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A CASE FOR HEURISTIC OPTIMIZATION METHODS IN FORESTRY

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CONTENTS

Forestry problems are a potential field for applying heuristic or inexact solution techniques. Reasons for using heuristics in forestry decisions are presented, and potential areas of application are summarized. An example application using ramdom search is discussed.

1. INTRODUCTION

With rising competition for scarce resources, forest managers are increasingly concerned with estimating optimal solutions to complex problems. Heuristic procedures are often useful in solving such problems.

Definitions of heuristics include: "simple procedures, often guided by common sense, that are meant to provide good but not necessarily optimal solutions to difficult problems, easily and quickly" (Zanakis and Evans 1981), and procedures "for solving problems by an intuitive approach in which the structure of the problem can be interpreted and exploited intelligently to obtain a reasonable solution" (Nicholson 1971).

Simple examples of heuristics in forestry include such rules-of-thumb as thinning to basal areas equal to the site index or harvesting the oldest timber first. Heuristics are often more complex, however, and involve iterative algorithms. Although this general class of optimization methods is not commonly applied in forest land management, we discuss its potential. As an example, we review a random search approach for estimating optimal thinning schedules and rotation ages for existing timber stands.

2. REASONS FOR USING HEURISTICS

Several authors have discussed areas of application or reasons for using heuristics (see Muller-Merbach 1981, Silver *et al.* 1980, and Zanakis and Evans 1981). These approaches have potential where exact methods such as linear or dynamic programming are presently inapplicable or impractical. Relevant cases in forestry are:

1. *Resource limitations* (budget, time, etc.) may preclude the modeling effort often required to formulate and solve forestry problems with exact methods such as linear or dynamic programming.
2. *Exact methods may not be available* or may be computationally unattractive. Private nonindustrial landowners, for example, rarely have access to linear programming algorithms for harvest scheduling. Computational costs alone can be prohibitive for problems involving small tracts or low product values.

3. *Inexact data* is frequently a problem in forestry. Statistically estimated growth models, forecasted prices and interest rates, etc., result in imperfect model predictions.
4. *Repeated solutions* are often required. Stand-level problems, for example, often must be solved on a stand-by-stand basis, thus requiring easily applied methods.
5. *Large integer problems* can arise in forestry. Selecting numbers of trees to harvest, for example, can have an astronomical number of possible integer solutions. Such problems are frequently advocated as a field of application for heuristic algorithms (see Kovacs 1980, or Muller-Merbach 1981).

3. POTENTIAL FORESTRY APPLICATIONS

Optimization problems in forestry fall into two broad areas: (1) land and timber management, and (2) harvesting and manufacturing forest products. Most applications of heuristics have been in the latter area. Decision problems abound in selecting in-woods loading sites and facilities for procurement, transportation, storage, and processing of raw materials and finished products. Problems may also involve machine combinations in harvesting or processing forestry goods.

An excellent example of applying heuristics in forest products manufacturing was reported by Haessler (1975, 1983). For given user requirements, Haessler estimated the number of production rolls of paper to be processed for each pattern type, while minimizing the value of trim loss and the costs of changing patterns. The combinatorial problem could not be solved with existing algorithms, and a heuristic procedure was used to obtain results superior to previous methods. In Haessler's (1983) procedure, customer orders define a set of goals for each cutting pattern. The goals include maximum allowable trim loss and bounds on the number of rolls for each pattern. A search procedure determines a cutting pattern which meets the goal, or the goals are reduced and the search continues. In this manner, cutting patterns are defined until all customer orders are satisfied.

Potential applications of heuristics also abound in producing solid wood products. The lumber industry, for example, has placed great emphasis on optimizing methods, including various inexact procedures.

Potential improvements in recovery and efficiency are of increasing concern due to higher volumes of small diameter logs, rising wages, taxes, and log prices, and increasing world demand for forest products (Williston 1979).

Optimization problems in land and timber management have been classed as stand-level and forest-level (Hann and Brodie 1980), and may involve even- or uneven-aged forest management. Stand-level decisions concern individual stands of trees, while forest-level decisions concern entire forests or collections of stands. Forest-level decisions are usually more complex than stand-level guides, and may involve problems which cannot be solved with available optimization methods. Forest-level harvest scheduling models prescribe forest-wide harvests for a given planning horizon, and can be difficult to solve with exact methods if nonlinear functions are used, or if large integer problems are formulated. Decision variables are typically continuous: X_{ij} = acres of stand type (i) allocated to management sequence (j), or acres regenerated in period (i) and harvested in period (j) (Johnson and Scheurman 1977). In cases where forest stands or compartments are managed as homogenous units, however, binary formulations may be necessary (Bare and Norman 1969 and Konohira 1981). In such models, X_{ij} = 1 if area (i) is cut in period (j), and 0 otherwise. Heuristic procedures can be used for such problems, but as in all cases, should only be considered if exact methods are unavailable or impractical.

The potential for using heuristics in stand-level problems is great. For example, such approaches may be used in uneven-aged, stand-level forest management to estimate optimal numbers of trees to harvest after each cutting cycle. Using continuous variables, Adams and Ek (1974) and Martin (1982) applied nonlinear programming methods to such problems for northern hardwoods. Adams and Ek's formulation is particularly appropriate for heuristic solution since problems were reported in obtaining convergence with the gradient projection algorithm they used.

Site quality, species composition, size distribution and many other factors affect the best management policy for individual stands of timber. Most stands must therefore be individually considered, and if composed of lower-valued species, management guidelines must be prepared inexpensively. Heuristic procedures are particularly viable for stand-level decisions since many problems are inherently integer and nonlinear, and must be solved on a stand-by-stand basis at relatively low cost.

As an example of applying heuristic methods to stand-level decisions, we now discuss random search for estimating optimal thinning schedules and rotation age. Random search algorithms are a subset of heuristics where feasible candidate solutions are randomly generated.

4. ESTIMATING OPTIMAL THINNING AND ROTATION

4.1 Nature of the Problem

Given an existing timber stand, how should harvests take place over time? Decisions involve the number of trees to cut from each diameter-class and species at various points in time and the age of final clearcut. Finding an objective-maximizing strategy is particularly complex when harvests are specified by species group and diameter class. Often the number of possible integer solutions is so large that exact solution techniques are impractical.

We specified hypothetical two-species stands and predicted growth and structure over time using stand-table projection (see Ek 1974). An integer nonlinear programming problem was formulated with present value maximization as the objective, and numbers of trees cut (over time) by species and diameter as decision variables. Final harvest was assumed after the last fixed-length growth period projected, and optimal harvesting plans were estimated for 1 growth period, 2 growth periods, etc. The overall optimal thinning and final harvest plan is that with the highest present value.

4.2 Random Search Solution Methods

Heuristics involving random search have been used to solve problems in such diverse areas as chemical engineering (Luus and Jaakola 1973), plant-layout (McRoberts 1971), and making prescription drugs (Conley 1981a). We evaluated the relative performance of two random search methods–simple and multistage–in solving thinning and rotation problems for mixed-species stands.

Simple random search involves randomly generating feasible integer solutions and computing objective function values. The estimated optimum policy is the best solution obtained from a large set of evaluations. A simple statistical justification for the approach was presented by Brooks (1958) and Conley (1980), and criticized by Spang (1962) and Golden and Assad (1981), among others.

Multistage random search resolves certain problems with simple random search by evaluating multiple sets (stages) of random solutions. After each set, potential ranges for decision variable values are reduced, and are centered around their values in the optimum solution thus far. Potential solutions are thus concentrated in a reduced area of the feasible region. Representative multistage methods include those of Luus and Jaakola (1973), Mabert and Whybark (1977), and Conley (1981b).

4.3 Thinning and Rotation Results

Simple and multistage random search were initially evaluated for a two-species harvesting problem with 2,000,000 possible integer solutions, and a maximum present value of $485.76 determined by exhaustive search. Both methods produced cutting prescriptions with present values within 1 percent of the optimum, using less than 30 seconds of execution time on an IBM 3081.

A more complex problem was also formulated, and optimal thinning schedules estimated for projections of 1, 2, and 3 growth periods. For one growth period alone, over 8 trillion possible integer solutions existed. Multiperiod harvesting plans were generated sequentially, period by period, to exploit the dynamic structure of the problem and to prevent generating a prohibitively large number of infeasible solutions. In all trials, higher present values resulted using the multistage approach. (Additional details are presented in Bullard 1983 and Bullard and Klemperer 1984).

Random search heuristics merit further study in estimating solutions to both stand- and forest-level problems. Clough (1969), Dannenbring (1977), and Golden and Alt (1979) have shown ways to quantify how close such algorithms can come to an estimated true optimum. From an initial sample of randomly generated solutions, these methods statistically derive point and/or interval estimates of the extreme values, for which the management prescription is unknown. Sampling then continues until the best solution generated is within a specified percent of the statistically estimated extreme value.

5. CONCLUSIONS

Heuristic procedures range from rules-of-thumb to iterative algorithms, with the common property that convergence to an optimum is not guaranteed. Inexact methods should not, of course, be used for problems where exact methods are both available and practical. For many applied problems in such fields as industry, commerce, and administration, however, efficient converging algorithms have never been developed, creating a major domain for heuristics in practice (Muller-Merbach 1981). Applications in forestry are not confined to land and timber management, but may include problems in forest harvesting and product manufacturing, or equipment design and use.

The two greatest advantages for applying heuristics to forestry problems are the ease of application and the possibility for wide implementation of model results. Random search methods for optimizing thinnings and rotations, for example, could be implemented on a microcomputer, as very little computer memory is required. Possibilities for widespread use of models is greatly enhanced by such a capability.

The greatest disadvantage of heuristic methods is that the precise degree to which estimated solutions approach the optimum is unknown. Caution is needed in cases with potentially great differences between optimal and near-optimal objective values. With iterative methods, however, optimal values can be statistically estimated from the sample and compared with the best value for which a management plan has been generated.

As in any field of application, the quality of heuristics applied to forest-related problems is of prime concern. Quality is related to computational effort, the degree to which optimal solutions are approached, the chance of a poor solution, and the degree to which potential users understand the procedure (Silver *et al.* 1980). With proper attention to such factors, heuristics can be a useful, practical means of estimating solutions to many applied problems in forest management, harvesting, and product manufacture.

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