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

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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

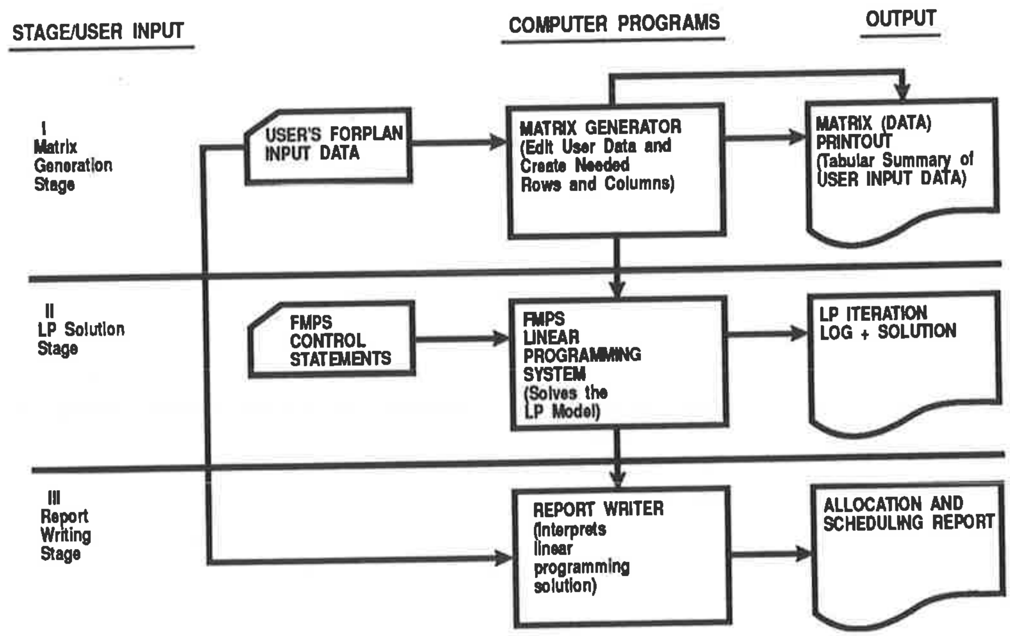

Figure 1. System structure of FORPLAN (FORest PLANning model).

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

$$\text{maximize (minimize)} \quad \sum_{i=1}^{I} \sum_{j=1}^{P_i} \sum_{k=1}^{K_j} C_{ijk} X_{ijk} \qquad (1)$$

subject to

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

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

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

and

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

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

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

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).

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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