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MODELS FOR ENHANCING THE PLANNING CAPABILITY OF THE NATIONAL FOREST SYSTEM[1]

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ABSTRACT.--Describes three approaches which have the potential for improving the analytical capability of the U.S.D.A. Forest Service, vis a vis the preparation of multi-resource plans for the National Forests. The first--Modelling to Generate Alternatives (MGA) -- is designed to generate distinctly different and satisfactory solutions to planning problems. The second -- de Novo programming -- operates under a "soft optimization" environment where constraint limitations are viewed as flexible and not predetermined or fixed as in traditional mathematical programming. The third -- Computer Assisted Analysis (CAA) -- is a new tool applicable to general model management, particularly for large scale linear programming systems like FORPLAN.

Forest planning on the National Forests as mandated by the National Forest Management Act of 1976 (NFMA) is a complex task requiring many varied analyses. The U.S.D.A. Forest Service, in its attempt to implement NFMA, has developed and is currently implementing a planning model called FORest PLANning (FORPLAN). FORPLAN is a large scale linear programming (LP) model developed since the passage of the NFMA to provide an analytical structure that portrays the multiple-use interaction and management alternatives for a National Forest (Johnson, 1986).

Despite its reported success and acceptability by some National Forests, some concerns have been raised about the adequacy and suitability of FORPLAN as a planning tool for the National Forest Planning System (Bare and Field, 1987; Iverson and Alston, 1986; Alston and Iverson, 1987). These concerns also have been raised by people involved directly or indirectly in the development, analysis and evaluation of the model itself, as evidenced by the two national workshops held in 1986 (U.S.D.A., 1986,1987). Nevertheless, in spite of its reported limitations, FORPLAN has been institutionalized and is expected to remain as the primary analytical tool for National Forest planning.

The purpose of this paper is to examine other modelling approaches that address some of the limitations of FORPLAN. These approaches have some desirable characteristics that can enhance the existing planning capabilities of FORPLAN. Further, they have general application and can be used to help guide management decisions at the individual stand level or on a forest with a much smaller area or scope than a National Forest.

Before presenting these alternate planning models, a brief review of the major criticisms of FORPLAN is in order. A more lengthy review is available in Bare et al. (1987). First, FORPLAN was originally too closely aligned with the functional interests of timber management. Although later corrected, this bias certainly did not foster early acceptance of the model. Second, the model is very large and does not lead to the generation of spatially feasible schedules and plans. Third, it has never been made clear whether the model produces answers or is seeking insights; whether it is an accounting or analysis tool; whether it

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operates at the strategic, tactical or operational level of management; or whether it is an optimizing or satisficing tool. Fourth, by focusing on the production of a simultaneous land allocation and resource output schedule, FORPLAN has ignored the advantages inherent in a more hierarchically-based approach to planning. While none of the approaches discussed below addresses all of these criticisms, they do provide additional capability not now found in FORPLAN.

APPROACH I: MODELLING TO GENERATE ALTERNATIVES

Models have been considered as potentially useful tools in the planning and decision making processes. Specifically, mathematical optimization and simulation models have been used in various forest management applications (Bare et al., 1984). However, concerns have been raised about the capability and suitability of using mathematical models particularly under complex decision environments (Brill, 1979; Liebmann, 1976). In forest planning, for instance, Allen and Gould (1986) have described public forests as complex and wicked systems which cannot be successfully optimized by choosing the rationally "best" solution.

Modelling to Generate Alternatives (MGA) has been proposed as a decision making framework for dealing with complex problems where there may be "unmodelled" issues, or other aspects of the problem which are inherently qualitative and hence cannot be adequately included in a mathematical model. The basic philosophy of this approach is "to generate alternative solutions" rather than to "optimize" as is the case in most conventional mathematical models.

MGA is a general approach for generating alternative solutions that are: 1) satisfactory with respect to the objectives (rather than "optimal"), and 2) maximally different with respect to the decision variables. Hence, MGA can be used as a tool in generating solutions that are "satisfactory" with respect to the "modelled" objectives, and widely different with respect to the decision variables. Further, some of these alternatives may be better than others with respect to the "unmodelled issues".

The primary motivation underlying MGA is that by generating a sufficient number of distinctly different and satisfactory alternatives, a wider span of the decision space can be searched, providing a wider range of choices for the decision-maker to consider. A multiple-use planning example demonstrating the use of MGA is described by Mendoza et al., (1987).

One MGA method, developed by Brill (1979), is described below:

Step 1. Obtain an initial solution using any method (e.g., maximize one of the objectives)

Step 2. Obtain an alternative solution by solving:

$$\text{Min} \sum_{j=1}^{J} X_j \qquad (1)$$

$$\text{s.t. } Z_k(X) \geq T_k \qquad (2)$$

$$x \in X \qquad (3)$$

where J = set of indices of the basic decision variables in the original solution

T_k = target specified for objective $Z_k(X)$

$x \in X$ = set of feasible solutions

X_j = basic variable j.

The objective function suggests that generated solutions are "maximally" different. That is, if the minimum value of (1) is zero, the generated solution is "completely" different in terms of the set of decision variables which are basic (i.e., nonzero). If the value of (1) is greater than zero, a "less distinct" solution is generated. Mendoza et. al. (1987) describe the difference between solutions (i.e., the "distinctiveness" of generated solutions) with respect to the decision variables, as well as the objectives (including those that may have been unmodelled).

Generating Alternatives under "Fuzzy" Environments

As pointed out earlier, MGA has been proposed as a framework for dealing with complex problems for which there are important unmodelled issues. Looking at the formulation described in (1) - (3), it can be seen that the generation of satisfactory solutions is based on the attainement of a minimum target level specified by T_k. Further, one may point to the fact that these levels are "best estimates" of the minimum satisfactory attainment of the objectives. Moreover, these estimates are single-valued, static and, therefore limit the flexibility and "complexity" of the problem that can be handled by MGA. More importantly, for planning purposes, it may be better to model these estimates as intervals instead of point estimates. One method which can increase the flexibility of the objective targets, as well as the constraints, is the use of Fuzzy Mathematical Programming (FMP).

FMP is a relatively new approach which is designed to accomodate the "fuzziness" of most real world problems. Fuzziness can be in terms of uncertainty, vagueness, ambiguity, or imprecision inherent in defining and parameterizing a mathematical model or relationships within the model (e.g., objective functions and constraints). FMP has evolved primarily because of the well-recognized "rigidness" and inflexibility of conventional and traditional mathematical models. Since its inception 20 years ago, it has developed rapidly as evidenced by the rich literature currently available (Zimmermann, 1985).

The FMP approach of MGA as formulated in (1) - (3) may be briefly described as follows:

Find a solution X, such that;

$$Z_k(X) \gtrsim T_k; \text{for some or all objectives} \quad (4)$$

$$\Sigma a_{ij} X_j \lesssim b_i; \text{ for fuzzy constraints} \quad (5)$$

$$\Sigma a_{ij} X_j \leq b_i; \text{ for "nonfuzzy" const.} \quad (6)$$

The relation in (4) is the "fuzzy formulation" equivalent of the objectives as previously described in (2). Note that the formulation takes on a different meaning or interpretation. In (2), the objectives are expressed as "strictly greater than or equal to" inequalities. In (4), the symbol "$\gtrsim$" indicates a more flexible interpretation which can be linguistically expressed as; "about, approximately, or should not be considerably different from." The relation in (5) is likewise fuzzy or vague in the sense that "$\lesssim$" might not be meant in the strictly mathematical sense but rather small violations might be acceptable. Hence, b_i in (5) can be interpreted as aspiration levels instead of strict bounds as in (6). Solution methodologies available and being developed for the formulation expressed in (4) - (6), work by 1) formulating a "crisp" mathematical form so that conventional programming procedures can be used (e.g., MAXMIN approach), or 2) treating the problem as strictly fuzzy so that "fuzzy decisions" may be generated.

Using the above definitions, the MGA objective can be fuzzified by adding the relation below:

$$\Sigma X_j \lesssim Z_u \quad (7)$$

where Z_u is a "fuzzy surrogate measure of difference". Hence, (7) allows the generation of "widely different solutions" instead of "maximally different solutions" as in (1).

APPROACH II. dE NOVO PROGRAMMING

MGA, as described in the previous section is suitable for planning under complex environments. Its philosophy is to generate distinct and satisfactory alternatives for the decision maker to consider. Operating under the general umbrella of "soft optimization" (Zeleny, 1986), de Novo programming offers a slightly different approach. This approach recognizes the fact that not all constraints are really hard in the sense that they are "fixed". Some constraints can be considered "soft" and hence are flexible, can be changed, adjusted or designed. Therefore, the basic philosophy of de Novo programming is not to "optimize a given system" but rather to "design an optimal system". As Zeleny (1986) indicates, planning under de Novo programming operates under the philisophy of "If it ain't broke, improve it", not "If it ain't broke, don't fix it."

De Novo programming addresses an entire range of LP problems: 1) all constraints are "soft" and are to be designed, 2) all constraints are "hard" and are to be taken as "given" (i.e. traditional LP formulation), or 3) some constraints are treated as soft while others are hard. A brief description of this approach is given below.

Consider a standard linear programming formulation:

$$\text{Max } Z = \Sigma C_j X_j \quad (8)$$

$$\text{s.t. } \Sigma a_{ij} X_j \leq b_i; \; i = 1, \ldots, m \quad (9)$$

$$X_j \geq 0 \quad j = 1, \ldots, n$$

If we allow b_i to become variable (i.e., soft instead of hard), then an alternate formulation is:

$$\text{Max } Z = \Sigma C_j X_j$$

$$\text{s.t. } \Sigma a_{ij} X_j - b_i \leq 0 \quad (10)$$

$$\Sigma p_i b_i \leq B \quad (11)$$

$$X_j \geq 0$$

where p_i is a "design attribute" (e.g., price/cost of resource b_i) and B is a "design criterion (e.g., budget).

De Novo programming requires solving a series of LP problems where one "hard" constraint is appended at each iteration. For this reason, the solution algorithm is sometimes referred to as the External Reconstruction Algorithm (ERA) by Zeleny (1986). ERA is based on the simple philosophy that since only "active" constraints determine the optimal LP solution, there is no need to work initially with "all" constraints. Only "active" constraints are considered and added at each iteration. This solution approach plays a significant role in de Novo programming because "soft" and "hard" constraints can be conveniently handled. Bare and Mendoza (1987) describe an application of this approach in forest land management planning.

FORPLAN Enhancements

Both MGA and de Novo programming offer perspectives which could lead to the enhancement of the FORPLAN system, and both could be incorporated within FORPLAN with minimal cost and effort. Clearly, MGA would result in even more computer runs for the typical National Forest, but the benefits would be reflected in the analysis of a wider array of planning alternatives. Further, the "unmodelled" aspects of forest planning have a better chance of being addressed than under the present approach to planning. De Novo programming would require the Forest Service to design constraint levels now viewed as fixed. This could ultimately lead to more efficient management, but it might open the Agency to additional pressures from the public.

Both approaches promote the notion that FORPLAN is seeking insights and not answers, and that analysis, not accounting, is the primary focus of the planning effort. To the extent that incorporation of MGA and de Novo programming concepts can be accomodated, these would be positive enhancements. Criticisms related to the use of a more hierarchially-based planning system, model size, or lack of spatial relationships would not be addressed by either approach. However, both approaches would be positive steps in terms of moving the Forest Service towards a more adaptive system of management.

APPROACH III: COMPUTER-ASSISTED ANALYSIS

Computer-Assisted Analysis (CAA) is a relatively new, but valuable tool for general model management, particularly for large scale linear programming models like FORPLAN. Such models, by virtue of their size, can become too complex for the analyst to adequately understand the contents and interrelationships inherent in the model. Hence, there is a need for some computer assistance to enable the analyst to conduct and provide better analysis of the complex problem formulated as an LP model. This is the main focus of CAA.

CAA can be useful in a number of ways. In particular, if the LP model contains no feasible solution, then CAA can provide some form of a "traceback" mechanism which may allow the identification of erroneous elements (e.g., coefficient values), or even illogical relationships. That is, CAA can be used to trace infeasibilities in the LP model. The traceback capability can be useful even in the case of a feasible solution, particularly when it seems to provide counter-intuitive results.

For policy makers and/or planners, it may also be necessary to probe deeply into the meaning of a solution. It is often not what the numerical quantities are, but how they are derived that matters. Further, it may be necessary to analyze impacts of a policy comprehensively. This might involve a sensitivity analysis, including a logical "chain effect" which traces the consequence of a given perturbation throughout the system(Greenberg, 1982).

Successful implementation of CAA has been reported in the literature. For instance, in energy modelling, a CAA system called PERUSE (Kurator and O'Neill, 1980) was developed for the large scale linear programming model called Midterm Energy Market Model (MEMM). This system provides an interactive query of the LP matrix and solution values, and is designed to provide computer assistance to modellers/analysts for: debugging, verifying, and analyzing model runs. It has been reported by Kurator and O'Neill (1980) that PERUSE is a powerful and useful tool at the Federal Energy Administration [now Enegy Information Administration (EIA)].

In a subsequent work, Greenberg (1983) developed a system called ANALYZE which built upon the foundation laid by PERUSE. ANALYZE is designed to perform some of the capabilities of CAA, namely: verification, debugging, interpreting results, simplication, and sensitivity analysis.

Implementing FORPLAN with CAA

Modelling efforts leading to the development of FORPLAN have required many years of effort and have succeeded largely through the dedicated efforts of many people. And, the current version of FORPLAN is expected to continue to evolve into a more acceptable, implementable, and manageable model. Further modelling efforts will be useful in refining FORPLAN and enhancing its planning capability.

One aspect which could provide a useful enhancement for FORPLAN is the development of a Computer-Assisted Analysis System. Such a system would be designed to support FORPLAN and could be useful in a number of ways, particularly in the implementation phase of FORPLAN. While draft National Forest Plans are already finalized, it is doubtful that the final plans will remain unchanged throughout the implementation process. And, it can be anticipated that required changes will create the pressure to revise the plan; once again requiring the use of FORPLAN.

In updating/revising FORPLAN, CAA can be useful in a number of ways. First, in view of its traceback capability, it can trace infeasibilities during the revision process. This could save a significant amount of time previously spent in figuring out the sources of infeasibilities for some National Forest plans. CAA can also be useful in tracing a logical "chain effect"; a step often necessary for analyzing policy impacts. This capability in CAA is sometimes referred to as "diagnostic analysis." Moreover, CAA may also assist the analyst/decision maker in "explaining" the plan based on results obtained from FORPLAN. The capability to explain these results and better understand the interrelationships within the model can help create a "positive outlook" from outsiders/interest groups and consequently better acceptance of the revised plan. Finally, CAA can be used as a tool for justifying the changes through better understanding of the intricacies of the FORPLAN model.

SUMMARY

The primary focus of this paper is to briefly describe three alternative approaches to forest planning which, if adopted, could lead to enhancements of the FORPLAN system. Clearly, experience with these systems is much more limited than it is with the traditional linear programming based FORPLAN system. However, it is clear that modifications in FORPLAN are in order if the model is to continue in its dominant role as the primary analytical tool for forest planning. While the adoption of any one of these approaches only partially answers the major criticisms leveled at FORPLAN, they do offer the promise of a more responsive and adaptive planning system for future planning efforts within the Agency.

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