches of the size and shape that best correspond to societal criteria for the region, ecological aspect are also considered. A private company is in a trial phase of MOSAIC management near Waswanipi. Although their mosaic pattern is more regular than the one used on the WCMF and their cut blocks are slightly larger, this company continues to have to contend with similar problems: higher operational costs and time and labor consuming planning efforts. Actually, this MOSAIC cutting is regulated by law in this region.

Currently, there is no integrated methodology for conducting forest planning based on MOSAIC patterns that allows for an a priori evaluation of the effect(s) of a given management plan on economic and non-fibre-related values. In the absence of the necessary tools to evaluate such a management approach combined with business as usual methods and new approaches based on natural disturbance, the process of public consultation for forest management may become unnecessarily frustrating and adversarial.

In response to this situation, a project was carried out to develop a geographic information system (GIS)-based decision support tool. The project was conducted in cooperation with one forestry company, a native-owned and operated harvesting corporation, and the managers of the WCMF.

OBJECTIVES

The primary objective of this project was to develop a spatially based forest management decision support tool that is designed specifically to provide information on the financial and non-economic consequences of a given forest management plan on MOSAIC forest management.

The secondary objectives were:

To increase understanding of the cost associated with managing the boreal forest in patches of varying sizes with respect to values of non-fibre-related forest values.

To facilitate the capacity of forest companies to develop innovative forest management strategies to provide financial profit while respecting non-fiber-related values.

To provide a mechanism by which all groups that use forest resources can feel that they are part of the forest management process.

LITERATURE REVIEW

Decision support for forest management and planning activities has undergone two revolutions since computers began to become more commonplace in the late 1960s. The first was a quantitative revolution; among the domains that initially benefited from this increased computing power were forest growth and yield modelling (e.g., Sullivan and Clutter 1972, Ek 1974), and forest planning optimisation through operations research (e.g., Stuart 1981, Bullard et al. 1985). The question to which an answer was sought from quantitative tools of this era was generally “How much?” (“How much wood will be on the forest in 10 years if I employ a particular silvicultural treatment?” “How much will it cost to extract 1000 m3 from the forest?”)

The second revolution was not quantitative, but instead was spatial: “Where?” became the fundamental question rather than “How much?”. (“Where can I harvest economically?” “Where do I need to undertake reforestation?”) The increasing power and decreasing cost of GIS software fed this spatial revolution. As a result, studies seeking to optimise forest planning activities while considering spatial constraints began to appear on such diverse subjects as road planning (Nelson and Brodie 1990) and harvest scheduling (O'Hara et al. 1989). Non-fibre-related forest uses such as wildlife habitat (Baker et al. 1995) and watershed management (Schloss and Rubin 1992) have also been studied in a spatial context. Others commercial tools are also available to perform forest management analyses (Patchworks, Woodstock, etc.) however it's difficult carry out analyses at tactical level (5 years plan).

All of the studies cited in the previous paragraph made use of the capacities of a GIS to examine spatially related topics in isolation of each other. However, because of its analytical capabilities, GISs have also been used to integrate research derived from various research domains into a single management tool (e.g., Brown et al. 1992). The benefits of using a GIS for such a purpose are not confined to analytical capabilities, however. Visualizing and communicating the effects of various forest management strategies is also one of the strengths of a GIS (Orland 1994). Another important benefit is the capacity to pose "what if?" questions and to evaluate the results of a variety of different management scenarios.

The MOSAIC approach presents challenges and opportunities in the province of Quebec as well as in other regions of the boreal forest. In this type of forest, harvesting systems have not been designed to be excessively mobile and flexible. As stated by Rummer et al. (1998), ecosystem management will foster a need for harvesting systems that can be economically viable for various silvicultural methods. Therefore, given the actual equipment and contractor base, perhaps the greatest challenge for wood procurement foresters will be to minimise ever-increasing harvesting and road construction costs. Several models dealing with cut-block size and spatial distributions have acknowledged higher capital spending and maintenance costs for roads because of equipment and labour movements (Zundel 1992, O'Hara 1989). Cost reductions dictate that close attention is given to movements between cutting blocks and road network layout.

The development of a viable wood procurement strategy requires that harvesting cost be minimised. But at the same time, decision-makers must also attempt to maximise the positive externalities of their strategies. Recent developments in Canadian fibre quality requirements for paper mills have induced changes in procurement strategies that favour better process control. Models have been designed to assist decision-makers in their choice of a harvesting solution that will best fit their needs. For example, Wang (1994) provided a decision support system (DSS) that, based on case studies from northeast China, can be used to monitor multi-stage inventories in forest harvesting while taking into account environmental, economic, and safety considerations. It is possible to build on such general structures by adding, for example, a more complete road network analyses tool such as ROADPLAN (Newnham 1995) or the branch evaluation model such as that provided by Dean (1997). The underlying objective of the present study is to use MOSAIC as an opportunity to improve forest usage during harvest.

METHODS

The first step in this project was to assemble information from "knowledgeable" sources for input into the proposed GIS-based decision support tool. Most data was collected at the Waswanipi Cree model Forest (WCMF). The territory is typical of boreal forest found across Quebec. Company records on operation costs were obtained. Meeting with Cree representatives allowed identifying important issues related to traditional land use by the community. Wildlife data and indicators were obtained through meetings with Crees and biologists knowledgeable of the region. The objective at this stage was to learn what critical information is required to properly compare diverse harvesting scenarios.

Once the data had been obtained the challenge was to develop a process that considered all relevant input and variables to compute indicators for a set key criteria. It is on the basis of these criteria that scenarios can later be compared. The DSS general structure is schematically represented in Figure 1.

Forest management scenarios are generalized on the basis of a set of spatial parameters and operational, social, and biophysical variables. These, in turns, are used as inputs defining each scenario. The inputs are processed to provide quantitative information for a set of four criteria. A brief description is made of these criteria and indicators. Details about the calculations and formulas used to compute these indicators can be found in the software user guide (Valeria et al. 2006).

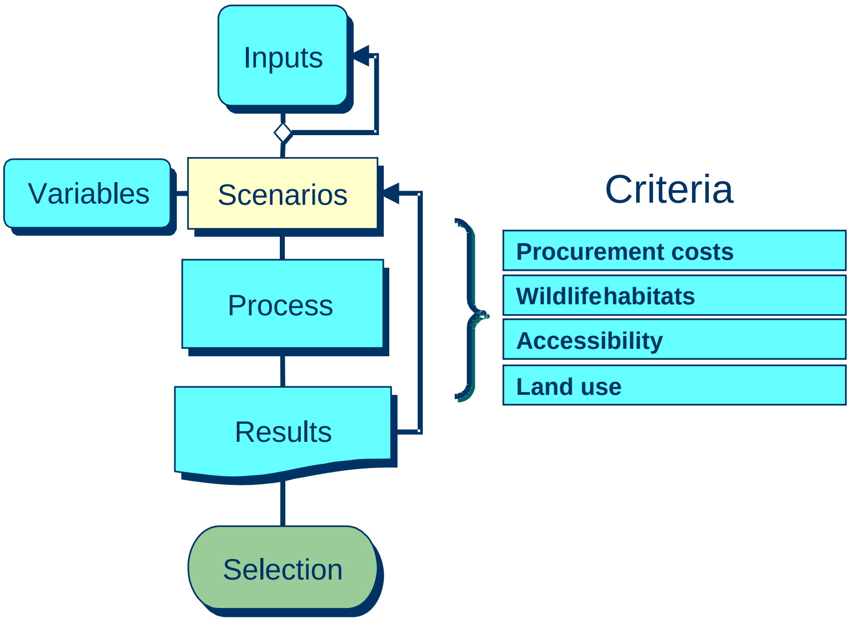

Figure 1. *The SDSS general structure.*

Procurement costs

Wood procurement costs are computed through an economic model that incorporates productivity and cost functions. The model takes into consideration four subsystems; planning (timber cruising, delimiting blocks), road network (construction, maintenance), harvesting activities (harvest, moving) and transportation (hauling, loading). The user must define the area where operations will be conducted. Based on the spatial information managed with the GIS, most costs are automatically computed through various algorithms. Harvesting and skidding productivity can be modelled using functions available on literature. Alternatively, user defined parameters allow for the estimation of a production function based on local knowledge or forest company records.

An innovative harvest blocks clustering approach was developed to simplify spatial measurements of variables affecting procurement costs. Adjacency rules, spatial indices, and operational factors are used to write scripts that permit the identification of operational clusters (figure 2). A cluster represented harvest activities within an area that machines may operates without lowbed truck for displacement.

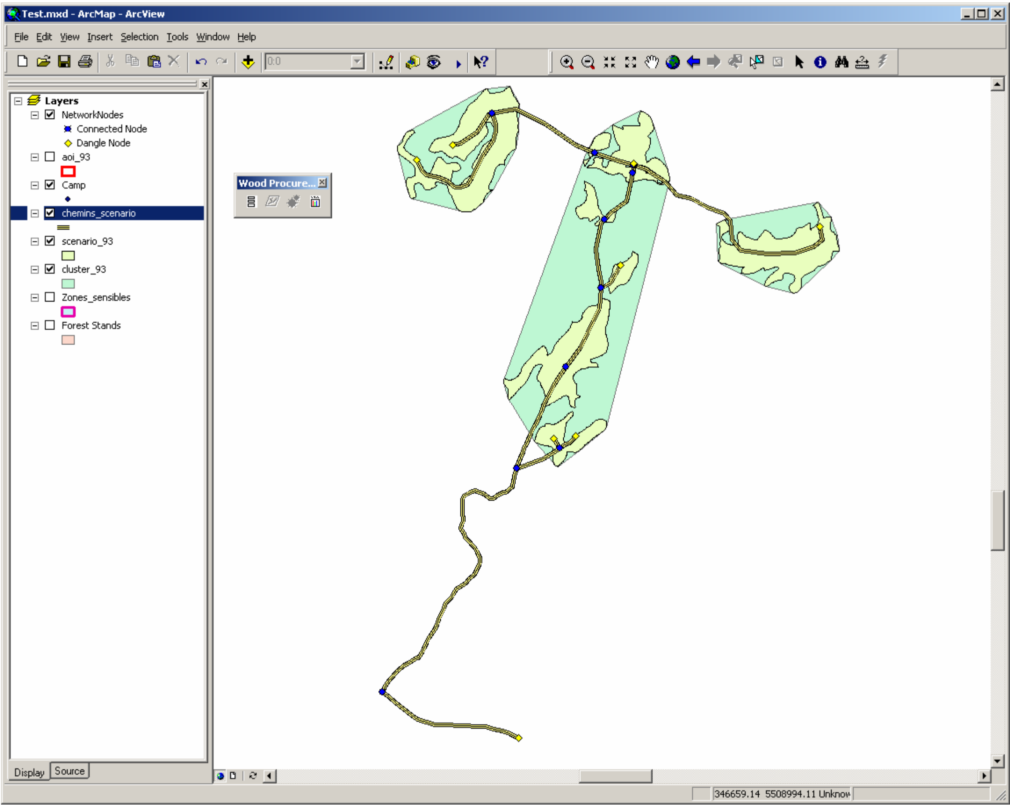

Figure 2*. Clusters of harvesting blocks with their access roads.*

Wildlife habitat

Several indicators are used to evaluate wildlife habitat. The first set of indicators presents the distribution of forest stands by age class and cover type. This provides and indication of the forest landscape after harvest. The second set includes quality habitat indices for moose, marten, and rabbit. Finally, the area in continuous mature forest cover is measured.

Accessibility

Two indicators are evaluated to report on accessibility. The percentage of the area accessible by road is measured using a buffer zone of a predefined width. The proportion of sensitive areas made accessible because of harvest is estimated by tallying the number of sensitive areas intersected by the previously defined buffer zone. Sensitive areas are defined by local users and can take several forms: camp, burial ground, river landing, etc.

Land use

Land use is reflected through seven indicators: 1) total harvested area, 2) total harvested volume, 3) number of cutting blocks, 4) number of clusters, 5) total road distance, 6) number of sensitive areas overlapped by at least one cutting block, and 7) total harvested area and area recently harvested.

A set parameters forms (figure 3) permit users identify data, units, productivity formulas, harvest methods, distance method estimation (real, closest border, closest centroid), harvest treatments (partial cut or clear cutting) to compute all four criteria.

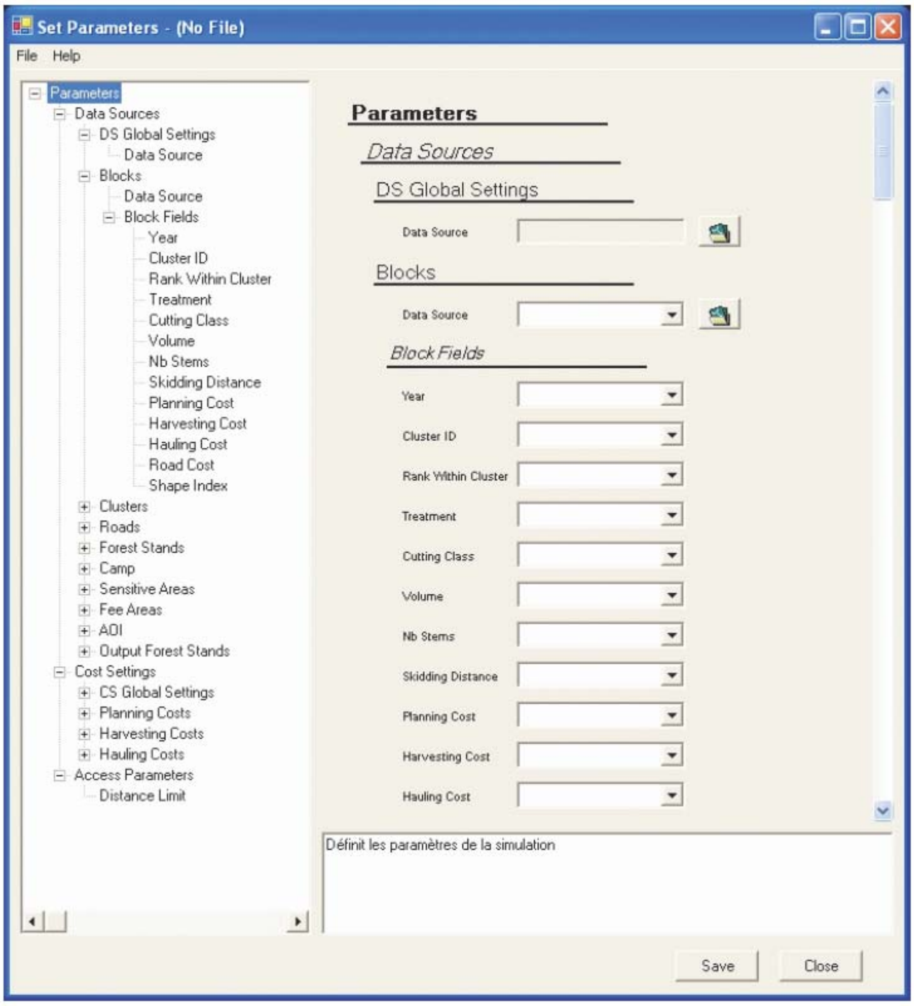

Figure 3. *Parameters forms of Wood procurement planning tool.*

RESULTS

All the scripts required to evaluate the above mentioned criteria were coded in visual basic and .NET. The result is a software called the Wood Procurement Planning Tool (WPPT) that works in conjunction with a GIS. To install the application, the following are required: an ArcGIS/ArcView 9.2 or higher licence; a Spatial Analyst licence; Microsoft Windows 2000 or XP with the latest service pack installed; Microsoft Excel.

Once the user has provided the required spatial and numerical information, the software compute values for the selected the indicators of all four criteria. Preliminary results are displayed through a series of forms (Figure 4, figure 5).

Using WPPT, forest planners can efficiently interact with other stakeholders in the area to prepared wood procurement scenarios that meet their respective objectives. The best-suited scenarios can then be evaluated and compared using a decision matrix that outlays critical decision-making variables (Figure4, figure 5). The matrix is intended at summarizing the results and should help decision makers establish the tradeoffs of selecting one option over the others. Results may be exported in XML format and presented in a convivial way as show in figure 6.

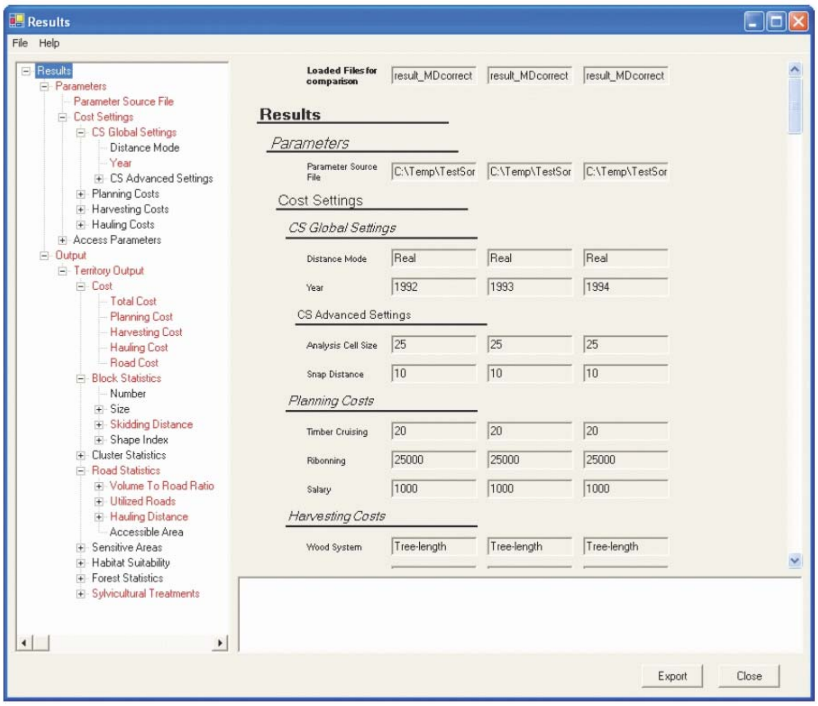

Figure 4*. Form generated by the tool to providing quantitative information for each criteria and for each scenario.*

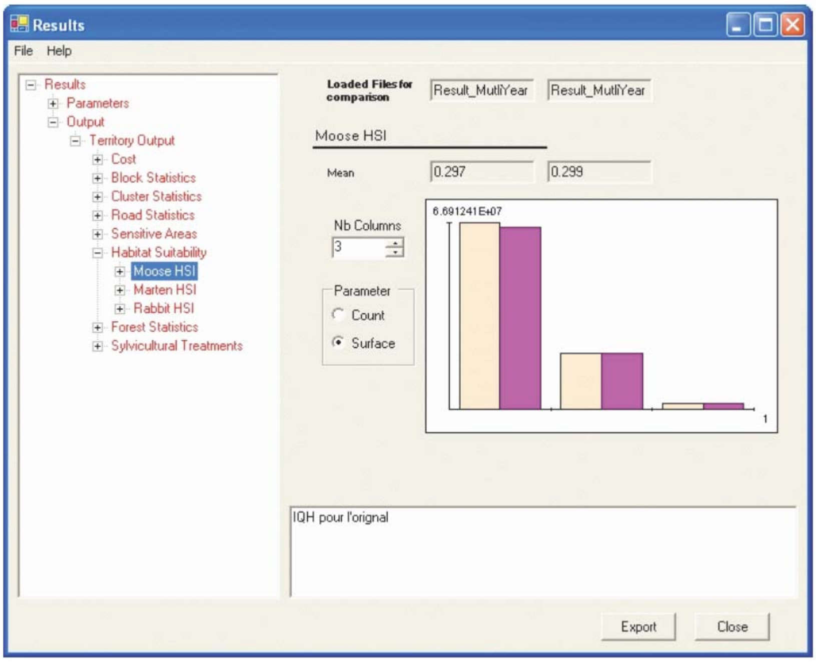

Figure 5. *Form generated by the tool to providing quantitative information for each criteria (wildlife habitat in this case) and for each scenario.*

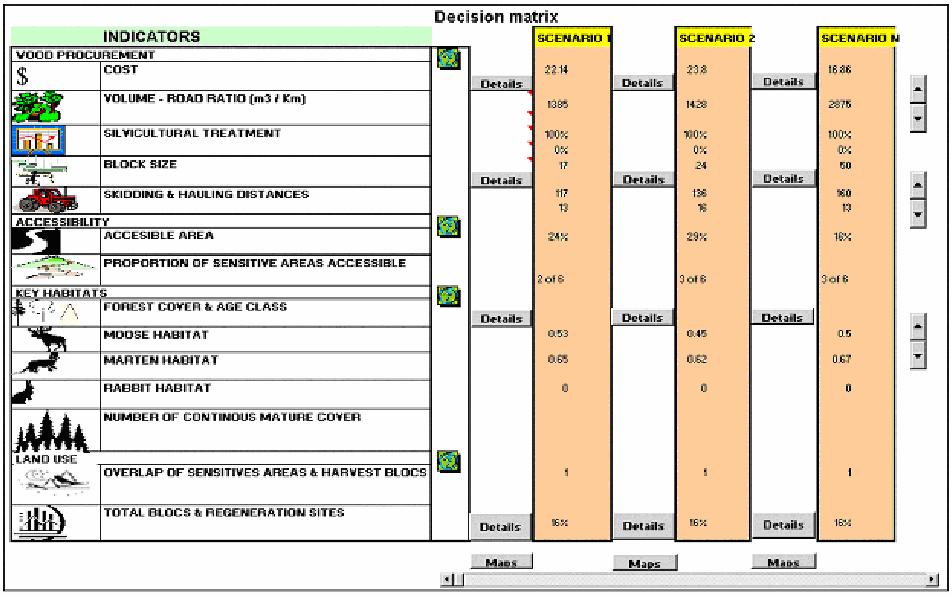

Figure 6. *Matrix used to compare competing scenarios.*

CONCLUSION

WPPT is a decision support tool that is effective in comparing forest management scenarios on the basis of procurement costs, wildlife habitat, land and accessibility. The model is currently tested in "real life" situation in the boreal forest of northern Quebec. Results indicate that it is useful to foresters who have to must prepare forest management plans in situation where local population has to be consulted. Because the software runs as an extension to ArcGis 9.x it is relatively simple to integrate it with other spatial planning aids.

In its current form, WPPT does not attempt to find an optimum solution. There is no immediate plan to develop such a function in the near term. Rather, plans are underway to provide a more complete set of indicators in regards to hydrology and soil impacts after harvest. Also, improvements in the financial model could provide more flexibility to consider in more details the long-term costs of each scenario.

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BIBLIOGRAPHY

Baker, B., Cade, B., Mangus, W., McMillen, J., 1995. Spatial analysis of sandhill crane nesting habitat. Journal of Wildlife Management 59:752-758.

Brown, J., White, C., Holcroft Weestra, A., Wedgwood, R., 1992. Use of the SPANS GIS in the development of an ecosystem management model for the Central Canadian Rockies Ecosystem. Proceedings: The Canadian Conference on GIS, March, Ottawa, Ontario, p. 258-265.

Bullard, H., Sherali, H., Klemperer, W., 1985. Estimating optimal thinning and rotation for mixed-species timber stands using a random search algorithm. Forest Science 31:303-315.

Cook, J., Irwin, L., 1985. Validation and modification of a habitat suitability model for pronghorns. Wildlife Society Bulletin 13:440-448.

Davidson, D., Theocharopoulos, Bloksma, R., 1994. A land evaluation project in Greece using GIS based on Boolean and fuzzy set methodologies. International Journal of Geographical Information Systems 8:369-384.

Dean, D.J. 1997. Finding optimal routes for networks of harvest site access roads using GIS-based techniques. Canadian Journal of Forest Research 27:11-22.

Edenius, L., Elmberg, J., 1996. Landscape level effects of modern forestry on bird communities in north Swedish boreal forests. Landscape Ecology 11:325-338.

Ek, A., 1974. Nonlinear models for stand table projection in northern hardwood stands. Canadian Journal of Forest Research 4: 23-27.

Leung, Y., 1982. Approximate characterization of some fundamental concepts of spatial analysis. Geographical Analysis 14:29-40.

Nelson, J., Brodie, J., 1990. Comparison of a random search algorithm and mixed integer programming for solving area-based forest plans. Canadian Journal of Forest Research 20: 934-942.

Newnham. R.M. 1995. ROADPLAN: a tool for designing forest road networks. Journal of Forest Engineering 6(2):17-26.

O'Hara, A., Faaland, B., Bare, B., 1989. Spatially constrained harvest scheduling. Canadian Journal of Forest Research 19:715-724.

Orland, B., 1994. Visualization techniques for incorporation in forest planning geographic information systems. Landscape and Urban Planning 30:83-97.

Potvin, F., 1998. The American Martin and clearcutting in the boreal forest: a telemetric and geomatic approach. Unpublished Ph.D. thesis, Université Laval, Québec, Québec. 245 pp.

Rummer, B., Baumgras, J., McNeel, J. 1997. Forest operations for ecosystem management. In: Barbour, R. James; Skog, Kenneth E., eds. Role of wood production in ecosystem management: Proceedings of the Sustainable Forestry Working Group at the IUFRO all division 5 conference; 1997 July 7-12; Pullman, WA. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 46-52

Schloss, J., Rubin, F., 1992. A "Bottom-Up" approach to GIS watershed analysis. Proceedings: GIS/LIS '92. November, San Jose, California, p. 672-679.

Stuart, W., 1981. Harvesting analysis technique: a computer simulation system for timber harvesting. Forest Products Journal 31: 45-53.

Sullivan, A., Clutter, J., 1972. A simultaneous growth and yield model for loblolly pine. Forest Science 18: 76-86.

Wang Lihai. 1994. Optimal operation planning for integrated forest harvesting and transport operations from the forest to the mill. Journal of Forest Engineering. 6(1):15-22.

Zundel, P.E. 1992. Planification des choix et de l'affectation de systèmes d'exploitation forestière à moyen terme. Doctoral dissertation. Université Laval, Québec, Canada.