THE PIPELINE PROBLEM: A TACTICAL LEVEL APPROACH LINKING FOREST LEVEL PLANNING TO PROJECT PLANNING.

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ABSTRACT.—A case study of the problem of developing a schedule to plan projects is presented along with the integer goal programming formulation used to link strategic forest plans with operational project plans. The difficulty of coordinating project plans using the old compartment-based order-of-entry system with the new forest plan management area designation is discussed. The solution required the creation of larger land groups for project planning and the coordination of human resources between districts.

INTRODUCTION

The purpose of this paper is to recount a specific instance of forest plan implementation and report on an approach for linking outputs established by a strategic plan to the planning and implementation of individual projects. Optimal solutions had the role of providing a logical starting position in the planning process.

The National Forest System in the United States uses two levels of planning: strategic forest planning and project planning. Strategic planning is the process for establishing management directions, focusing on issues of public concern, explaining how management will affect key sites, producing important outputs, and protecting vital resources and ecosystems (U.S. Congress, 1992). Strategic forest plans are made for an entire national forest using a longtime horizon. Project planning is a process for achieving the conditions and outputs established in the strategic plan. A project plan is made for an area that is usually smaller than the whole forest (for example, a watershed, compartment, or management area) for a time period limited to completion of the project (usually only a few years). A project plan is at the operational level of the hierarchical planning classifications system: strategic, tactical, and operational (Gunn, 1991). In the Southern Region, a compartment order-of-entry system achieved one phase of tactical level of planning.

The Southern Region of the National Forest System has been managing project planning (ultimately timber resources) using a systematic order of entry by compartment for about 30 years. The order-of-entry system began in the 1960's. The land was stratified by "compartments," which averaged about 1,000 acres each. The centerpiece of compartment planning was the compartment prescription, prepared by silviculturists, which assigned treatments in every compartment at least once in 10 years. During any year, compartments planned for treatments were widely distributed across the district to assure a diverse age class mix. This disbursal entry scheme has influenced the timber resources available today. In the mid-1980's, the entry sequence became disrupted by land allocations made in forest plans. Management areas in the forest plan did not coincide with compartment boundaries and lands "not suitable for timber production" now average about one-third of each compartment. These major disruptive factors resulted in difficulty in achieving an even flow and orderly sequence of timber management activities. Therefore, adjustments to the compartment entry sequence were needed to account for the new forest plan decisions.

The compartment order-of-entry sequence provided a tactical link between forest strategic goals and projects. Staff officers commonly use the term "pipeline" to summarize the project-planning work sequence. Many activities and goals must be coordinated within each project-planning undertaking. Many projects must be in various stages of completion at all times in order to keep the "pipeline" flowing (Fig. 1). The term also conveys the time delay for a project plan to move from start to completion. At a base level, a forest has an allowable sales quantity (ASQ) which it desires to meet on a yearly basis. To achieve the ASQ, a sufficient number of project plans must be completed

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each year. Up to a year earlier (even longer in some areas), project planning must have been started in several areas in order to meet current ASQ.

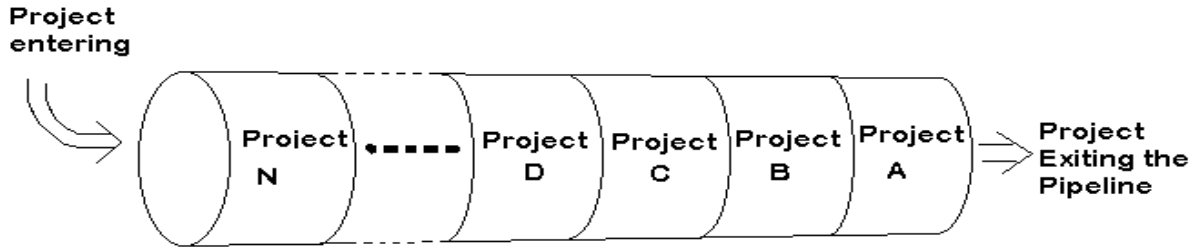

Figure 1.—The pipeline contains a series of project plans in different states of completion from start to finish. If there is an interruption of projects entering the pipeline, or if there is a bottleneck in the pipeline, the amount of projects exiting may not satisfy forest goals.

The development of each harvest project on a national forest takes so long because of the number of resources which must be analyzed, the amount of detail in which they must be analyzed, and the legal requirements which must be met. When developing a strategic forest plan, the information available and required is extensive, and the detail required for a project plan is usually not available. The information needs for a project plan are much more detailed and site specific than required for a forest plan, but before these can be collected, a decision must be made on which area of land to survey and analyze . The survey is labor intensive, requiring several types of specialists (Table 1). The decision on where to plan is a tactical management problem of how to best link strategic to operational levels. A decision to analyze an area must be made on to before analysis can begin.

Table 1.—Some of the surveys and specialists required by law in the development of a harvesting project

Survey Objective	Specialist
Archeology	Archeologist
Threatened and Endangered Species	Biologist
Roads and Access	Engineer
Timber Resources	Silviculturist
Wildlife	Wildlife Biologists
Scenery	Recreation
Aquatics	Wildlife Biologist

Several characteristics of the Pipeline problem make it interesting. Two of the more salient characteristics are an uncertain outcome of the survey and analysis and the amount of effort needed to analyze an area that is a function of several factors. Each area has unknown characteristics that may make it an unsuitable candidate for a harvesting project. Many of these remain unknown until the detailed survey and analysis has been completed. After all the work is done, you may not have a project plan that will help contribute to strategic goals. Uncertainty by itself is not enough to make this a problem, but with the addition of limited human resources (the specialists in Table 1), there is a probability that you may not have enough specialized labor available to meet strategic plan goals if you do not consider the effort involved. Furthermore, even if all attempted projects are successfully planned, you still may not have completed enough to satisfy strategic goals, since actual resource amounts and availability are unknown until after survey completion. In summation, it is necessary to plan for efficient pipeline building. This

plan provides one of the tactical links between strategic and project planning in the forest management planning hierarchy.

LOCAL SETTING: SCHEDULE OF ENTRY ON THE NANTAHALA AND PISGAH NATIONAL FORESTS

The 1987 forest plan began a flow of events which caused the compartment order-of-entry sequence to fail. A major cause was the new standards for timber suitability, specifically the category of lands "not suitable for timber production." On average, one-third of each compartment was no longer available to meet timber objectives. Timber suitability was designated by the USDA Forest Service definition of management areas. A new entry schedule should have been created using these units. However, even though the connection between management areas and entry schedule is clear to us today, it was not conspicuous during early plan implementation. The historic compartment entry schedule was modified to fit the new plan, but the modification didn't work well for long. Table 2 summarizes how poorly it actually did work. Over the 4-year period shown, less than 50 percent of the volume goals were achieved.

Table 2.—Timber sale pipeline targets and accomplishments by fiscal year

Fiscal Year	Target	Attained	Percent Attained
	- - - mmbf - - -		
1992	48.0	9.5	20
1993	15.0	11.1	74
1994	20.0	8.6	43
1995	10.1	5.4	54

mmbf = million board feet

At first it wasn't clear what the problem was, so a team was formed to investigate why targets were not being achieved. Table 3 summarizes the salient result of the investigation. Evidently, more than half of the cove hardwoods, and 33 percent of other types, were not available for timber production. Cove hardwoods is the most productive land type on the Nantahala and Pisgah National Forests (NPNF). More than half of the most productive land is not available for production of timber. The conclusion of the investigative team was that the spatial application of plan standards substantially reduced the available acres for timber production.

Table 3.—Reduction in land available for timber supply by spatial factors and land type

Factor	Cove Hardwood	All Other Types
	- - - - - - - percent - - - - - - -	
Riparian Areas	22	4
Roadbeds, nonforest inclusions, tract configuration that restricts access	22	22
Archeology Sites and special habitats	2	2
Old Growth Standard	5	5
Total	51	33

In addition to the above problems, in 1990, former Chief of the Forest Service Dale Robertson ordered a plan revision which was to consider alternatives to clearcutting. The amendment was completed by 1994, resulting in substantial changes to the timber program. New harvest and regeneration methods, along with a more detailed plan analysis, showed that about one-quarter of the land is actually available to meet timber production goals.

This brings us to the to the spring of 1996, when the results of disjointed hierarchical planning became all too apparent. By midyear, 14 of 29 projects had been completed with more than half of the fiscal year projects still requiring analysis! Virtually all fiscal year 1997 projects were short of completion. The pipeline was almost dry. There was doubt about being able to sustain a timber sales program even at the low levels in the revised plans.

Recognizing land availability as an underlying cause, we suspected several reasons for the drop in project completion. First of all, most project efforts involved just one compartment (a remnant of the historic order-of-entry schedule), which dispersed personnel over more areas and diluted the focus of their efforts. The second suspect is the expansion of complex analysis needed to complete a timber sale. In 1988, most timber sales required about a two-page environmental assessment (EA) that was tiered to the forest plan. It is now common for an EA to be 100 pages or more. At this time it was apparent that we needed to refocus on managing the people who do the work.

AN INTEGER GOAL PROGRAMMING FORMULATION

Our goal was to develop at workable system for building timber pipeline, based on reducing the number and distribution of planning efforts and finding ways to document complex comprehensive analysis. The forest management team wanted to come as close as possible to the Pisgah/ Nantahala Strategic Forest Plan ASQ each year over the next 10 years. The problem statement evolved into minimizing deviation from the ASQ set by the strategic plan, subject to the amount of human resources available to develop project plans, but it was not the final problem statement (see the section entitled “Applying the Procedure”). The formulation shown below (equations 1-7) uses a goal programming approach. Table 4 summarizes the variables used in the formulation.

$$\text{MIN} \sum_{j=1}^{m} \left(d_j^+ + d_j^- \right) \quad (1)$$

$$\text{S.T.} \sum_{i=1}^{n} \left(\mathrm{V_i X_{ij}} \right) + \left(d_j^+ - d_j^- \right) = \mathrm{VT} \; [j = 1,\ldots,m] \quad (2)$$

$$\sum_{i=1}^{n} r_i x_{ij} \le RT_j \qquad [j = 1,\ldots,m] \quad (3)$$

$$\sum_{i=1}^{n} b_i x_{ij} \le BT_j \qquad [j = 1,\ldots,m] \quad (4)$$

$$\sum_{i=1}^{n} s_i x_{ij} \le ST_j \qquad [j = 1,\ldots,m] \quad (5)$$

$$\sum_{j=1}^{m} x_{ij} \le 1 \; [i = 1,\ldots, n] \quad (6)$$

$$x_{ij} = [0,1] \; [i = 1,\ldots, n] \quad (7)$$

[j = 1,…,m]

where

x_{ij} = a zero/one variable. 1 if area i is entered in period j.
n = number of areas

m =	number of years in the tactical volume flow pipeline.
i =	subscript for areas
j =	subscript for year
BT_j =	labor time available to survey plant life in year j
ST_j =	labor time available to perform sales preparation activities in year j
RT_j =	labor time available to survey and design roads in year j.
r_i =	labor time needed to survey and design roads in area i.
b_i =	labor time needed to survey plant life for area i.
s_i =	labor time needed for sales preparation activities in area i.
d^-_j =	under achievement of volume target year j
d^+_j =	over achievement of volume target year j
V_i =	estimated volume available in area i
VT =	yearly ASQ goal.

Equation 2 is the goal constraints. There is one for each year in the planning horizon. Equations 3, 4, and 5 are the survey labor constraints, and equation 6 is the requirement that an area is entered no more than once during any 10-year period.

Note that there are three categories of labor required to develop projects: plant survey, sales preparation, and road planning. These three are not necessarily the only categories nor are three separate categories necessary. Assigned tasks are interchangeable to some degree. For example, a silviculturist may be able to perform all tasks while a forest engineer may not be qualified to perform a botanical survey and a botanist may only be able to perform the botanical survey. The next section will discuss various ways of addressing the interchangeable labor problem.

PROCEDURE AND INITIAL SOLUTIONS

Using the above formulation, we wanted to develop and recommended a schedule for planning projects over the next 10-year period. Once this recommendation was developed, each district would review the schedule. Having district personnel judge the reasonableness of the schedule helps increase confidence in it. The following procedure was followed to produce the initial recommendation.

1. We subdivided the NPNF into 113 logical areas for additional study and analysis. Staff foresters call these areas “analysis areas.” The term “analysis area” as used here does not have the same meaning as the “analysis area” used in forest planning. These “analysis areas” are heterogeneous, contiguous areas that represent sensible opportunities for project analysis. These areas average 8,900 acres with a range from 770 to 31,000 acres. To avoid confusion, the term “planning areas” (PA) will be used from now on instead of “analysis areas.”
2. We copied the “Continuous Inventory of Stand Conditions” data base for the NPNF into a Paradox© relational data base. A data field was added for each stand in a PA.
3. We calculated the acreage available for harvest each of the next 10 years. To do this, a series of data screens were constructed to filter out stands not suitable for harvest.
    a) The first screen was based on the early successional species (ESS) standard from the NPNF forest plan (III-29 to III-31). The acreage of allowable harvest available in each PA was calculated using this standard. Using this, the allowable acres in PA’s could increase over the 10 years as stands mature.
    b) The second screen filtered out stands which did not have the minimum age for harvest. This could also increase over the 10 years as stands matured.
    c) We applied the third screen to the acres remaining after (b). The available acres were reduced further for other standards. Riparian areas are a major example of this. A random sampling procedure established that 29 percent of “cove hardwoods” and 11 percent of other forest types were within riparian areas.

d) Finally, we compared the available acres with the maximum allowable under the ESS standard. The comparison revealed that the ESS standard was most restrictive about 90 percent of the time. Therefore, the acres available using the ESS standard was used to complete the analysis.

4. We conducted interviews with specialists on the forest to obtain estimates of time required for project planning up to the National Environmental Policy Act (NEPA) decision. We used an average timber sale of 240 acres comprised of 8 units with 30 acres in each unit. Specialists were asked to estimate the time required to complete required tasks on this average sale. We further assumed that the average sale had medium access. Table 5 summarizes the results from the interviews. The person days per acre and the acres available in an PA over the next 10 years were added to the data base. Available acres change on a year by year basis as the ESS conditions change.
5. We needed an estimate of the work force. Table 6 summarizes the estimate of available work force on the NPNF at the time of the analysis. However, a larger work force could probably be assembled if the forest could not meet strategic goals with existing specialists. We thought that other people could be reassigned to project planning. Consequently, we decided that we could reasonably expect up to 3,000 person days per year available for project planning.
6. The programming language (PAL) in the data base program Paradox© was used to write a matrix generator for the problem. We solved this problem as an integer program with the mathematical programming software ORSYS. The solution provides a schedule of entry for planning areas over the next 10 years that will minimize deviation from strategic ASQ levels.

Table 4.—Results of interviews with specialists: the number of days needed to perform required duties based on a site's access

Specialists	Access		
	Easy	Medium	Poor
Silviculture	50	60	75
Archeology	20	30	40
Botany	8	20	30
Wildlife	8	14	30
Scenery	5	10	20
Aquatics	2	7	20
Engineering	4	4	8

Table 5.—Work force calculations for potential project planning on the Nantahala and Pisgah National Forests

Specialty	Persons	Expected Days/Person/Year	Work Days Available/Year
Silviculture	7	120	840
Archeology	2.33	160	373
Botany	2.5	160	400
Wildlife	2.33	160	373
Scenery	1	160	160
Aquatics	2.33	160	373
Engineering	2	160	320
Total Days/Year			2,839

APPLYING THE PROCEDURE

The solution to the above problem, formulated as in equations 1 through 7, pointed out the need for new operational constraints and a major obstacle. First, even though one of the intents of this analysis was to pool labor resources over the two forests so that an efficient order-of-entry schedule could be found, the initial solution allocated an unacceptable amount of the work to one forest. Now we had a new question to answer: What is an acceptable distribution of work between the two forests? Because of issues involved, it became apparent that the only acceptable distribution was to treat each forest equally. Thus, each forest would be given an approximately equal amount of labor resources to allocate internally. Second, the major obstacle was that ASQ goals were consistently underachieved with the amount of labor available. This problem more or less negated the work allocation problem, and of course, helps explain why the pipeline was going dry in the first place. It also clearly emphasized that the forests needed additional labor resources to meet strategic goals.

A request was made to analyze this new problem. The terms were to find an efficient order for each forest with 1,500 person days available per forest. The labor constraints—equations 3, 4, and 5— were combined into a single goal equation for each forest.

$$\sum_{i=1}^{n} r_i x_{ij} - d_j^+ = RT_j \qquad [j = 1,\ldots,m] \quad (8)$$

where r_i is now the labor time needed to plan area I,

RT_j is the labor time available in period j, and

d_j^+ is over use of labor period j.

The objective now was to minimize deviation from ASQ while minimizing excess labor requirements. Two new solutions—one for each forest—were developed.. These solutions were then taken to each forest where district personnel evaluated solution reasonableness.

Some of the results of the timber sale pipeline are displayed in Table 7. The PA and EA columns shows the total number of planning areas needed to plan for the year and the least number of EA's needed. One of the major benefits, as stated by district personnel, is that by using larger PA's fewer EA's need to be written. We expect to have about one-third the amount of NEPA documents compared with current levels. In addition, adjacent planning areas scheduled in the same year may be assessed in one document. The acres available for timber harvest in the PA's are listed in the "Available Acres" column. These are an estimate of the acres available to meet timber production objectives using the ESS in the strategic plan. Using volume per acre estimates, approximately 3,000 acres per year are needed to meet plan objectives. In 1999, we will have difficulty meeting timber targets. We are scheduled to be short in accessing 860 acres, and in addition, 40 percent of the PA's are rated as high difficulty. This problem needs to be addressed further by the district personnel. The person days column exceeds the goal of

3,000 person days per year every year except 1999. However, it was one of our expectations for the new project planning schedule to more efficiently utilize human resources by focusing effort from many small to fewer large project planning efforts. Hopefully the forests can achieve this efficiency gain, reduce the number of person days required, and be within the expected labor resource. The results of this analysis will be tested over the next 10 years. Analysis estimates of the proper order of entry for project planning will be judged a success if the strategic level ASQ is satisfied with existing personnel (i.e., if the pipeline doesn't run dry). The solution contains both a quantitative element (the integer goal program) and a qualitative element (the knowledge and experience of the forest's staff). If insufficiencies are found with this solution, it is the responsibility of management to make adjustments and move to a better solution.

Table 6.—Summary of project planning schedule: number of planning areas (PA's), environmental assessments (EA's), available acres, and person days required for sales preparation by year on the Nantahala and Pisgah National Forests

Year	PA's	EA's	Available Acres	Person Days
1997	14	11	3507	2727
1998	12	10	4057	3039
1999	10	10	2140	3193
2000	11	9	4160	4200
2001	10	9	4321	4018
2002	10	9	4933	4541
2003	10	9	4362	3903
2004	10	9	4485	3587
2005	88	8	4235	3183
2006	12	10	5116	3527

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