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Brian Kent, B. Bruce Bare, Richard C. Field, Gordon A. Bradley,

OR PRACTICE

NATURAL RESOURCE LAND MANAGEMENT PLANNING USING LARGE-SCALE LINEAR PROGRAMS: THE USDA FOREST SERVICE EXPERIENCE WITH FORPLAN

BRIAN KENT
USDA Forest Service, Fort Collins, Colorado

B. BRUCE BARE
University of Washington, Seattle, Washington

RICHARD C. FIELD
The University of Georgia, Athens, Georgia

GORDON A. BRADLEY
University of Washington, Seattle, Washington

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FORPLAN (FORest PLANning) is a large-scale linear programming system used to support national forest land management planning. It is available in two versions, and is used extensively to help interdisciplinary planning teams develop forest-wide plans as dictated by the National Forest Management Act of 1976. Nine years of experience clearly show that while the system is working in a technical sense, troublesome issues remain. This paper begins with an overview of how USDA Forest Service planning has evolved. We then give mathematical formulations for portions of FORPLAN models and examples of how the system is used to aid planners on national forests. We present an evaluation of the use of FORPLAN that addresses five criteria including, problems associated with large-scale models and systematic, comprehensive planning, Forest Service organizational issues, the role of foresters in national forest management, and conflicts over competing land uses. We then consider lessons for operations research practitioners. Finally, we discuss a number of conclusions and recommendations, the most important being the need for the Forest Service to more clearly specify the role of forest planning in the overall agency planning hierarchy and the role of FORPLAN in forest planning.

The USDA Forest Service is responsible for managing 191 million acres of national forest land which annually produces 12.6 billion board feet of timber; 9.9 million animal unit months of grazing; 242 million visitor days of recreation; 425 million acre-feet of water, and other environmental and aesthetic benefits (USDA 1989). The Forest Service was organized in 1905 and has enjoyed a long and fruitful history of managing the nation's timberlands for a multiplicity of uses. However, throughout history, the agency has been dogged by conflicts over the balancing of resource outputs—something that has intensified in the post-World War II years.

Reacting to judicial findings, public pressures for increased environmental awareness, and growing demands on the resources of the National Forest System, Congress passed the National Forest Management Act (NFMA) in 1976. Among other things, this act, and its associated regulations, direct the Forest Service to prepare integrated land management plans for each of 122 administrative units representing 154 national forests. Final guidelines for implementing the NFMA were published in September 1979 and revised in 1982. Under these regulations, all plans "shall provide for multiple use and sustained yield of goods and services from the National Forest System in a way that maximizes long-term net public benefits in an environmentally sound manner (*Federal Register* 1982).

In December 1979, the Associate Chief of the Forest

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Service designated the Forest Planning Model (FORPLAN) as "the required primary analysis tool" for national forest planning. FORPLAN is a linear programming (LP) system that consists of a matrix generator and a report writer, both of which interface with a commercial mathematical programming solution package (i.e., the Functional Mathematical Programming System developed by the UNISYS Corporation). Personnel from each administrative unit used the FORPLAN system to build a series of large-scale LP models to represent alternative management plans for their unit. As described by Field (1984), "the system is used to construct forest models which simultaneously allocate forest land to general management objectives and schedule the treatments and the resulting product flows."

In this paper, we provide an introduction to the FORPLAN system and an evaluation of how it is used. Our introduction covers the evolution of the planning environment in the Forest Service and the FORPLAN system, the formulation of FORPLAN LP models, and examples of how these models are used by national forest planners and decision makers. Our evaluation focuses on these criteria: 1) analytical and computational problems associated with large-scale LP models, 2) the need for systematic comprehensive planning, 3) organization and management style of the Forest Service, 4) professional beliefs of foresters and their role in national forest management, and 5) conflicts over competing land uses of the national forest system.

While it may seem inappropriate to undertake an exhaustive evaluation of FORPLAN with only nine years of experience, two recent conferences sponsored by the Forest Service have been devoted to this topic (USDA 1986, 1987), and Alston and Iverson (1987) have assessed FORPLAN's strengths and weakness in relation to Timber RAM. The importance and urgency of these evaluations, as well as the present effort, stem from the fact that NFMA requires that all forest plans be redone every ten years. Some national forests completed the "first round" of planning in the early to mid-1980s and are, therefore, within a few years of beginning the exercise again. One can regard the first round of planning as a learning experience. To capitalize on this before the agency enters a replication of what may have been the most expensive ($100 million; Field 1984) and ambitious operations research effort in the civilian sector of the U.S. Government, careful evaluation of the planning regulations and the methodology are in order.

The balance of the paper consists of six sections: a short description of the evolution of the environment for land management planning in the Forest Service and the FORPLAN system; a description of the FORPLAN system and selected aspects of the LP models that can be formulated with it; a sampling of experiences in using FORPLAN to respond to NFMA; the evaluation mentioned above; our observations with regard to lessons for operations research practitioners; and our conclusions and recommendations for the future. In the next three sections, we give enough background information to provide the reader with a basis for understanding the setting for our critique.

1. FOREST SERVICE PLANNING ENVIRONMENT AND EVOLUTION OF THE FORPLAN SYSTEM

1.1. Planning in the Forest Service

The systematic, integrated approach to planning and management, as mandated by the NFMA and its attendant regulations, stands in stark contrast to earlier Forest Service attempts at planning. Prior to the passage of the Multiple Use Sustained Yield Act of 1960, autonomous functional plans developed for the major renewable resources were dominant in agency thinking. With the passage of this act, multiple use planning guides were required to help coordinate these various functional plans. However, these guides never evolved to the point of fully integrating resource planning across the agency. Enactment of the National Environmental Policy Act (NEPA) in 1969 resulted in the Forest Service instituting a new approach to planning whereby interdisciplinary teams developed integrated resource plans for portions of national forests known as planning units (Bradley 1986). While functional planning was de-emphasized in the development of unit plans, its continued presence created confusion and led to implementation problems. Unit planning was discontinued with the arrival of forest-level planning as mandated by the NFMA.

Briefly, the principles enumerated in the final NFMA regulations (*Federal Register* 1982) are to: 1) establish goals and objectives for multiple use and sustained yield management of renewable resources without impairment of the productivity of the land, 2) consider relative values of all renewable resources, 3) recognize that national forests are ecosystems whose management must consider the interrelationships among all resources found therein, 4) protect and, where appropriate, improve the quality of renewable resources, 5) preserve important historic, cultural and natural aspects of our national heritage, 6) protect and preserve the right of American Indians, 7) provide for the safe use and enjoyment of forest resources by the public, 8) protect all forest and rangeland resources from depredations by pests in an ecologically-sound manner, 9) coordinate with local land and resource planning efforts of other federal agencies, state and local governments, and indian tribes, 10) use a systematic, interdisciplinary approach to ensure coordination and integration of planning activities for multiple use management, 11) involve the public early and frequently in all planning efforts, 12) establish quantitative and qualitative standards and guidelines for land and resource planning and management, 13) manage National Forest System lands in a manner that is sensitive to economic efficiency, and 14) be responsive to changing conditions of land and other resources and to changing social and economic demands.

As specified in the regulations, interdisciplinary teams were established for each forest and charged with following a 10-step planning process consisting of: 1) identification of issues, concerns and opportunities, 2) development of planning criteria, 3) inventory data and information collection, 4) analysis of the management situation, 5) formulation of alternatives, 6) estimation of the effects of alternatives, 7) evaluation of alternatives, 8) preferred alternative selection, 9) plan approval, and 10) monitoring and evaluation. Steps 4–7 are accomplished with the aid of the large-scale LPs generated by the FORPLAN system.

The rational planning process endorsed by the NFMA clearly identifies a systematic procedure for conducting land and resource planning (Cortner and Schweitzer 1980). However, the act does not directly address a specific method or technique for balancing the various resource outputs across the National Forest System, nor does it direct planners to identify any particular combination of multiple use outputs. Perhaps, more importantly, the act does not mandate any organizational changes in the agency in order to achieve integrated multiple use planning. Consequently, the Forest Service remains a highly decentralized agency, seeking uniformity and consistency through a common set of planning principles and guidelines. However, individual administrative units are allowed considerable freedom in pursuing their own objectives.

1.2. A Brief History of FORPLAN System Evolution

The genesis and evolution of FORPLAN within the context of the Forest Service planning and environment is available elsewhere (Iverson and Alston 1986). Briefly, FORPLAN is the outgrowth of a series of LP systems developed and used by the Forest Service during the past 20–25 years. Chief among these has been: 1) RCS (Resource Capability System), 2) RAA (Resource Allocation Analysis), 3) Timber RAM (Timber Resource Allocation Method), 4) MUSYC (Multiple Use Sustained Yield Calculation Technique), 5) ADVENT (a system for program budgeting), and 6) IRPM (Integrated Resource Planning Model). These systems, plus others, influenced the development and acceptance of FORPLAN. While none of these systems produced models that did an adequate job of multiresource planning and allocation, the developers of FORPLAN chose to modify MUSYC—an existing timber management scheduling LP system—rather than start from scratch. It became apparent soon after the release and adoption by interdisciplinary teams, that this system, hereafter referred to as Version 1, "had inadequate capability to address forest planning problems in the way they were seen by the analysts and managers of the national forests" (Johnson, Stuart and Crim 1986). One of the major deficiencies was that the system was too closely aligned with the functional interests of timber management within the agency. Other technical problems included: 1) model size, and 2) difficulty in generating spatially feasible schedules (Iverson and Alston). Nevertheless, this system was used by approximately two thirds of the administrative units (Kent, Kelly and Flowers 1987).

Version 2 was developed and released in reaction to these criticisms. This system was a vast improvement over Version 1 and included these major changes: 1) it was functionally neutral, i.e., it did not emphasize one functional interest of the agency over another, 2) it was compatible with Forest Service accounting systems, 3) it provided for different kinds of land organization, data entry and data input conventions, 4) it reduced the opaqueness of input choices, and 5) it provided increased flexibility in problem formulation (Johnson, Stuart and Crim). Version 2 was used initially on approximately one-third of the administrative units of the National Forest System. Administrative units that originally used Version 1 have been converting gradually to Version 2 and approximately one-half are using the later version.

As this brief historical overview illustrates, the Forest Service has considerable confidence in a rational approach to problem solving as implemented in a politically charged environment. Furthermore, the choice of LP as the primary analysis tool illustrates that the agency is interested in an objective-oriented approach where optimum solutions are the focus of the analysis (Johnson 1987).

2. A DESCRIPTION OF THE FORPLAN SYSTEM

2.1. System Overview

Each version of FORPLAN is comprised of a set of a computer programs that serve the following important functions (Figure 1):

1. Edit the user's input data to insure that it contains all the information required to formulate a FORPLAN model.
2. Generate the input data required by the LP solver.
3. Interpret the LP solution in the form of tables, graphs, etc. that can be understood by natural resource professionals not trained in operations research.

The system organization and functions outlined in Figure 1 are typical of most, if not all, LP packages developed

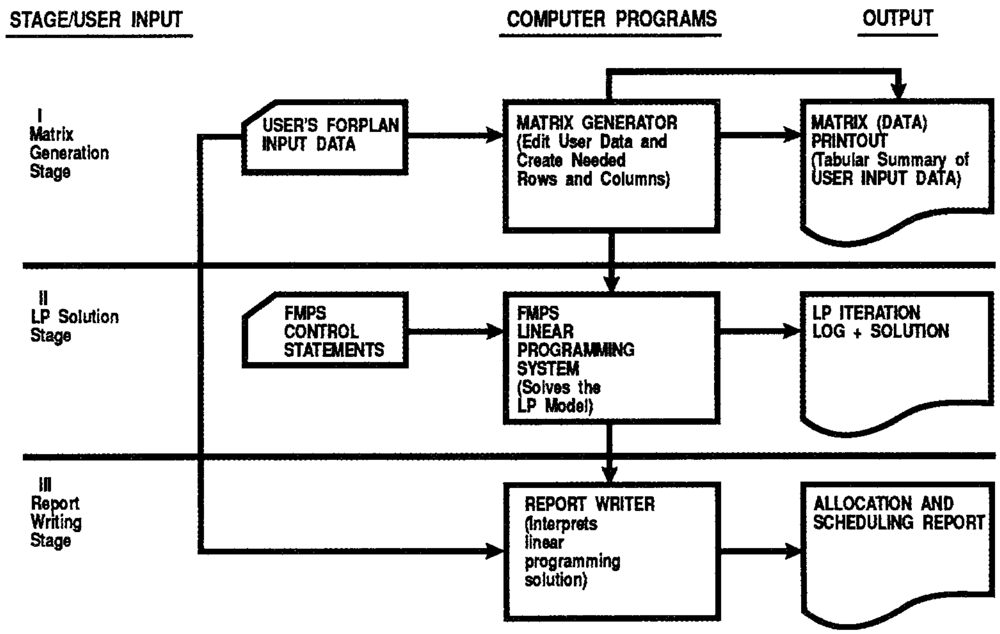

Figure 1. System structure of FORPLAN (FORest PLANning model).

for natural resource management applications. What is different is the complexity of the system being modeled (a national forest) and the planning problems the models are intended to address. Perhaps the most important function of FORPLAN (hereafter, the unqualified term FORPLAN refers to both versions) is to provide a framework for viewing the multiple use planning problem on a national forest. That is, each version offers a menu of alternative LP formulations of this problem.

Version 1 is written in UNISYS-specific FORTRAN V and is not portable. In an effort to rectify this problem, Version 2 is written in ANSI 77 (full standard) FORTRAN and has been converted to run on IBM mainframes and IBM-compatible microcomputers. Because of this, Version 2 is utilized by some universities and other organizations outside the Forest Service.

Version 2 evolved largely as a result of the lessons learned from the use of Version 1. As such, it offers a more diversified menu of formulation options, primarily because of the increased capability to represent resources other than timber. For example, with the exception of a few specialized timber-related costs and returns, the Version 1 user could represent at most 20 costs, returns and outputs in a model. However, the Version 2 user can represent up to 300 of these. In addition, he or she has much greater flexibility in representing output production levels and management practices that actually occur on the ground, and in viewing all the implications of each management choice as it would be represented in the model being formulated. This last item is especially important as one of the main criticisms of Version 1 was its *black box* nature with regard to how input data were actually incorporated in the LP model. More details on these and other options can be found in the two FORPLAN overview documents (Johnson 1986 and Johnson, Stuart and Crim 1986).

2.2. FORPLAN Model Formulation

In addition to choosing which costs, returns and outputs to track, and hence, to be able to constrain and/or report on, the user has to choose how to represent the forest land base and the desired management practices in the model. Examples of such practices include timber harvesting, range improvement projects, wildlife habitat projects and recreation facility maintenance. The user can also choose from a wide range of constraints that may be imposed on virtually anything that is represented in the model. Here, we discuss the basic formulation used to represent the forest land base in a FORPLAN model. We also give examples of constraints that users would typically incorporate in their models. Full details on alternative land formulations and constraint types can be found in Kent, Kelly and King (1985) for Version 1, and Johnson and Stuart (1987) for Version 2.

In all FORPLAN models, the land base is represented as a collection of strata which are called *analysis areas* (Kent, Kelly and Flowers). Analysis areas usually represent groupings of acres that respond in the same or a similar fashion to a given set of management practices. As an example, an analysis area may be comprised of all acres occupied by mature stands of mixed conifer sawtimber. Typically, there will be several hundred of these strata defined (Kent, Kelly and Flowers).

For each analysis area, one or more sets of management practices, known as *prescriptions*, are defined. Prescriptions are represented in FORPLAN models by one or more decision variables, one for each time period in which the prescription can be implemented.

Mathematically, this construct of prescriptions and analysis areas is represented in FORPLAN models as

$$\begin{array}{l}\text{maximize} \\ \text{(minimize)}\end{array} \quad \sum_{i=1}^{I} \sum_{j=1}^{P_i} \sum_{k=1}^{K_j} C_{ijk} X_{ijk} \tag{1}$$

subject to

$$\sum_{j=1}^{P_i} \sum_{k=1}^{K_j} X_{ijk} = A_i \tag{2}$$

for $i = 1, \ldots, I$ and $X_{ijk} \geq 0$ for any i, j, k, where

X_{ijk} = the acres allocated to the kth timing choice of the jth prescription defined for the ith analysis area;
C_{ijk} = the per acre contribution to the objective function of the kth timing choice of the jth prescription defined for the ith analysis area;
I = the number of analysis areas defined for the forest;
P_i = the number of prescriptions defined for the ith analysis area;
K_j = the number of timing choices of the jth prescription defined for the ith analysis area;
A_i = the acreage of the ith analysis area.

This is a Model 1 formulation (Johnson and Scheurman 1977), which is available in both versions of FORPLAN, and is the one most frequently used. The decision variables represent all management activities associated with each prescription timing choice that can occur on a given acre throughout the planning horizon (typically 15 decades). An alternative formulation (Model 2) that incorporates a different definition of the decision variables is also available to users of each version. However, it has been utilized on a relatively small number of national forests.

The forest land base constraints just described appear in all FORPLAN models utilizing a Model 1 formulation. There is also a wide variety of optional constraints that users incorporate in their models. Examples include constraints required to ensure that policy restrictions and minimum management standards are met, constraints on output production targets, constraints on budget revenue, and constraints on wildlife habitat. Collectively, these constraints may take many forms; some will be applied to the entire forest, while others will be applied only to subsets of the forest. In addition, each constraint can be imposed for one or more time periods (decades) during the planning horizon.

We will give the mathematical form of two examples of typical constraints. One common policy restriction that forest plan alternatives must meet is that the forest-wide timber harvest volume never decline on a period-by-period basis throughout the planning horizon. These constraints take the form

$$\sum_{i=1}^{I} \sum_{j=1}^{P_i} \sum_{k=1}^{K_j} H_{ijkd} X_{ijk} - H_d = 0 \quad \text{for } d = 1, \ldots, D \tag{3}$$

and

$$-H_d + H_{d+1} \geq 0 \quad \text{for } d = 1, \ldots, D-1 \tag{4}$$

where the the terms not defined previously are

H_{ijkd} = the per acre volume of timber harvested in period d for the kth timing choice of the jth prescription defined for the ith analysis area;
H_d = the total timber volume harvested across the forest (in millions of cubic feet) in the dth period;
D = the number of periods in the planning horizon.

Frequently, the need arises to constrain the amount of suitable wildlife habitat on a portion of the forest. This habitat is usually measured with an index that represents the estimated proportion of an acre that is suitable habitat. This index is a function of factors like the type of vegetation present on an acre, the age of this vegetation, and the type of management being implemented. To simplify the notation, we present the form of this constraint on a forest-wide basis but, in practice, it will be defined for a watershed or critical wildlife habitat area

$$\sum_{i=1}^{I} \sum_{j=1}^{P_i} \sum_{k=1}^{K_j} (WHI)_{ijkd} X_{ijk} \geq W_d \quad \text{for } d = 1, \ldots, D \tag{5}$$

where the terms not defined previously are

$(WHI)_{ijkd}$ = the wildlife habitat index value in period d for the kth timing choice of the jth prescription defined for the ith analysis area;
W_d = the minimum number of acres of suitable wildlife habitat required in period d.

Regardless of whether a Model 1 or 2 formulation is chosen, problems with the spatial feasibility of FORPLAN solutions arise when they are implemented on the ground. As Kent, Kelly and Flowers point out:

> Many FORPLAN models incorporate what has become known as a basic simultaneous allocation (BSA) formulation (Kent, Kelly and King), or alternatively, a strata-based formulation (Johnson and Stuart). In this formulation, acres are allocated to prescriptions—more or less independently—analysis area by analysis area. This independent

allocation often creates problems when the resulting optimal solution is mapped on the ground. For example, spatially illogical results, such as the location of a clearcut in the middle of a roadless area, can occur. In an attempt to resolve these spatial difficulties, an alternative formulation was developed. In Version 1 it is known as aggregate emphases (AE) (Kent, Kelly and King), and in Version 2 as coordinated allocation choices (CAC) (Johnson and Stuart). This formulation differs in some details between the two versions but functions in the same manner.

In this formulation, the forest is subdivided into contiguous areas (often watersheds) referred to as *allocation zones*. One or more sets of spatially compatible prescriptions are defined for the analysis areas in each zone. Each set is represented by one or more decision variables that are linked to the appropriate prescription-related decision variables by a set of acreage transfer rows. We present full details on this formulation in Appendix A and the problems that arise from its containing integer variables.

3. EXPERIENCES WITH THE USE OF FORPLAN

We turn our attention to a brief discussion of experiences with the use of FORPLAN for national forest planning. The two examples presented here are typical, although the experiences differ in detail from forest to forest.

Perhaps the most significant characteristic of FORPLAN models taken as a group is their variability. There are several, somewhat interrelated, reasons for this. First, and perhaps foremost, because FORPLAN is a national system, it is used on national forests with widely different vegetation, topography, suitable uses, and demands for products and services (Kent, Kelly and Flowers). As an example, some forests produce large quantities of timber, while others produce relatively little timber but offer opportunities for high quality recreation. Public demands for goods and services also vary widely from forest to forest. Consequently, the nature of the planning problems that must be addressed varies.

In addition to variations in FORPLAN models across forests, model formulations also vary considerably for a given forest as the analysis progresses through planning Steps 4–5. For example, models developed for benchmark alternatives (Step 4—analysis of the management situation) are typically loosely constrained while those developed during the formulation of alternatives (Step 5) are often tightly constrained. To accommodate these varying needs, both versions of FORPLAN have several different types of constraints that may be specified by the user (Johnson 1986 and Johnson, Stuart and Crim 1986). Some of the implications of this variability are shown in Table I in terms of selected model size parameters (Kent, Kelly and Flowers).

Table I
Value Ranges for Selected FORPLAN Model Size Parameters

Model Size Parameter	Range of Values
Number of rows	1,000–5,000
Number of columns	15,000–120,000
Number of nonzero elements	100,000–3,000,000
Number of unique nonzero elements	750–15,000
Density	0.5%–3%

To further elaborate on these points, consider the following brief description of the plan alternatives developed by the Kootenai National Forest, which comprises 2,245,000 acres located in northwestern Montana. This forest used Version 1 to develop 16 benchmark alternatives and 12 forest plan alternatives (Haugen 1987).

The primary role of benchmark alternatives is to determine both resource production capabilities, such as the amount of timber that can be harvested, and the tradeoffs that result from the imposition of management restrictions that are required by law, policy, etc. As such, they serve to define a framework of production and management possibilities within which the forest plan alternatives must fall. Table II contains summary information on six benchmark alternatives (Haugen) pertaining to the constraints that were analyzed and the resulting tradeoffs in net present value (NPV), as determined from the objective function. These are typical examples of items considered in formulating benchmarks for most national forests.

Benchmark analysis results and public input are used to frame forest plan alternatives. These alternatives differ from benchmarks in that they represent more balanced plans for managing the forest, where balanced means the incorporation of a broad range of public issues, management restrictions and management objectives. Benchmarks, on the other hand, as shown in Table II, are designed to analyze the tradeoffs of specific groups of constraints or to assess production capabilities. The constraints on timber harvesting policies and management restrictions explored in the benchmarks are, for the most part, included in the forest plan alternatives. Table III contains summary information for six of the Kootenai National Forest's forest plan alternatives (Haugen). Again, the themes presented in this table are typical for forest plan alternatives for most national forests. Note that the first alternative presented in Table III is actually a benchmark alternative described in Table II. It is not unusual for certain benchmarks to also be considered as plan alternatives.

It is important to recognize that the final set of benchmark and plan alternatives are the end product of

Table II
Summary Information for Six Kootenai National Forest Benchmark Alternatives

Timber Policy Constraints	Management Restrictions Constraints	Objective Function Value (NPV for 15 decades at 4% in millions of dollars)
Harvest restriction[a]: none Harvest flow[b]: ±25% Harvest floor[c]: 345 MMCF	None	2,083
Harvest restriction: CMAI Harvest flow: none Harvest floor: none	None	1,924
Harvest restriction: CMAI Harvest flow: none Harvest floor: none	Grizzly habitat	1,768
Harvest restriction: CMAI Harvest flow: none Harvest floor: none	Grizzly habitat Soil/water restrictions	1,202
Harvest restriction: CMAI Harvest flow: none Harvest floor: none	Grizzly habitat Soil/water restrictions Old growth/diversity	1,171
Harvest restriction: CMAI Harvest flow: NDY Harvest floor: none	Grizzly habitat Soil/water restrictions Old growth/diversity	1,143

[a]None means final harvesting can occur as early in stand life as merchantable volume accumulates; CMAI means final harvesting cannot occur until average annual growth rate begins to decline.
[b]Refers to total harvest volume decade by decade; ±25% means harvest can rise or fall up to 25% decade by decade; NDY means harvest can never decline below previous decade's harvest level.
[c]Minimum total harvest volume in first decade in millions of cubic feet.

analyzing many developmental alternatives, which incorporates public input and management concerns as identified by Forest Service personnel. It is not unusual for planners of forests like the Kootenai to formulate and analyze 150 or more alternatives, and hence, FORPLAN models, as they develop this final set.

The previous discussion provides an overview of the nature of the alternatives developed using FORPLAN on a national forest. While this is the primary use of the system, it serves some other useful purposes. One of the most important is that it provides a framework within which the forest planning problem can be conceptualized and modeled. Along with this, each FORPLAN model, especially if Version 2 is used, can keep track of information on a large number of items, such as acres treated in certain ways, management practices, costs and levels of output production for subareas of the forest. Consequently, FORPLAN is a very powerful accounting tool, and in the case of Version 2, is designed to link directly with other agency accounting systems. Another use is that of simulation or simulation/optimization. Repeated variation and solution of FORPLAN models constructed to represent either part, or all, of a national forest is often very useful in answering what-if questions (Stuart 1984). In some cases, FORPLAN is being used in this way for forest plan implementation analysis.

The most important final products of the forest planning process are the final forest plan and the final environmental impact statement for the plan. We close this section of the paper by briefly recounting an incident in the Shoshone National Forest where these documents were put to effective use (Mealey 1987). In 1985 and 1986, exploratory gas and oil drilling in the Shoshone was challenged in court. While both challenges were overturned, the cost to the government was significantly reduced (from $133,000 to $10,000) in 1986. This occurred because the planning documents were not completed on the Shoshone until 1986. In 1985, two draft and one final environmental impact statements were prepared to show compliance with the National Environmental Policy Act, whereas only a brief environmental assessment was required the following year because the forest planning documents provided the documentation necessary to demonstrate legal compliance for exploratory drilling.

4. FORPLAN EVALUATION

A reading of contemporary literature on forest planning reveals a great deal of variation concerning the perceived effectiveness of current Forest Service planning efforts under the NFMA. For example, Field concludes that,

Table III
Summary Information for Six Kootenai National Forest Plan Alternatives

Major Theme of Alternative	Objective Function Value (NPV for 15 decades at 4% in millions of dollars)
Provide for cost effective land base for timber management base for timber management with no additional acres being allocated to wilderness	1,143 (this is the last benchmark in Table II)
Provide for significant big game habitat using elk as an indicator species	658
Allocate all inventoried roadless areas (403,700 acres) to wilderness	1,034
Continue the current direction of management which includes greatly constrained budgets	460
Provide significant protection to all roadless areas, designating 81,300 acres as wilderness, and giving emphasis to nonmotorized recreation and visual quality throughout the forest	1,064
Final (adapted) plan—provides a combination of wilderness, roadless, wildlife, recreation and timber management opportunities	733

"as long as top management continues to support the applications of advanced technology, the general trend toward increased acceptance of operations research in the Forest Service will also continue." Iverson (1986) believes that, "... in spite of the limitations inherent in any attempt to abstract from holistic reality through modeling the complex ecosystems that constitute our national forests, the benefits may yet exceed the costs." O'Toole (1983) concludes that, "the Forest Service has reached the level of total unintelligibility." Lastly, Barber (1986) believes that large FORPLAN models are unnecessary, too costly, and "almost totally opaque to their users."

Alston and Iverson provide a detailed evaluation of FORPLAN that focuses on four considerations: 1) silviculture and management, 2) economic and social, 3) spatial and transportation, and 4) computational. Whereas they conclude that FORPLAN is doing a good job of solving many of the weaknesses inherent in Timber RAM—a predecessor LP timber harvest scheduling model—they express concerns about the need to ensure that it is used carefully and properly. They hypothesize that analysts and planners may have fallen into the trap of using FORPLAN more to answer innocent questions than to focus on the identification and analysis of critical issues.

How then did FORPLAN gain such a significant role in national forest planning? Johnson (1987) offers three plausible reasons: 1) it was available, 2) it helped break the hold of professional omnipotence, and 3) it helped shield the Forest Service from its critics by providing a formidable roadblock to any group wishing to influence the future management of any national forest. To these three reasons, a fourth related to the consistency of planning procedures across forests could be added. With this background, we begin our evaluative review, utilizing the five criteria given in the Introduction.

4.1. Analytical and Computational Problems

In their evaluation of FORPLAN from an operations research perspective, Bare and Field (1987) ask three questions: 1) does FORPLAN work?, 2) is it the right technique and is it used correctly?, and 3) are the results useful? Their short answers are: 1) yes, but..., 2) possibly, but probably not, and 3) occasionally.

The first of these questions deals with the technical basis for FORPLAN. The significance of violating the assumptions of LP within the context of FORPLAN is discussed by Bare and Field. Apart from these problems, the principal frustration with FORPLAN lies with the cost and difficulty of solving some of the models created. A single run costs between \$50–\$500, although some run costs exceed several thousand dollars. CPU times range between 4–100 minutes, although most runs take 30–65 minutes. These data are for the Functional Mathematical Programming System (FMPS) Sprint algorithm operating on a UNIVAC 1100/92 mainframe at the U.S. Department of Agriculture's National Computer Center at Fort Collins (NCC-FC).

In terms of solution difficulties, there are three major problem areas: the inability to solve a given model due to its size and/or the mathematical structure of its constraints; the resolution of infeasibilities that occur frequently as plan alternatives are developed; and the resolution of fractional solutions for the integer variables in CAC formulations (see the Appendix).

During the first 2 or 3 years FORPLAN was used, it was common to encounter models that were either difficult or impossible to solve. Efforts to improve solution capabilities included investigations into ways to adjust FMPS tolerances and parameters, benchmarking of *problem* models on other systems, and finally, the development by UNISYS Corporation of several special enhancements to the FMPS system (Kent, Kelly and Flowers). Using these enhancements along with tolerance and parameter adjustments, notable progress in being able to solve FORPLAN models has been made. Nevertheless, it is fair to conclude that these models are still taxing the capacity of both computer hardware and software. Given that more powerful computers are being introduced and that improvements in linear programming algorithms will continue, we conclude that, "Yes, FORPLAN is working." However, Alston and Iverson observe, ". . . efficient computer processing will not overcome problems created by analysts who construct large models that do nothing more than tax the resources and patience of forest managers."

The problems of infeasibilities and mixed integer solutions have proven more difficult to resolve. Frequently, in the development of plan alternatives many constraints are imposed on the model, often with complex interactions between them. It is these constraints and interactions that cause infeasibilities, but FMPS typically indicates that the amount of available land is the source of the problem. Since changing forest area is not an option, FMPS is of little help in resolving infeasibilities. About the only recourse available to analysts is to add constraints incrementally and to keep careful records of this model evolution. Unfortunately, this can increase the number of problems that must be formulated and solved in order to develop an alternative.

The mixed integer solution problem is similar because, as pointed out in the Appendix, the user has no obvious procedure to follow for problems of the size typically formulated for national forest planning. Partially for this reason, heuristic procedures that find integer but not optimal solutions are often advocated in the literature (O'Hara, Faaland and Bare 1989). However, these heuristic procedures have not been tried on CAC formulations. Instead, either information gained from the fractional solution is used to define new prescription packages, or insights gained from repeated model solution and analysis are used to force desired sets of integer decision variables into solution for each alternative.

Probably the major problem with the use of FORPLAN in the Forest Service has been the lack of a clear understanding of the role of FORPLAN analysis in forest planning. This, in turn, has made it difficult to answer the second and third questions raised by Bare and Field. For example, is FORPLAN an *analysis* or an *accounting* tool? Is it to be used to guide strategic, tactical, or operational planning? Are planners seeking *answers* or *insights* from FORPLAN runs? Is the model to be *optimized* or is it to be used as a *simulator*? Depending upon one's source of information, all of the above can be cited as valid uses of the system and, in fact, situations exist where it has been used in each of these ways. Yet, this wide array of possible uses has created confusion in the minds of forest users as well as planners and decision makers. Furthermore, it helped create a chasm between these groups of people. Clearly, a system designed to analyze strategic alternatives will possess different characteristics than one designed to function at an operational level.

Particularly in the early days of the forest planning exercise, these problems were exacerbated by the fact that all involved with the process, i.e., analysts, planners, FORPLAN system developers, and agency managers, were learning a new and complex way of approaching the management of national forest lands. For example, few had given much thought to the question of . . . "what type of planning (i.e., strategic, etc.) should be conducted at the national forest level?" Also, the capabilities needed for effective multiple-use modeling in Version 1 were not well understood. This lack of understanding also applied to the limitations of the use of large-scale LPs for this type of application (i.e., the spatial feasibility of solutions on the ground).

The existence of some of these issues (if not ways to resolve them) became clearer after two to three years of forest planning experience. Shortcomings and design flaws with Version 1 became apparent. The situation was further complicated by the fact that Version 1 was being developed at the same time it was being used and documentation was largely unavailable, thus making the system even harder to use and understand than would otherwise have been the case. Unfortunately, instances occurred where software related problems, arising from simultaneous development and use, were used to obscure the fact that the system was not applied properly in the first place. Both software and application problems tended to contribute unfavorably to perceptions of FORPLAN, a problem that unfortunately still persists to some degree today, especially for those who are neither trained in nor directly involved with the use of the system.

Some of the lessons learned from these early experiences were put to good use. For example, the designers of Version 2 sought to develop a system that was general enough to serve as an effective tool for all planning applications. Capabilities were added to allow the system to function effectively for operational, as well as tactical and strategic planning (Johnson, Stuart and Crim 1986 and Stuart 1984). In addition, a capability was added to the report writer to enable it to facilitate analyses focusing on the acquisition of insights through simulation (Stuart) and to enable it to provide more help with accounting questions through linkage with flat file data base software (Bevers 1986). How well Version 2 can function in these various capacities is a question that only time and agency experience can answer. Some measure of its potential for success can be found in the evaluation of FORPLAN's suitability for meeting analytical requirements provided by Teeguarden (1987).

Unfortunately, questions such as what type of planning should be done at the forest level are still unanswered.

4.2. Comprehensive Planning

The NFMA specifies that the Forest Service "use a systematic, interdisciplinary approach to ensure coordination and integration of planning activities for multiple use management." Teeguarden points out that a rational comprehensive approach to planning (Lindbloom 1959) was adopted by Congress in NFMA. Furthermore, the many complex requirements of the act call for decisions that are rationalized in terms of specific objectives and criteria. This can be seen in the *zero-based* approach incorporated in the implementing regulations and in the 10-step planning process described earlier in this paper (Cortner and Schweitzer 1983).

Out of all this came a clear mandate for a *rational comprehensive* approach to developing forest plans. There also appears to be a strong suggestion in the regulations that LP might be an appropriate tool. Even if rational comprehensive planning and the use of LP are accepted as given, there exists more than one way to proceed with analysis (Bare and Field). However, for the most part, Forest Service analysts concluded that only the development of a large-scale model capable of handling forest-level planning would satisfy legislative intent. This ultimately led to single, large LP models capable of simultaneously handling land allocation and scheduling decisions for a broad array of renewable resources. Perhaps it was felt that this would shield the agency from challenges (brought by outside groups) that a plan was unacceptable because it was not based on a comprehensive analysis.

The most complex models were those that attempted to deal simultaneously with strategic, tactical and operational planning. These had model size parameters toward or beyond the upper limits of the ranges shown in Table I. As might be expected, these models were the most difficult and expensive to solve, and as Bare and Field suggest, might well have pushed the technique of LP beyond its practical limits. When one considers the complexity and size of the problems being addressed, this is not surprising.

Given the advantage of hindsight, it appears that too little attention was devoted to evaluating the tradeoffs between comprehensiveness and understandability. Irland (1985) notes that, "comprehensiveness is a trap . . . comprehensive planning fails to sort the strategic from the trivial, wastes resources on secondary concerns, paralyzes the will in the face of complexity, and bogs down in empirical debates for lack of direction." Allen and Gould (1986) further detail these criticisms in irrefutable fashion. An alternate approach to a single large-scale LP model, which did receive some attention by Forest Service analysts, involved a multistage model (Crim 1982, Mitchell 1986). However, the prevailing philosophy was in favor of the comprehensive approach. More recently, it has been noted that smaller, simpler models are increasingly being used to gain insight into certain aspects of ecosystem-management problems (Alston and Iverson).

4.3. Organization and Management Style

Apart from the technical issues just discussed, several more organizationally oriented issues have played a significant role in influencing the acceptance of FORPLAN. As reviewed earlier in this paper, the Forest Service is a large, decentralized agency steeped in the tradition of functional planning with regions and forests operating relatively independent of each other. With passage of the NFMA, use of a single LP system was decreed from the Washington office. Prior to this decree, the Forest Service had very little operations research (OR) tradition. Applications such as timber harvest scheduling LPs were developed and utilized by small groups of researchers and some timber planners. The sudden, mandated use of FORPLAN brought an OR technique into the professional lives of many resource specialists, planners, managers, etc., who had no prior OR experience or training. This was true also, of many of the publics who interacted with agency personnel in the development of forest plans. In addition, the Forest Service has a very strong *can do* tradition and approach to doing business. How well has the agency responded to this new challenge and how well has FORPLAN fit into the organizational and management style of the Forest Service?

Bradley studied the acceptance of innovative integrated land management planning on 19 forests in Oregon and Washington (Region 6). He found that more complex forests (complexity was a composite measure consisting of the forest resource, organizations, and external environments such as surrounding counties) tended to accept the new integrated planning approach (vis à vis FORPLAN) to a greater extent than did the less complex forests. However, benefits resulting from planning did not differ according to complexity. With regard to FORPLAN, "planners expressed concern that their analytical work was being compromised." The principal analytical tool (FORPLAN) was frequently mentioned in negative terms. For many, FORPLAN was thought to be a mistake, a technique too complex for some in the agency as well as for the public who needed to understand how plans were developed and what the consequences of plans would be. Others felt that the "technique simply was not capable of accomplishing what it was supposed to accomplish" (Bradley).

As we pointed out earlier, FORPLAN was introduced to bring uniformity and consistency to agency planning efforts. However, with the advantage of hindsight, it is safe to conclude that too little consideration was given to the resources required to fully implement the process. The agency possessed neither the trained personnel (Field), nor the experience with large-scale land management planning models to be immediately successful (Bradley). In addition, the training that has been offered has been largely inadequate because the agency has not recognized that one and two week workshops are not sufficient background for planning and analysis problems of this complexity. That FORPLAN has been as successful as it has is tribute to the efforts of a dedicated and energetic work force.

4.4. Professional Beliefs

Until recently, professional foresters in the Forest Service have constituted the single largest professional group in the agency. However, with increasing attention being devoted to recreation, wildlife, watershed, cultural, and aesthetic values, professionals trained in other disciplines have been hired in increasing numbers. While this has been ''good'' in that it has further broadened the agency's historic commodity-orientation, it has weakened the power base of the professional forester within the organization.

In citing this as one of the reasons why FORPLAN was adopted so readily, Johnson (1987) states that, ''FORPLAN is one tool in an internal cleansing—perhaps exorcism is a better word—of the professional beliefs and tenets that have guided national forest management from its inception. It is part of the attempt to prevent professional groups within the Forest Service, especially foresters, from imposing their objectives for management of the forest on the rest of humanity.'' With the formation of interdisciplinary teams, foresters found themselves being regarded as one member of a team, and not the sole judge of what goals to pursue and how to best attain them.

However, as Bradley notes, most of the interdisciplinary teams for the national forests in Oregon and Washington were composed largely of foresters. This might be explained by the fact that timber is a significant resource on these forests. And, timber management planners have more experience with LP models than do most other disciplinary groups involved with land management planning. Nevertheless, the dominance of foresters and the priority given to timber was reported by many interdisciplinary team members to be a barrier to successfully achieving balanced plans.

FORPLAN has been the focal point of substituting analysis, based on a clear statement of objectives, for dogma and tenets of faith that have plagued forestry from its inception in this country (Johnson 1987). Perhaps any tool, whether simulation or optimization-based, would have suffered much the same fate and been subjected to many of the same criticisms and pressures. To this extent, FORPLAN ''shares the limitations of all mathematical models: the inherent inability to consider all linkages with the rest of the world simultaneously'' (Alston and Iverson). Nevertheless, FORPLAN has been a strong force in changing the image of professional forestry from one of ''man and nature'' to more of a ''rational analytical'' manager of natural resources (Field). This substitution of reasoning for judgment and faith has been necessary to provide the accountability legislated in the NFMA and demanded by the various users of the national forests. Concurrently, it has directed attention away from the decision makers and placed it on planners and analysts. Thus, while it has been a shield for the decision maker, it has been a lightning rod for analysts and planners.

4.5. Conflicts Between Forest Users

Both NEPA and NFMA mandated an increased role for public input in the formation of forest plans for the various administrative units in the National Forest System. Thus, a vehicle was required to allow these various users an opportunity to trace the effects of their proposals through the planning process. This clearly stimulated the acceptance of a rational, quantitatively-oriented operations research planning tool.

Increasing demands on the resources of the national forests began to surface in the late 1950s, as post-war America found itself with more leisure time at its disposal. As citizens began to use the national forests for recreational activities, conflicts with the more traditional commodity users began to increase. These conflicts continued throughout the 1960s and 70s, culminating in several major policy disputes (i.e., clearcutting on the national forests, roadless area studies, wilderness area expansion). In many ways, this was a continuation of the conflict over the balancing of resource outputs which led to the formation of the Forest Service at the turn of the century. Into this politically charged debate the Forest Service introduced a rational approach to planning based on the FORPLAN system.

FORPLAN did provide Forest Service planners with a means of tracing a particular user's suggestions for future management through to completion. However, as FORPLAN models increased in size, this became more and more difficult—even for the trained analyst! Thus, it is doubtful if the original purpose was often served. Furthermore, critics of the Forest Service plans educated themselves about the nuts and bolts of FORPLAN and began to use the system to their own advantage. This created additional problems for less knowledgeable users as well as for the agency.

Thus, the technically more informed user groups have greater influence on forest planning decisions because of FORPLAN. Undoubtedly, many users of the national forests were overwhelmed by FORPLAN and dropped out of the planning process—only resurfacing to provide comments on proposed actions that affected a specific issue, resource or land area of immediate concern to their interests.

5. LESSONS FOR PRACTITIONERS

Much of preceding discussion contains lessons for practitioners which can be characterized loosely as either organizational or operational. In assessing these lessons, it is important to consider both the organization and management style issues discussed and the timing of events in the early days of forest planning and FORPLAN development. In particular, the lack of an OR tradition and the *can do* approach to doing business need to be recognized. The timing of events is important because, as mentioned, planning approaches and analysis tools (i.e., FORPLAN) were being developed at the same time that national forest personnel were starting to develop plans. These factors conspired against effective OR practice in the following ways:

1. FORPLAN system developers found themselves forced to support users at the same time they worked on systems development.
2. Acceptance and understanding of forest planning and the role of FORPLAN was slow to develop for many of those in the agency not directly involved.
3. All involved more or less *dived into* the planning and analysis exercise without the advantage of prior careful specification, either of the planning problems that needed to be addressed in order to satisfy NFMA or of the types of analysis tools needed to assist in the work.

From this it is clear that a more controlled move into a major OR undertaking, such as this, is necessary. As pointed out, one reason FORPLAN was chosen was that it was available (Johnson 1987). Proper characterization of the planning problems to be addressed would greatly facilitate the identification of the types of analyses that are required. This would provide a better basis for a more effective initial design of tools than was the case with Version 1. At the same time, organizational issues such as acceptance of a new way of doing business and staffing up in critical analytical skill areas could be carried out. Unfortunately, in the Forest Service, with its relatively weak OR tradition, even if OR practitioners recognized these problems (as many did), they lacked the influence necessary to guide the organization around the pitfalls. Thus, while probably not as important in organizations with a strong OR tradition, the key lesson for practitioners in an organization like the Forest Service is to do everything possible to bring about a logical and orderly approach to such a major OR undertaking.

6. CONCLUSIONS AND RECOMMENDATIONS

What has been learned from the past nine years of experience with FORPLAN? First, and foremost, it is clear that the use of FORPLAN (primarily Version 2) has been significant in helping managers translate multiple use policies into action at the forest level. Functional planning is slowly taking a back seat to integrated land and resource planning throughout the Forest Service. Thus, progress has been achieved in a relatively short period of time. The agency can be proud of its accomplishments and is to be congratulated for undertaking such ambitious changes in its planning procedures—an effort unparalleled in modern times. As seen elsewhere in society, too much confidence is often placed on innovations introduced to solve problems. With the benefit of hindsight, it appears that the Forest Service has somewhat avoided this trap, although examples of overreliance on FORPLAN to solve all planning problems can be cited.

Nevertheless, it is clear from our evaluation that several issues need to be addressed if FORPLAN, or some similar system, is to be used successfully in future rounds of forest planning within the agency. First, a clearer understanding of the level of planning (i.e., strategic, tactical or operational) to be conducted at each phase of the 10-step planning process must be developed. For example, should the forest-wide planning that is done every ten years be largely strategic—or strategic and tactical in nature? Along with this, a better understanding of how to effectively use FORPLAN, or perhaps, how to redesign or replace it, so that it can function effectively as a tool at each level of planning is needed. One objective of this is to find ways to use the tool effectively while building smaller, hierarchically-based, easier-to-interpret models.

Second, more emphasis should be placed on using the system to seek *insights* instead of *answers*. In other words, there remains the issue of how to use FORPLAN in the forest planning exercise. Also, it is as important to understand what FORPLAN can and cannot do, as it is to understand how to use it. Only by giving careful consideration to these issues, can the trap of improper application of the system be avoided. Along these lines, Johnson (1987) points out:

> Planning models are valuable to planners and decision makers to the degree that they allow people to think through their problems. These are not predictive models of what will happen in the future. The data is (sic) too scant for that. Rather, they organize the objectives, constraints, and assumptions of the people using the model to help them answer the what-if questions as they search for solutions to planning problems. These models are not meant to dominate the process or drive out aspects of the thinking by planners or decision makers that cannot be quantified.

Said differently, one of the most important roles of FORPLAN is to provide a framework for analysis and decision making.

Our final issues are organizational ones. To be truly integrated, planning teams relying on FORPLAN need to have a broader representation of expertise across the disciplines of relevance to a particular forest. Also, decision makers, planners and forest users must continue to educate themselves regarding how best to utilize systems like FORPLAN in the management of our nation's forest resources. To facilitate this education, the agency needs to develop rigorous training programs in planning and analysis. As Alston and Iverson conclude, "a focus on the right questions needs to be implemented fully before one can expect the use of FORPLAN or any other optimizing model(s) will earn full endorsement by those involved in and affected by national forest planning." Finally, a greater acceptance for planning analysts must be developed, both in terms of a recognition of the importance of their role and in terms of the development of meaningful career paths for them within the agency.

We feel that technological advances will help the agency address some of the problems discussed. For example, the capability exists to generate and solve many FORPLAN models on IBM-compatible microcomputers, thus reducing analysis costs and providing analysts with opportunities to conduct sensitivity analysis. Moving FORPLAN to a microcomputer platform will also facilitate a redesign of the system to make it more user friendly and to develop linkages between it and other technologies, such as geographical information systems and relational data bases.

To reiterate, much has been accomplished during this first round of planning but much remains to be done. It is important to recognize that this exercise has been a learning experience for those involved. It is also important to recognize that the stakes are high, both for the agency and for the profession of forestry. As Teeguarden states:

> If the NFMA planning system doesn't work, it will be a major setback for the forestry profession, because a more prescriptive law surely will follow.

APPENDIX

The CAC formulation of acreage related contraints is

$$\text{maximize (minimize)} \quad \sum_{h=1}^{H} \sum_{m=1}^{M_h} \sum_{n=1}^{N_m} C_{hmn} Y_{hmn} + \sum_{i=1}^{I} \sum_{s=1}^{S_i} \sum_{j=1}^{P_s} \sum_{k=1}^{K_j} C_{isjk} X_{isjk} \tag{6}$$

subject to

$$\sum_{m=1}^{M_h} \sum_{n=1}^{N_m} Y_{hmn} = 1 \quad \text{for } h = 1, \ldots, H \tag{7}$$

and

$$-\sum_{h=1}^{H} \sum_{m=1}^{M_h} \sum_{n=1}^{N_m} A_{hmnist} Y_{hmn} + \sum_{s=1}^{S_i} \sum_{j=1}^{P_s} \sum_{k=1}^{V_{tj}} X_{isjk} - T_{is(t-1)t} + T_{ist(t+1)} = 0 \tag{8}$$

for $t = t_f, \ldots, t_w$, $s = 1, \ldots, S_i$, $i = 1, \ldots, I$

$Y_{hmn} \geq 0$; $X_{isjk} \geq 0$; $T_{is(t-1)t} \geq 0$; $T_{ist(t+1)} \geq 0$

for any h, m, n, t, i, s, j, k, where

- Y_{hmn} = the proportion of the hth zone allocated to the nth timing choice of the mth CAC defined for that zone;
- C_{hmn} = the contribution to the objective function of the nth timing choice of the mth CAC defined for the hth zone;
- H = the number of allocation zones defined for the forest;
- M_h = the number of CACs defined for the hth zone;
- N_m = the number of timing choices defined for the mth CAC;
- X_{isjk} = the acres allocated to the kth timing choice of the jth prescription in the sth prescription set defined for the ith analysis area;
- C_{isjk} = the per acre contribution to the objective function of the kth timing choice of the jth prescription in the sth prescription set defined for the ith analysis area;
- I = the number of analysis areas defined for the forest;
- S_i = the number of prescription sets defined for the ith analysis area;
- P_s = the number of prescriptions in the sth prescription set defined for the ith analysis area;

K_j = the number of timing choices of the jth prescription defined for the ith analysis area;

A_{hmnist} = the acres made available in the tth time period to prescriptions in the sth prescription set defined for the ith analysis area if the nth timing choice for the mth CAC defined for the hth zone is chosen;

V_{tj} = the number of timing choices for the jth prescription in the sth prescription set that implement (have their first management action) in the tth period;

$T_{is(t-1)t}$ = the number of acres made available for but not allocated to prescription timing choices implementing in period $(t-1)$;

$T_{ist(t+1)}$ = the number of acres made available for but not allocated to prescription timing choices implementing in period t;

t_f = the earliest period in which acres are made available to prescriptions from a given CAC;

t_w = the latest period in which acres are made available to prescriptions from a given CAC.

Important points about the formulation in Equations 6, 7 and 8 are:

1. This formulation assumes that the entire forest is subdivided into allocation zones. In practice, models are often comprised of a mixture of this formulation and that represented by Equations 1 through 5.
2. The A_{hmnist} represent acres of the ith analysis area that fall within the hth allocation zone. Analysis areas can fall into one or more zones, or in mixed formulations, lie partially or completely out of zones.
3. When $t = t_w$ in Equation 8, V_{tj} = the number of timing choices for the jth prescription that implement during or after period t_w.
4. In Equation 8, when $t = t_f$, the term $T_{is(t-1)t}$ drops out and when $t = t_w$, the term $T_{ist(t+1)}$ drops out. These variables allow prescription timing choices (X_{isjk}) to come into the solution that implement in a period later than period t for which a given Equation 8 is defined.
5. In Equation 8, the range of periods t_f to t_w during which acres are available for transfer is a function of the range of periods in which the prescriptions and the CACs can be implemented as well as the rate at which the analysis area can be accessed (a roading question).

The idea behind this formulation is to have one, and only one, of the Y_{hmn} in the optimal solution for each Equation 7, i.e., for each zone. When this happens, the set of prescriptions allocated to the analysis areas in each zone should prove spatially feasible when implemented. Because this mixed integer problem is solved as a linear program it often leads to splits between two or more sets of prescriptions in a given zone, i.e., more than one Y_{hmn} comes into solution in a given Equation 7. When this happens, part of a zone is allocated to prescriptions from one prescription set while the rest of the zone is allocated to one or more additional sets of prescriptions. This can cause problems because these different prescription sets may not be spatially feasible. Unfortunately, because there is no rigorous procedure for resolving splits, the user is left with figuring out how to modify the model in order to achieve an integer solution. We address this problem further in the evaluation section of this paper.

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