USING A DECISION SUPPORT SYSTEM TO IMPLEMENT ECOSYSTEM MANAGEMENT ON THE MENOMINEE FOREST: FROM THEORY TO APPLICATION

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ABSTRACT.—A hierarchical planning model was developed based on the needs of managers of the Menominee Tribal Forest in Wisconsin. The model utilizes a non-integer Model I goal programming formulation at the strategic level, and an integer Model II goal programming formulation at the tactical planning level. The strategic model is used first, to set general management direction for 150 years or more. The tactical model is then used to schedule compartment treatments in the first 10-15 years based upon the strategic results. The major use of the model is in planning cover type and age class diversity restoration based on ecological and production considerations.

INTRODUCTION

The forest management approach used by the Menominee tribe of Wisconsin (Landis 1992; Burgess 1996) provides a unique environment within which to explore analytical methodologies to support ecosystem management planning. The Menominee forest is comprised of approximately 205,000 operable acres in over 10,000 stands composed of 13 management cover types on 11 habitat types, as classified by Kotar and Burger (1988).

In our experience, the forest inventory and silvicultural practices used at the Menominee forest are as good as or better than any forestry organization anywhere. The knowledge and data upon which Menominee forest planning is based result from an exceptionally long-term and comprehensive view of their forest from the combined social, ecological, and commercial point of view. Menominee managers recognize the need for long-term planning as a basis for guiding their near-term operations, using a planning horizon of 150 or more years and a "seventh generation" philosophy. This philosophy is interpreted such that all actions taken by current managers must be evaluated in terms of their effects on the seventh generation of their descendants. The Menominee also recognize the link between ecological and economic sustainability, and base a significant aspect of their economic future on the ecological future of their forest.

This philosophy is the basis of the design of the planning model, TEAMS/M, which we have built to support Menominee forest management planning. The TEAMS/M model was developed based upon requirements specified by Menominee forest managers, after those managers came to the conclusion that existing forest management planning tools were unsuited to their unique requirements. TEAMS/M is in operational use, and has proven useful to Menominee managers in devising strategies for achieving their management objectives. The TEAMS/M model is a direct evolutionary outcome of the principles established and demonstrated in previous versions of TEAMS (Covington et al. 1988; Covington and Wood 1991; Wood and Covington 1991).

Briefly, the model is based upon the assumption that the Menominee forest is in key respects a management-driven system, and that the current and future forest results from the management activities humans have and will impose on it. The legacy forest (Covington and Wood, 1991) is the forest left to future generations as the result of

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management actions, and the Menominee look seven generations into the future. In designing a legacy forest, it is useful to ask the question “What forest conditions would we have liked to have inherited from forest managers of the past?”, and use that as a reference point in thinking about what we should leave for the future. Because the management objectives of tribal managers may change over time, either in response to changes in the forest or to evolving ecological knowledge or desires of the Menominee people, TEAMS/M has features which allow for great flexibility in redefining management strategies or objectives over time. The Menominee forest was certified as sustainably managed by Scientific Certification Systems and Smart Wood in 1992. These certifications document the fact that the wood products sold by Menominee Tribal Enterprises are produced in a socially and ecologically sustainable fashion, allowing the tribe preferential access to many markets.

MODEL DESIGN

The TEAMS/M model consists of 2 linked goal programming matrix generators, which generate tableaus in standard MPS format which are solved using commercial mathematical programming software. The first matrix generator, which addresses strategic-level (e.g., landscape-level, multiple rotation) planning, builds management formulations using non-integer goal programming and Model II (Johnson and Schuerman 1977) design. The second matrix generator schedules, on a yearly basis, the activities determined for the first planning period by the strategic model to set the path towards achievement of the legacy forest objectives, and uses a mixed-integer goal programming formulation and Model I (ibid.) design. Results from both models are incorporated into the Menominee Tribal Enterprises management information system (MIS) for use in evaluating alternative management options.

Both matrix generators construct management science formulations dynamically from user-defined management strata and a set of management objective and constraint parameters provided from the Menominee MIS. The strategic model is used first, to set long-term management direction for the forest, while the tactical model is subsequently used to allocate the first period management activities to compartments or landscape units. Decisions with respect to snag recruitment or retention, preservation of wildlife trees, and other site-specific ecological management issues are made as a part of operational planning, and is beyond the scope of the TEAMS/M model. It is our view that such tree-by-tree decisions are best made on the ground by well-trained ecosystem management professionals, and that a model can never equal the judgment of a professional looking at the situation on the ground.

The evolution of forest attributes or conditions over time is tracked via accounting variables in the management science formulations. TEAMS/M does not include a conventional biological or ecological simulation model (e.g., there are no regression-based growth estimators), but the model does track the evolution of gross structural characteristics (such as cover type area by habitat type, age class distribution by cover type, and area harvested by period) under alternative management policies over long periods of time.

To maximize the adaptability of TEAMS/M to different management situations, a fundamental element of the design of TEAMS/M is that it is stratum-based, and that the strata are dynamically developed outside of the model. This allows any management problem which can be represented by even- or all-aged management strata based upon cover types and habitat types to be modeled. The definitions of cover types, habitat types, and age classes are set by the user, and can therefore be used to represent a wide range of possible management problems. A self-scaling/self-adjusting software design, object-oriented programming techniques, and an analytical approach which allows for representation of complex management relationships in simplified form were used in the development of the model.

DEFINITION OF INPUT STRATA

TEAMS/M is a stratum-based model. The model is driven by the Menominee management information system, which summarizes stand-level inventory, continuous forest inventory information, geographic information, and a silvicultural prescriptions database into management strata and treatment options for use by the model. For purposes of preparing a data stratum for use in TEAMS/M, all stands within the same landscape unit which are of the same cover type on the same habitat type with the same set of management options, regardless of their current structure, are combined into a single data stratum. The even-aged areas within the stratum are classified according to age, while the all-aged areas of the stratum are assigned to an all-aged category. A maximum of 25 age classes are allowed, and they may be of any length up to 25 years each, but all age classes must be the same length. This gives the model the capability of representing even-aged cover types up to a maximum of (25 * 25 =) 625 years in age.

Four basic management options are possible for each stratum: natural conversion to another cover type (e.g., an overstory removal which allows natural regeneration/conversion to another species), forced conversion to another cover type (e.g., clearcutting followed by planting), and regeneration of the same cover type using either even-aged or all-aged management. Because habitat types and cover types are defined by the user through a control file, and the user has control over this definition, it is possible to define habitat types and cover types in any way meaningful to the user and to the analysis, thus providing great potential flexibility in the application of the model.

STRUCTURE OF THE STRATEGIC PLANNING MODEL

The Menominee have translated their planning problem into the following management objectives:

- achieve long-term regulation of even-aged cover types to maintain a sustainable balance of age classes with appropriate representation of mature age classes
- using a featured species concept, restore and maintain cover type/habitat type associations, emphasizing high value and high productivity timber species
- convert management of each cover type to a preferred system for that type (even- or all-aged) as designated by managers based on ecological and silvicultural considerations
- achieve a balance of cover types within each habitat type and forest-wide
- provide for a sustained steady flow of timber from the forest from both even-aged and all-aged management activities
- limit the personnel and investment required for planting by period

The management indicators used to set goals to achieve these management objectives are as follows:

- legacy area by cover type for the entire forest
- legacy age class distribution for each even-aged cover type for the entire forest
- legacy area by cover type for each habitat type
- area of forced conversion (planting) by period
- area harvested by cover type and in total by period

The strategic model serves to assist in finding an acceptable management solution to the goals established relative to all of these management indicators simultaneously, using a planning horizon of 150 years or more. In the strategic model, evolution of forest structure is modeled by the area of each cover type on each habitat type which is in each age class, or is in all-aged management. Menominee managers have developed optimal, minimum, and maximum harvest ages for each even-aged cover type based upon historical information, ecological knowledge, and production considerations. Stratum decision variables are automatically generated which reflect the possible treatments and timing options for each stratum, according to the set of management options specified for each stratum, the length of the planning horizon, and the minimum and maximum harvest ages for the cover types specified by managers. If the age of a stratum and the rotation ages of the even-aged cover types are sufficiently

short for multiple rotations to be possible within the strategic planning horizon, second and if necessary third entry decision variables are also generated, using a Model II formulation.

The function of the strategic model is to select a mix of treatments which, when applied to age classes of strata at specific times, will satisfy the management goals. The model selects the harvest timing of each management stratum element (e.g., acres of an age class) between the time it reaches minimum and maximum harvest ages, and selects one of the previously identified management options to be applied at that time. The management option selected for each management stratum is limited to the set of options identified by managers. No stratum may be harvested before minimum harvest age, and all strata must be harvested at or before maximum harvest age, but the selection of these ages is left to the discretion of managers and may be easily adjusted as necessary. All-aged strata receive treatments every period.

Based on the timing and treatment selected, the state of the management stratum element with respect to cover types, management regime, and/or age class in the legacy forest is calculated via accounting equations. For example, if each planning period is 10 years, and the planning horizon is 10 periods long (100 years), an area harvested in the first period will be between 90 and 100 years old in the tenth period legacy forest. Constraints restrict the ages at which harvesting occurs, to ensure the total acres harvested of a management stratum in a period does not exceed the total acres of each management stratum (e.g., given possible prior treatments) in that period which are above minimum harvest age. Acres must be treated in the period in which they attain maximum harvest age.

Since the strategic Model II formulation references all activities with respect to outcomes in the legacy forest, the model does not internally track forest structure or species composition in intermediate planning periods, nor does it provide facilities for setting goals with respect to intermediate forest conditions on the path to achieving the legacy forest. Although it is mathematically possible to accomplish this, with a problem of the size and complexity of the Menominee strategic model it would have caused the model to combinatorially expand, potentially to an insoluble size. Instead, reporting facilities outside of the planning model are used to calculate, for each planning period, the forest composition and structure resulting from a given treatment schedule. Since the composition and structure of the forest at the beginning of the management plan are known from inventory information, and the model provides treatment specifications for each treated management stratum by period, intermediate states of the forest may be calculated. By analytically aging the initial inventory and applying the treatments as specified in the model outcomes, the composition and age class structure of the forest in intermediate periods may be calculated for any scenario.

STRUCTURE OF THE TACTICAL PLANNING MODEL

Once an acceptable strategic planning solution is found, the purpose of the tactical planning model is to distribute the activities scheduled for the first planning period across landscape units (compartments in the Menominee case) by year. The Menominee forest is comprised of 109 management compartments, each with a unique composition with respect to habitat type, cover type, and age class distribution. The tactical model serves to equalize the level of activity and harvest from year to year, to coordinate activities with the compartment entry schedule, and to ensure that the activities required to establish the management path towards the legacy forest are actually accomplished.

The tactical model planning horizon is the same as one strategic planning period: up to 25 years. The tactical model functions via extraction of the first period treatment specifications from the strategic planning results, development of compartment-level timing options to accomplish the specified strata treatments, and selection from among the set of compartment-level timing options via mixed-integer goal programming, using a Model I design. The compartment-level timing options are generated automatically, and define packages of possible compartment entries within the first planning period.

First, the model allocates treatments across the compartments proportional to the amount of each stratum to be treated which is present in each compartment, in the case of treatments to even-aged strata using an “oldest first”

rule. This rule causes the model to first work through all compartments, selecting the oldest acres of the target stratum, then working through the compartments again selecting the second oldest, then the third, etc., until the total acres selected are equal to the acres which must be treated according to the specifications from the strategic model. Thus, compartments which have a disproportionate share of the older age classes will have a disproportionate share of the allocated treatments. Age classes which will only be partially treated, as well as the all-aged treatments, are allocated proportionally based on the amount of each stratum of the appropriate structure which is present in each compartment.

Timing options are then generated for each compartment which represent all possible combinations of initial entry years and frequency of entries given the parameters for each compartment specified by Menominee managers. The targeted stratum treatments for even-aged strata are equally distributed between entry years for each timing option, while the treatment of all-aged strata may be either distributed across entries or done in only one of the entries, depending on preferences expressed by managers. The number of entries per compartment within the period can also be set individually for each compartment, allowing particularly large or small compartments to be treated in either a single or multiple entries within the period. The year of last entry into the compartment may be specified as well, preventing the generation of timing options which would violate adjacency/greenup restrictions. Like rules applied to many similar forests (e.g., USDA Forest Service lands), Menominee policy imposes an adjacency/greenup requirement which specifies a minimum of 3 years between treatment of adjacent areas to limit the size and frequency of disturbances and their impacts on soil, vegetation, and wildlife, and to allow for some recovery between entries. Since specific harvest blocks are not mapped in our approach, the compartment-level timing options are automatically developed such that no compartment is entered more frequently than the length of the greenup requirement period, ensuring that harvests in adjacent areas cannot occur at intervals shorter than the greenup requirement.

Each timing option variable represents a “package” of stratum treatments applied in particular years which, taken together, accomplish the treatment targets specified for all of the strata within that compartment for the first planning period. The first period stratum treatments specified by the strategic planning model are automatically installed as the goal targets for the tactical model, becoming the right-hand sides of the corresponding goal equations. The tactical model then selects, via mixed integer goal programming, a treatment package for each compartment. When combined with the timing options assigned to the other compartments, the tactical model seeks to achieve the first period treatment targets while distributing activities and harvests relatively equally between years within the first planning period.

Hierarchical approaches which ignore spatial location at the strategic level may over-estimate harvest levels which may actually be achieved operationally. Underachievement is the result of site-specific operational restrictions (e.g., minimum or maximum treatment block sizes, previous harvesting patterns, adjacency/timing restrictions, etc.) which are not recognized in the strategic model. In the near-term, this is addressed via feedback between the tactical and strategic models. The strategic model allows for treatment prescriptions to be imposed for any planning period (e.g., requiring that a given amount of a specific treatment be applied to a particular cover type on a particular habitat type in a particular compartment in a particular period). Using this facility, the treatments achieved operationally may be installed as constraints in the strategic model. The model is then re-run to assess the effects of the actual treatments on the strategic plan and the legacy forest, and to determine what other compensating adjustments may be necessary.

ADJUSTMENT OF TARGETS AND GOAL/LIMIT PENALTY WEIGHTS

The major difference between goal programming and linear programming is the structure of the objective function (Field 1973). In goal programming, the objective function is structured to minimize the total penalties associated with deviation from the goal levels established for the management indicators. Two major sets of inputs are required from the user. The first of these is the specification of goal levels for each management indicator. In TEAMS/M, the goals are set by the user based upon an external decision process which defines desirable legacy forest conditions. This follows the same general notion as Field (1973) and Arp and Lavigne (1982), who rely on

the analyst and the planning process to determine what the target levels should be based on judgment and intuition. It is possible, of course, that target levels chosen in this fashion may be less than the target levels which could actually be achieved without cost to some other objective, yielding a dominated or interior solution (Dyer et al. 1979).

The second major input required from the user is the specification of the penalty weights associated with each goal. Penalty weights express the relative importance of individual goals with respect to each other, and to compensate for resources measured in different units or which assume greatly different values. Zeleny (1982) suggests an approach using a cardinal-weighting system where the value of the penalty weights required to achieve a satisfactory solution have no intrinsic meaning. In our model, it is the achievement of satisfactory characteristics in the final solution which is important, rather than the value of the penalty weights required to achieve it. This is the approach which has been followed in TEAMS/M, as we concluded that manual adjustment of penalty weights to achieve a desired legacy forest "mix" and compliance levels with the other goals was acceptable. This approach has been shown in operational use to provide management solutions acceptable to managers.

Many of these goals utilize two sets of underachievement and/or overachievement variables to construct a "stepped" penalty function for deviations from the specified targets, in a fashion similar to that used by Bell (1976). These operate such that an initial level of penalty is assessed for deviations from the target goals up to a certain level of deviation (the over- and/or underachievement penalties), and then a higher level of penalty is assessed for deviations beyond this level (the upper and/or lower limit penalties). This structure serves to allow the user to restrict deviations from the goal targets more tightly if they exceed an acceptable range.

It is of course possible that without sophisticated post-optimality analysis and goal ranging techniques, a dominated or interior solution may be produced and accepted as a management plan. If used in a rigid, one-pass planning process without significant exploration of alternative scenarios or targets, the model could result in a misleadingly narrow view of potential strategies and achievable outcomes. If used as designed, to explore a range of possible legacy forest scenarios in an ongoing iterative process of management design, the risk of adopting a suboptimal strategy is greatly reduced, as the management team gains a comprehensive understanding of the problems and opportunities. This latter approach has been the case in the Menominee use of TEAMS/M.

CONCLUSIONS

We decided upon an approach which will quickly and efficiently generate many "good" solutions, rather than building a model which after lengthy analysis would produce one "perfect" solution. That perfect solution would, in any case, never likely be actually implemented exactly as specified (Daugherty, 1991). The planning environment is constantly changing, as new issues emerge and new knowledge is acquired, and combined with the unpredictable nature of disturbance processes in forests this makes for a very dynamic planning environment. TEAMS/M can provide a new set of strategic and tactical planning solutions for a forest of the size and complexity of the Menominee forest in a few hours, and this can be accomplished by local managers without requiring the support of highly skilled operations research specialists. In our view, having a real-time planning tool which can be used to continuously update management plans at the landscape level, explore new options, and translate these plans into operational guidelines at the landscape unit level far outweighs the risk that any of these individual plans will be suboptimal. A socially acceptable solution need not necessarily be economically optimal, particularly if the solution achieves important social or ecological objectives.

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