AN INTEGRATED FOREST PLANNING MODEL: AN OVERVIEW[1]

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ABSTRACT. -- A prototype of an integrated forest planning package for use on microcomputers has been completed. We have made every effort to make this software package transparent and understandable to the user to avoid the problem that planning might be seen as a black box. Individual components of the integrated model can be used a stand-alone modules to serve specific aspects of forest planning. Each module is documented with a user's manual. Additionally, each program utilizes on-screen help facilities or menus to mimimize the need for reference to the user's manual. A major effort was made to produce comprehensive and understandable model outputs. The microcomputer-based system facilitates the development of optimal operational and strategic forest plans. It integrates two important planning modules. The first, an automated stand prescription writer, utilizes a silvicultural expert system for Lake States species to automate the process of developing stand-level alternatives over a full planning horizon. Another program translates these silvicultural alternatives into economic cashflows, reflecting the costs of carrying out the activities. These cashflows become the input into the second module, a management scheduling model based on the Hoganson-Rose algorithm. The algorithm, in contrast to conventional LP solution techniques, overcomes many of the problems of data aggregation, associated with most LP-based harvest scheduling models. The emphasis of the user-friendly planning environment is on output interpretation and ease of analysing many development scenarios. It provides planners with a powerful, yet transparent planning tool.

INTRODUCTION

Forest planning, due to long planning horizons and the associated uncertainty, is a complex and difficult undertaking. To assist in forest planning, quantitative tools have been developed for various aspects of the planning process, i.e., forest inventory and growth projection, silvicultural expert systems, stand-level investment analysis, spatial analysis, management scheduling and geographic information systems (GIS). However, few of these tools have been linked and fully integrated. The integrated timber management modelling system, being developed at the College of Natural Resources, University of Minnesota, allows user interaction and intervention in the planning process while automating the linkages between the various components (Pelkki et al. 1987). The key concepts of this system are the automated linkages between modules and the flexibility of the system for user intervention. Users can enter the process at any point to alter the inputs or intermediate outputs of the process. Thus, the system takes advantage of human decision-making abilities, while utilizing the computer to handle the substantial data processing task that is required to analyze the large number of plausible management alternatives.

DESCRIPTION OF THE INTEGRATED MODELLING SYSTEM

Figure 1 depicts the primary modules of the modelling system. The system is designed to automate and link the data synthesis and computer processing aspects of the planning process while allowing for user interaction and control. Each system component is capable of functioning as a stand-alone system. An overriding objective in designing the system is to develop the capability of examining forest-wide concerns (objectives and constraints) without losing stand-level detail though data aggregation.

The data base management system (DBMS) component is used to select the stands to consider in the analysis. The DTREES system (Pelkki and Rose 1987) produces several management alternatives (prescriptions) for each stand. Each alternative is a sequence of management actions to apply over the planning horizon. The Report Writer/Prescription Editor modules provide management summary reports and an automated format for editing prescriptions. The prescriptions developed for each stand are used as input to DUALPLAN, a management scheduling model which selects an "optimal" prescription for each stand based on overall forest objectives and constraints. DUALPLAN is a microcomputer based application of the Hoganson-Rose (H-R) management scheduling algorithm (Hoganson and Rose 1984). The GIS component of the system can be used for spatial analysis at any stage of the modelling process.

DTREES: A Stand-Level Prescription Writer

Decision **TREE** System (DTREES) can function both as a "front-end" prescription writer to a management scheduling algorithm (**DUALPLAN**) and as a management tool for evaluating specific options for an individual forest stand. It provides a list of alternative management sequences for each forest stand by simulating management activities and responses. Included in the DTREES system objectives are (1) use of a tree based growth projection system, (2) a modular systems design, (3) an understandable and user accessible silvicultural decision system, (4) retains individual stand detail, and (5) a flexible inventory data interface which will accept stand-level data bases used in the Lake States.

The primary goal of DTREES is to provide a range of plausible alternative management prescriptions for individual forest stands. The system is designed to model any forest stand type in the Lake States. Prescription alternatives are based on established silvicultural guidelines. Ease and clarity of use were major considerations in developing DTREES. Alternatives developed by DTREES can be input into a regional or forest-wide planning model or evaluated independently stand by stand in terms of their contribution to financial, wildlife, recreation, and conservation objectives. Based on the results of either type of analysis, modifications can be made in DTREES in terms of the criteria used to develop the prescriptions and new alternatives can then be generated.

DTREES provides a complete history of management actions, harvest and residual volumes for each alternative over the planning horizon. It accomplishes this by integrating a silvicultural decision system, a growth simulator, and regeneration routines. For each stand-alternative a decision system evaluates current conditions and generates harvest prescriptions, which are then simulated by removal of trees from an abbreviated tree list, i.e., a sample of representative trees in a stand. Residual trees for each alternative are projected to the next planning period; any stand-alternative that undergoes final harvest is regenerated and a new stand tree list is generated. For each planning period this sequence is repeated until the planning horizon is reached.

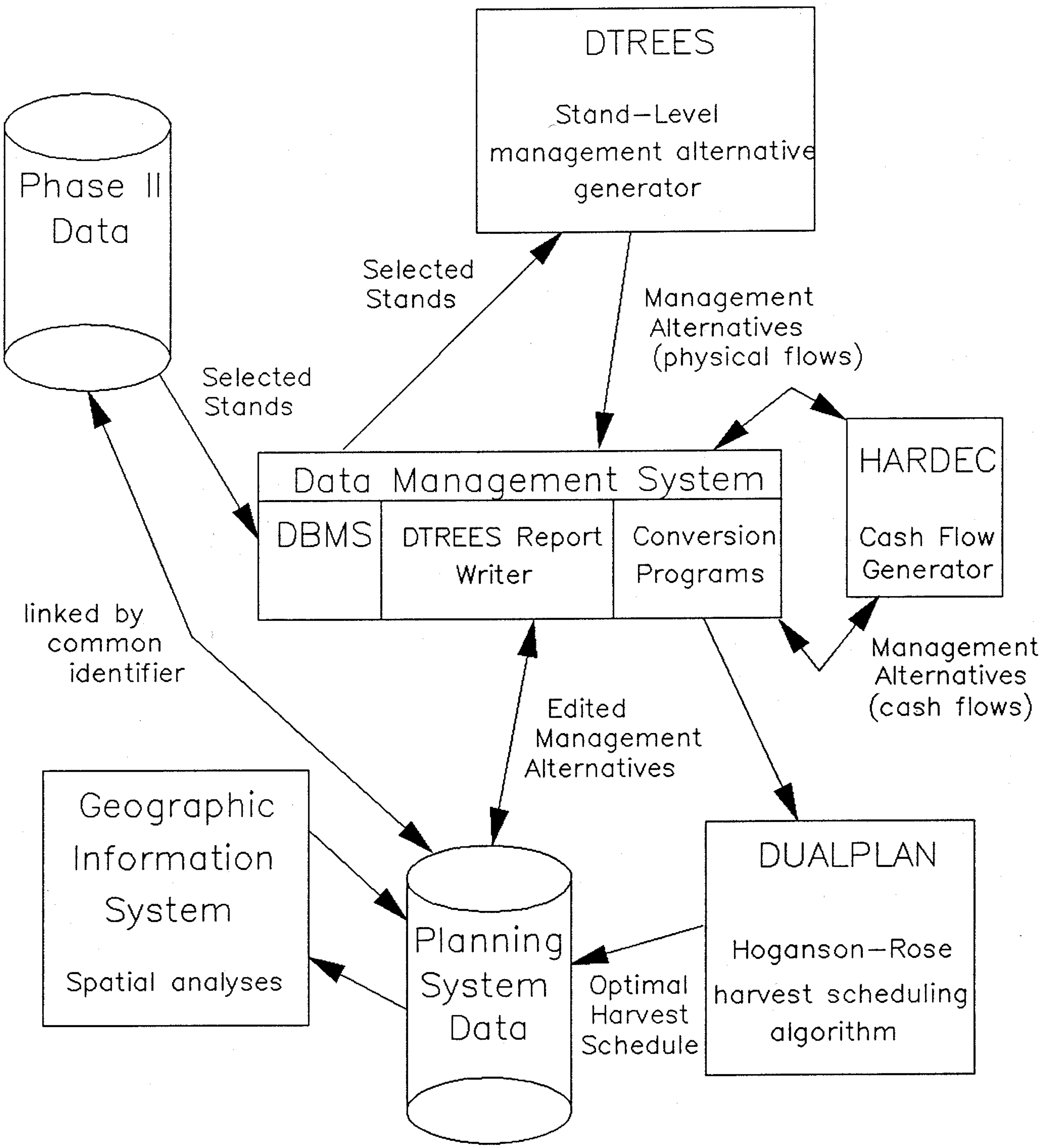

Figure 1. Principal Components of Forest Planning System

DTREES is a menu driven stand-level prescription writer. Silvicultural decision trees (Brand 1981a) are at the heart of DTREES. The decision trees are derived from silvicultural handbooks for Lake States cover types. These decision trees are used in such a manner that various feasible prescriptions are obtained for a stand at each point in the planning horizon. The stands are modelled through time using the GROW subroutine (Brand 1981b) from the STEMS growth simulator (Belcher, et al. 1982). Coefficient data sets are available for the Northeast and Southeast regions of the US, and as upgrades and improvements on GROW are made, the modular approach will make the transition to the latest model quite simple.

The difficulty in modelling regeneration is reflected in the fact that tree-level regeneration models are non-existent or few in number in the Lake States. Aspen and red pine regeneration models are currently the only tree-level regeneration models available (Ek and Brodie 1974; Belli 1986). The regeneration of stands in **DTREES** is, therefore, accomplished by empirical regeneration lists derived from permanent plots in the Lake States. Because the stand data are associated with a tree list, the growth response and the level of silvicultural detail are well described. DTREES takes advantage of the fact that no data aggregation is required, and processes each stand individually, projecting each stand's response to a harvest activity as it occurs. Also, planners need not worry about the possibility of aggregating across some important timber class or spatial identities.

Two methods are available for altering prescriptions generated by DTREES. One method is through the DTREES expert system itself. By changing the critical parameters through which silvicultural decisions are produced, the prescriptions will be altered when the stand data is re-run through DTREES. Another, method is with the Prescription Editor/Report Generator. This system will allow the user to eliminate prescriptions and to generate their own prescriptions for stands directly.

DERIVING ECONOMIC CASHFLOWS

Silvicultural alternatives, generated by DTREES, need to be translated into economic cashflows that reflect the underlying costs of carrying out activities such as site preparation, planting, thinning, harvesting, and transport. This translation is accomplished with a user-friendly program called HarDec. HarDec was created to compare harvesting systems to silvicultural prescriptions, obtain wood product volumes, determine harvesting costs, and calculate transportation costs. The program was designed to be user friendly and to provide maximum flexibility through extensive use of matrices. The size of the matrices is defined by the user and the data that will populate the matrices can be determined through any means available to the user.

DUALPLAN: A MODEL FOR FOREST-WIDE PLANNING

Data aggregation is certainly one of the most pressing problems facing linear programming (LP) based forest planning models. The H-R timber scheduling algorithm helps solve the problem of data aggregation by drastically reducing computational time. This algorithm has received positive reviews (Davis and Johnson 1987). DUALPLAN is a microcomputer version of this algorithm.

The H-R algorithm takes advantage of several characteristics of the forest management scheduling problem. The algorithm capitalizes on the structure of the general LP formulation of timber management scheduling models. These models generally contain an enormous number of variables and constraints that describe the stand-level conditions and management options. These variables and constraints are tied together by relatively few forest-wide constraints. In terms of the equivalent dual problem, the forest-wide problem is tied together by the few dual variables that correspond to the forest-wide constraints. If the values of these key dual variables were known, then the forest-wide problem could be decomposed and solved in parts where the dual variables are nothing more than input and output price adjustments to recognize the impact of stand-level actions on the constraints that describe forest-wide concerns. With the values for the key dual variables known, the optimal stand-level prescriptions can be determined by comparing alternatives using cash-flow analyses. These would include measures of the benefits and costs of forest-wide impacts using the values of the key dual variables as unit prices for their corresponding input or output and time period. Essentially the H-R algorithm takes estimates of the key dual variables, solves the problem based on those estimates, and then uses the results to reestimate the values of the key dual variables. This process is repeated until the correct values for the key dual variables are found.

A key to the H-R algorithm is the economic interpretation of the key dual variables. For the problem in which the objective is to minimize the costs of achieving a set of desired output levels over time, each key dual variable represents the marginal cost of production for the corresponding product and period. One usually has some idea as to the approximate cost of timber production at the margin. Also and more important, is the relationship that must exist for the marginal costs of timber production over time. Obviously with the options available to shift rotation lengths for most stands, it is hard to imagine a case in which there could be large shifts in marginal costs between periods unless there were also enormous differences in output levels over time. And not only are serial relationships likely between the marginal costs for specific products, but it is fairly easy to estimate how output levels would change as changes are made in the marginal cost of production. This is easily understood when one considers the dual formulation of the problem and the pricing mechanism used to value and select alternatives; For example, raising marginal cost (price) estimates would likely make it profitable to produce timber on more stands or manage some stands more intensively and thus the timber output, for the forest, in general, would increase. Also for example, if one wanted to shift output from period 2 to period 3, this could likely be accomplished simply by raising the marginal cost estimate (price) in period 3 relative to the same estimate for period 2 to make it beneficial to delay harvest until period 3 for more stands. The H-R algorithm uses such simple concepts to search for the appropriate values for the key dual variables.

To help simplify the process and stop the solution process, the algorithm is also based on the fact that forest-wide constraints are difficult to specify and, from a practical standpoint, are likely to have some tolerance limit. For example, if one were to formulate an LP formulation to require 500 units to be produced in every period, it is likely that an optimal solution for the formulation that produced 500 units plus or minus some tolerance limit -- say 5 units -- would also be an acceptable solution. Compared to standard LP approaches this is intuitively appealing; standard LP approaches maintain primal feasibility throughout the solution process; this requirement significantly limits the degree by which solutions can change on successive iterations of the solution process (even inequality constraints aimed at introducing tolerance limits are converted to equality constraints using slack and surplus variables). In contrast, the H-R algorithm maintains dual feasibility, the conditions for optimality, and simply searches for a solution that is close enough to primal feasibility, close enough to a problem formulation that adequately describes the problem.

A desirable characteristic of the H-R algorithm is its ability to utilize intermediate model results. Valuing ending inventory is a good example. Methods for describing ending inventory considerations are fairly difficult with standard LP approaches; it is difficult to estimate values for ending inventories and ending volume or acreage constraints can be both limiting and rather arbitrary. With the H-R algorithm, the values for ending inventories can be based on the values of the key dual variables; as these values change in the solution process, the value of ending inventories can also change. In other words, ending inventory values can be based on what is learned about the problem during the solution process. The concept of learning during the solution process has the potential to be incorporated into other aspects of the modelling process as well. Some of these opportunities are currently being explored.

The potential limitations of the H-R algorithm seem to be its need to consider a large number of management units, its inability to model nontimber constraints, and the number of forest-wide constraints that it can incorporate and still operate efficiently. The number of management units required by the model depends on the tolerance limits allowed in the constraints.

Limitations due to nontimber forest-wide constraints are much less understood. Nothing in the algorithm itself limits the recognition of nontimber inputs or outputs. The key must be whether relationships in the dual variables for nontimber products are similar to those of timber products. Test cases have not been made, but our general belief is that nontimber outputs should not cause significant problems because they are still tied directly to the forest and the relatively slow process by which it changes.

Limitations due to the potential number of forest-wide constraints are also difficult to judge because of the limited experience with the algorithm. Undoubtedly the difficulty of handling forest-wide constraints will vary between cases. The greatest complicating factor is the degree to which forest inputs and outputs are interdependent; problems with joint production options involving mixed stands and product substitution are undoubtedly likely to reduce the efficiency of the algorithm as more products are recognized. On the other hand, situations in which the production processes are not tied directly are likely to allow one to recognize constraints for a significant number of production inputs or outputs without causing significant reductions in efficiency. To date, most applications have recognized three product types with constraints over ten ten-year planning periods with significant interactions between products. For individual product types distinctions can be made for different products within a "product type" by assuming fixed value relationships for the different subcomponents; for example, species A pulpwood might be assumed to be worth $5 more per cord than species B. Most applications have required less than 50 iterations to satisfy constraint levels to within approximately 2 to 3 percent deviations.

DUALPLAN uses the QuickBASIC language and is interactive to allow users to graphically examine intermediate results and adjust most model parameters. Processing time has been extremely fast on an IBM PS/2 Model 60 computer. In a simple test using the standard run options in QuickBASIC, approximately 25,000 stands with two simple alternatives per stand were processed per minute. For DUALPLAN, stand-level information is stored in a series of small binary files to speed input and output and still allow for easy data editing and stand level analysis.

A significant aspect of DUALPLAN and this modelling approach is the shift in emphasis away from "the schedule" developed for a specific set of assumptions with the shift towards the key dual variables (marginal costs of production) for a specific model formulation. This shift should be very helpful in planning as most economists would agree that the marginal costs of production are key factors to consider in strategic forest planning. With linear programming methods there is a tendency for these key model results to become lost in the large amount of output. The key to model use in planning is the ability and ease in which the model can be used to help the decision-maker gain a better understanding of the problem. A significant advantage of DUALPLAN is that stands are entered into the model as individual planning units, not as a portion of aggregates of various site and age classes. This level of detail produces a solution that is not only a strategic plan, but could also be used directly as an operational plan.

REPORT WRITER AND PRESCRIPTION EDITOR

The prescription editor can be used to manually edit, delete or add stand prescriptions for any stand. This component allows the user to easily adjust, eliminate or add prescriptions as necessary, without re-entering DTREES. The report writer will take input from either DTREES or DUALPLAN (and eventually from the GIS) and convert the large data files into management reports. Because both DTREES and DUALPLAN can be stand-level modelling programs, they can produce large amounts of data for a planning area. The report writer summarizes the stand-level data and will produce a variety of reports. Thus, the user will not have to manually interpret a large, often obtuse data file. Rather, after running DTREES and/or DUALPLAN, the user can concentrate on reviewing and interpreting the results.

FUTURE MODEL EXPANSIONS

Geographic Information System

A GIS can serve in both input and output of the overall system. In the input phase, the GIS can perform spatial analysis on the study area and store results for each stand. Stand attribute data can be overlaid and recombined to create useful information alone or for use in the overall system. In the output phase, any of the data generated from spatial analysis, economic evaluation, DTREES or DUALPLAN can be shown alone or in combinations as output of the GIS. This may include maps of marginal cost zones, optimal silvicultural prescriptions, stands scheduled for harvest over time, and road haul distances. The outputs can help identify problems and adjust inputs to more adequately model the problem.

Currently, Tydak's SPANS program is in use as the system's GIS. This raster based system efficiently stores data in the quad-tree format. There are advantages as well as disadvantages to both raster and vector based systems. To increase flexibility of the GIS module, and thus the overall system, incorporation of both types is our goal. PC ARC/INFO is being studied as the possible vector based system, due to its widespread use, ability to store topological relationships, and the availability of a networking module (useful for road system and other line data analysis). If the promised vector extension to SPANS becomes available, the integrated SPANS package may provide the greatest capabilities and fewest problems.

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