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MULTIPLE USE RESOURCE MANAGEMENT ON NATIONAL FORESTS VIA GOAL PROGRAMMING.

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Multiple use resource management on

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I. INTRODUCTION

A. Problems and General Objectives

Multiple-Use forestry is defined in Terminology of Forest Science, Technology, Practice and Products (Ford-Robertson, 1971; p. 175) as: "any practice of forestry fulfilling two or more objects of management, ..., e.g. production of both wood and pasture".

The distinguishing part of the definition is the phrase "two or more". The forest manager practicing multiple use forestry is concerned with producing a multitude of products. The manager is concerned not only with timber production, but also with such products as recreation, water, forage, wildlife, etc.

Multiple Use forestry presents new problems to the forest manager; primarily more complicated resource allocation problems. The multiple use forest manager is concerned with producing the "best" mix of goods and services from the forest. Some of these goods are of a complementary nature (some timber harvesting is advantageous to wildlife production via habitat improvement), yet others are definitely of a competitive nature (full utilization of forage reduces timber yields). Some goods are "market goods" in that they are bought and sold every day (timber for example), however items such as wildlife and recreation are better classified as nonmarket goods in that many consumers are of the opinion that they should be provided free of charge, or, at most, a nominal fee, to the public according to Duerr (1963). In fact, in the past, recreation and wildlife production was viewed as a by product of good timber management by most forest managers including public land managers.

1. Role of the USFS (United States Forest Service)

The USFS, being the major federal agency responsible for the management of public forest land, is intricately involved in the multiple-use management problem.

Administrative responsibility for the National Forests (NF) was delegated to the Secretary of Agriculture and the Forest Service via the Organic Administration Act of 1897:

> ...the Secretary of Agriculture shall make provisions for the protection against destruction by fire, and depradation upon the public forests and NF ... and he may make such rules and regulations and establish such service as will insure the object of such regulations, namely, to regulate their occupancy and use and to preserve the forest therein from destruction... .

Hence, it only seems expedient to focus attention on the type of problems the USFS encounters in attempting to practice multiple use forestry.

2. Focus of study

The main focus of this study will be on developing an analytical framework from which one can analyze the available data (the inputs), in light of the management objectives, for the explicit purpose of evaluating available management strategies. Determination of the best mix of goods and services from the forest is a desired result. The forest manager will usually have several management strategies open to him. In order to choose among strategies, the manager must know what the trade-offs are in accepting one strategy over another. The main idea here is to analyze the very important interdependence of forestry activities and resources with the hope of determining the potential of an area to meet management goals.

The multiple use forestry problem is essentially a resource allocation problem. Scarce resources (forest land, labor, and budget) must be allocated to various management activities in order to produce the desired mix of goods and services. In allocating resources, knowledge of objectives and their relative importance; valuation of goods and services; and knowledge of the relationship between resources and end products is very necessary. The degree to which one can specify these items will, ultimately, limit the type of analysis which can be performed. This study will suggest an approach which is flexible enough to work with the extensive range in sophistication of information available to the public forest manager. In some instances, the manager will be limited to strictly ordinal ranking of objectives; in other cases, the manager will have sufficient information to specify cardinal weighting of objectives. Other types of information such as production coefficients and goal level specification will vary in the degree to which they can be identified in an objective way.

Basically, this study will deal with the question; given the objectives of management and their constraints, how should one allocate resources to various management activities in order to provide the best mix of goods and services?

The type of analysis used in this study is understandably affected by two major practical considerations:

1. data availability
2. current methodology (the way decisions are now being made).

The study attempts to answer questions which the public forest manager feels are important and relevant to his particular decision making environment. No attempt is made here to suggest how things should be. The study takes as given the goals of management and the type of information available to him. With this information as given, the study focuses on the problem: how can one best meet stated objectives via a well coordinated management plan? Alternative management strategies will be evaluated in light of management objectives and operational constraints.

B. Historical Development
(of the Multiple Use Problem)

The USFS has, for a long time, been faced with the problem of determining the products for which they should manage the National Forests. This is a natural consequence of the changing needs and wants of the American people over time. The National Forests and the USFS were created by the Organic Administration Act of 1897 (30 Stat. Sec. 34-36) with protection and preservation of public forest land being the primary concern. The major product was timber as it was needed to build homes; hence the Act of 1897 specifically mentions the necessity to furnish a continuous supply of timber for the use and necessities of the citizens of the United States. As time elapsed, the needs of the American people changed and these changes required a shift in direction for the management of the National Forests. The shift was essentially one from forest protection to resource management.

Several developments have contributed quite heavily to the changing needs of the American people over the past sixty years. The population has become much more urbanized; mobility has increased tremendously; the standard of living has continually increased; and quite recently, there has been the development of a "conservation ethic" among a great number of our citizens.

These developments have significantly affected the types of goods and services desired from the National Forests. Protection and preservation are still considered very important as is timber production. However, recreation of various kinds, hunting, and grazing are considered much more important than in the past. One needs only to look at the degree to which our National Parks and National Forests are filled with recreationists each year; and the tremendous number of hunters and fishermen who take to our public lands each year. The emergence of various conservation groups such as the Sierra Club, the Audubon Society, the Issac Walton League, etc. indicate the continued concern for the conservation of our public forests.

1. Multiple-Use and Sustained Yield Act of 1960

Until the passage of the Multiple-Use and Sustained Yield Act of 1960 (MU-SY), (74 Stat. Sec. 215), the USFS did not have a clear cut legislative mandate to use as a guide for multiple use management.[1] Consequently, there was continual pressure on the USFS from groups with conflicting interests such as private timber producers, and conservation groups, to promote management practices which favored their positions or welfare. There was a definite need for official management direction.

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[1]Alston (1972) has provided a good summary of the legislative mandate for multiple use forestry, which evolved over a period of approximately sixty years (1897 -- 1960).

The passage of the MU-SY act has probably done more to promote the concept of multiple use management than any other event in American history. It is the first truly, relatively unambiguous federal legislation, giving the USFS a mandate to manage public lands with multiple use being the overriding forest policy guideline. The MU-SY act has focused attention on what goods and services are to be considered in the decision making process.

It is in the MU-SY act that Congress lists all of the renewable surface resources to come under the management of the USFS:

> ...It is the policy of the congress that the National Forests are established and shall be administered for outdoor recreation, range, timber, watershed, and wildlife and fish purposes. ...The Secretary of the Agriculture is authorized and directed to develop and administer the renewable surface resources of the NF for the multiple use and sustained yield of the several products and services obtained therefrom. In the administration of the NF due consideration shall be given the relative values of the various resources in particular areas.

The above statement from the MU-SY act specifically mentions the various goods and services which must be considered in any management decision. The National Forests are not to be managed for just one good; all goods are to be given due consideration depending on their relative values.

Presumably, it is left to the discretion of the local forest manager to determine the relative values. Alston (1972) mentions that nowhere in the legislation is there any definite indication as to what priority system the administrators of the MU-SY act are to follow. Ridd (1965) mentions the possibility that priorities would be determined in light of the dual considerations of local site capability and consumer demand for the various products.

2. Two concepts of multiple use

In discussing the history of multiple-use forestry in the United States, one must be aware of two very different concepts of the multiple-use philosophy. These concepts have developed over time and differ primarily in the framework suggested as viable in managing for the various goods and services.

a. Dominant use concept G. Pearson (1943) was probably one of the first to promote what is now called the "dominant use" concept by Hall (1963) and others. Pearson (page 243) described his view of multiple-use as: "an adjustment to the site, seeking to develop each use to a high degree of efficiency on the lands best adapted to it". Pearson (page 243) compares multiple use with the better class of farms in the Mid West:

> ...the most level and fertile lands are devoted to grains and hay; sloping lands are those disected by drainage courses and are used for pasture. If there are any sandy soils, they are likely to be planted to orchard, and rough lands or those subject to overflow are kept in wood lot. The progressive farmer may also derive some revenue from the sale of hunting privileges. There is a place and fine for every activity. When crops have been harvested, cattle are turned into the fields to salvage waste and utilize volunteer growth. Hunters are barred from fields until after the harvest.

Pearson implies that, although multiple use may mean several simultaneous uses of an area, it also means that areas highly suitable for one use should be managed primarily for that use. For example, areas highly suitable for timber production should be managed primarily for timber products. Other uses should be allowed as long as they are compatable with the primary use. Unfortunately for Pearson, his article was interpreted by many people as saying that timber production would be the primary use in most cases, i.e. recreation, grazing, water, etc. would not be considered, except as an afterthought. According to Hall (1963), the dominant use concept is based on the belief that land should be used to the fullest extent possible and that priorities must be established.

b. Equal priorities concept At the same time Pearson (1943) wrote his article, Dana (1943) wrote an article on multiple use emphasizing the importance of considering forest products other than timber; such as grazing, wildlife, water and recreation. Dana (1943) suggests that forest areas can and should produce more than one product at a time. He mentions the fact that, although some uses are incompatible, many are compatible in varying degrees. The approach to multiple-use proposed by Dana has been called the equal priorities doctrine by Hall (1963).

There are two basic tenets of the equal priorities doctrine as listed by Hall (1963, p. 278):

> 1. "Multiple use involves harmony & coordination of uses, but does not necessarily require a combination which produces the maximum yield per acre of land of any one output. Nor does it require the combination which produces the maximum economic benefit."
> 2. "No one use has priority over another."

3. Multiple use today

These two doctrines have been the source of a long controversy. This controversy is still continuing, although there is an apparent trend toward more widespread acceptance of the dominant use concept.

Two major Presidential commissions have sought to clarify multiple use. The Public Land Law Review Commission (PLLRC) (1970) suggested that incompatible uses of forest resources on public lands be more thoroughly segregated than was then common practice. It did this via three recommendations. Number 4 suggested that management of public lands should recognize the highest and best uses of particular areas of land as dominant over other authorized uses. Number 78 called for the prompt identification and protection of areas of high scenic, aesthetic, and recreational value on the public lands. Number 28 suggests that dominant use timber production units be created and timber management in them intensified with additional investment in practice to increase and improve growth. All of these recommendations sought to separate incompatible uses and to assure that particular levels of benefit will actually be received (e.g. the increased growth due to investment in timber management).

Unfortunately, these recommendations were interpreted in a way apparently not intended by the author of the PLLRC recommendations. The PLLRC report was widely interpreted to be calling for timber as the dominant use on all public forest land. Furthermore, dominant use on any area for any purpose was interpreted to mean total exclusion of all other uses. The result was a major public outcry, and a resounding defeat for the Timber Supply Bill of 1970. Ambiguity of language in the report of the PLLRC and certain peculiarities of the Timber Supply Bill certainly contributed to this result. But, the fact is that a rather carefully resolved case for the dominant use concept was lost in largely semantic confusion.

The next attempt to clarify multiple use was made by the President's Advisory Panel on Timber and the Environment (1973). This panel was created after a period of high and unstable timber prices, inflation, keyed in some modest part to housing and raw material costs and rising conflicts over use of forest resources. Thus PAPTE was created to reconsider problems which the PLLRC failed to solve at a practical level since its recommendations were so widely misinterpreted.

The Presidents' Advisory Panel made many recommendations dealing with a whole gamut of topics. Its recommendations relating to the continuing multiple use controversy can be usefully simplified as follows:

a. Separate seriously conflicting uses by promptly designating additional wilderness areas and other areas with high recreational value;

b. Substantially increase the investment in timber management on designated areas through more long-term financing;

c. Then, increase timber harvest from these designated areas will be possible;

d. Create a national forest policy for resolution of any remaining conflicts.

The recommendations of the Presidents' Advisory Panel initially met a fate somewhat like those of the PLLRC, although the sources of the difficulty are more apparent. The Office of the Management and the Budget (as reported in an analysis and editorial in the September 26, 1973 issue of the Portland Oregonian) reacted unfavorably toward all of the recommendations except the one for an immediate increase in timber cut. Thus, the controversy continued still larger.

There are, however, some hopeful trends toward resolution of this controversy. Perhaps the most important has been a major conference in May 1974 sponsored by the Resources for the Future. This conference brought together a large group with diverse and potentially conflicting interests in forest resources. Marion Clawson (1974) carefully analyzed principal uses of forest resources. He found many uses quite compatible, e.g. wilderness, watershed use, and some wildlife values. But, he found three uses highly intolerant of each other particularly when vigorously pursued: wilderness, intensive recreation, and intensive timber growth and harvest.

Both Clawson and other participants in the conference suggested greater separation of incompatible uses. They further suggested creation of a coalition of interests to achieve the decisions and financing necessary to bring this about. Lee James (1973) and Con. Schallau (1974) have also made similar suggestions. While concensus was less than complete, and this is still more hope than fact, the public concensus necessary for actual clarification of multiple use does seem much closer.

The suggestion by James (1973) to classify lands into various tracts is probably the most recent attempt at transforming multiple use from a "concept" to a "practical policy". It is a positive indication that land use planning, in some form or another, is coming to public forest management. James (1973) discusses the possibility of a shift toward managing land in separate tracts whereby incompatible uses are provided for on separate tracts. This practice avoids the conflicts in use which are so apparent when attempting management of mixed-use tracts.

There are still two major questions which must be answered before one can usefully apply multiple use forestry via the forest zoning idea presented by James (1973).

1. Area - what size area is one talking about? Ridd (1965) stresses that multiple-use is an area oriented concept which consists of a mosaic of uses on an area. It is not required that each acre in question be utilized for all possible uses. One unit may emphasize recreation, another hunting, another timber, etc. The idea is that the area (made up of individual units) is to be considered as a multiple use entity. The area should be large enough to provide sufficient latitude for periodic adjustment in use (rotation of units for example) to conform to changing needs and conditions. Habitat requirements of wildlife, for example, would be a major factor in determining the size of a unit devoted primarily to wildlife.

There is a trend toward larger areas (100,000 to 200,000 acres) versus smaller areas (10,000 to 50,000 acres). It seems that application to larger areas facilitates the practice of management strategies designed to alleviate conflicts. Larger areas allow a more complete interface among the various uses of the forest.

2. Dominance - How dominant is the dominant use? Dominant use should not mean the pre-emption of other, secondary uses. Secondary uses on a unit should be allowed to

the extent they do not seriously interfere with the primary use.

There are variations in intensity of conflict among forest uses on public land as one travels from one region of the country to another. Relatively few conflicts occur when there is ample public forest land to accommodate all uses and quite naturally, few conflicts arise where there is an absence of public land. Major conflicts develop when regions exhibit the following characteristics:

1. relatively dense populations;
2. less than adequate amount of public land to accommodate all potential users;
3. significant development of a "conservation ethic".

Portions of the western and eastern United States exhibit all of the above characteristics, hence they are regions in which the intensity of conflict is greatest.

The Midwest in an area where conflict is relatively light for the very same reasons that portions of the west and east are designated otherwise. Southwestern Missouri, the focus of attention for this study, is a case in point. The population density in SW Missouri is quite low; there is more than adequate public land (including state land) to accomodate potential users; and the "conservation ethic" is in its infant stage in this area. The infant stage of development of the "conservation ethic" here is understandable to this author because he feels the "conservation ethic" developed in other areas primarily as a response to an obvious scarcity of forest resources. Forest resource scarcity is not as apparent in SW Missouri. Other additional items, can, perhaps, account for the low level of conflict in SW Missouri:

1. poor condition of the timber product markets;
2. low capacity of the land to produce timber products;
3. sizable State forest management program.

These items indicate the reduced level of importance of timber products in the immediate area, hence reducing possible conflicts between timber use and recreation or hunting. Also, the State Conservation Department has absorbed some of the demand for forest products in the area, thus reducing pressure on the Forest Service.

II. PROCEDURES

A. Multiple Objective Decision Making in General

When an agency such as the USFS applies multiple use forestry, they are essentially confronted with a multiple objective[1] decision making problem. One approaches the problem in much the same way one would approach any decision making problem. The decision maker goes through a series of steps as listed by Ackoff and Saseini (1968) and shown in Fig. 1:

1. Identify the problem;
   a. define the possible courses of action; i.e. identify the controllable variables
   b. define the environment; i.e. the uncontrollable variables
   c. define the criteria of choice; i.e. the objectives and their relative importance
2. Implement the selected course of action;
3. Compare the results with the desired results;
4. Make adjustments if necessary.

The major difference between multi-objective decision making and single objective decision making is in defining an acceptable criteria of choice (step 1c). The multi-objective

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[1]For purposes of this thesis, objectives and goals will be used interchangeably, i.e. they will both take on the same meaning.

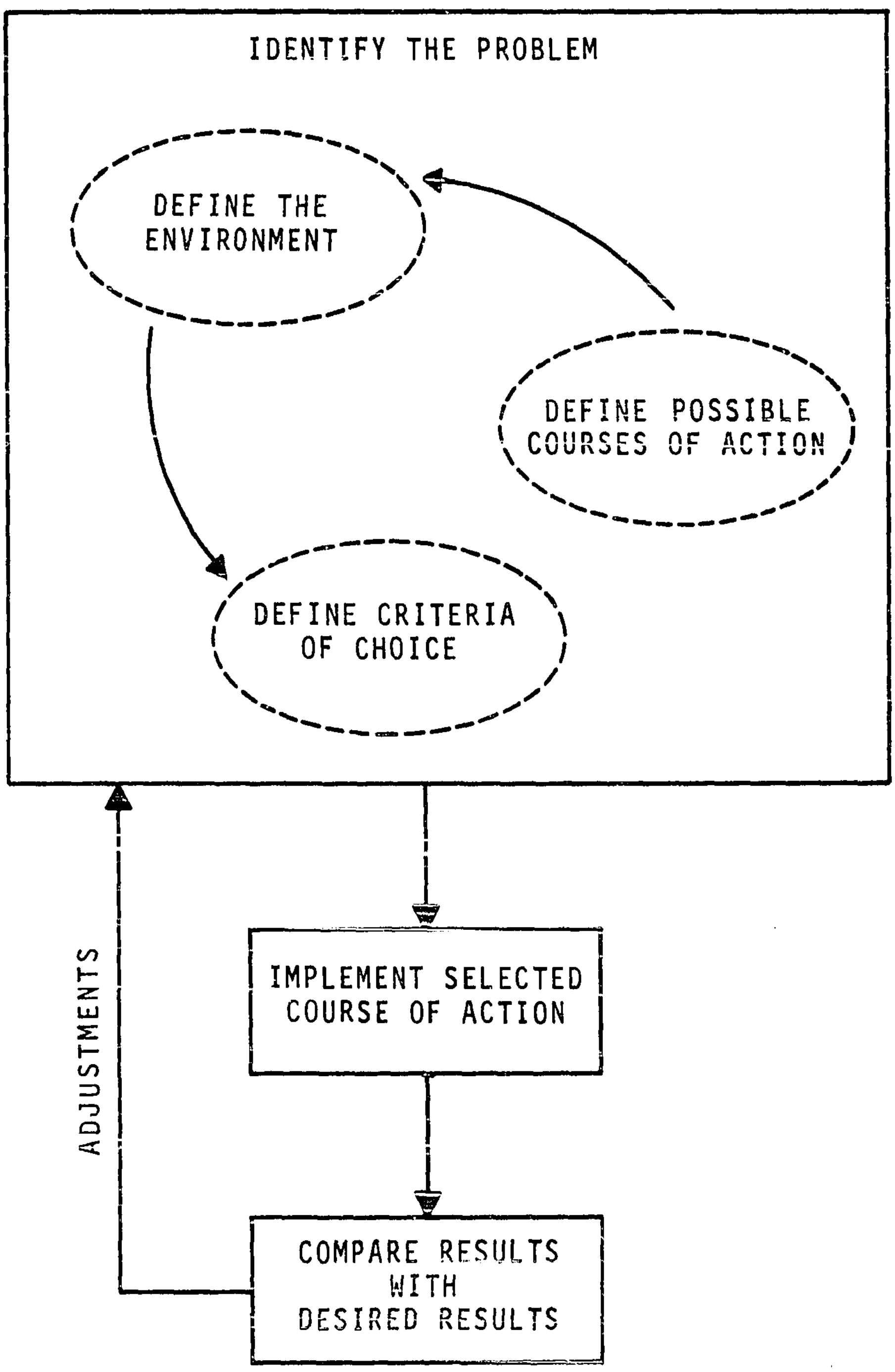

Fig. 1. Steps in the decision making process

decision maker often requires a criterian which is multi-dimensional in nature; i.e. a criterion which allows one to evaluate sometimes, conflicting goals which do not necessarily have a common denominator, such as profit maximization or cost minimization. In defining a criterion of choice in this situation, one must deal with the goal ranking problem.

Very seldom can all goals be met with existing resources; if they could, one would not need the science of economics. Complicating the problem is the fact that sometimes, the goals are incomparable. The decision maker indeed has a problem in that the relative importance of the various goals must be determined as well as possible.

In order to determine the relative importance of the goals, the analyst will need to examine his own set of circumstances. What is more important to his situation; pulpwood production or recreation production; forage production or saw-log production; etc. The relative importance of the goals will ultimately depend on the objectives of management. The MU-SY act of 1960 however, does not state how the various goals are to be ranked.[1] The act simply suggests that relative value of goods and services in each area are to be considered in the decision making process.

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[1]Ranking, ordering and weighting will be used interchangeably in this thesis. This will be to avoid confusion in interpretation during the development of the thesis.

There are two major ranking schemes which one may turn to for assistance:

1. Pre-emptive ordering or <u>ordinal ordering</u>;
2. Archimedean or <u>cardinal ordering</u>.

1. Archimedean ordering

Archimedean ordering is a type of weighting system whereby outcomes (goals, activities, deviations from goals, etc.) are treated as being of the same order of magnitude. This ordering system is often used in conventional linear programming applications and applications of the classical economic models. The relative importance of each goal or activity is indicated via a cardinal value. For example: the objective function, maximize $z = 2\ x_1 + 4\ x_2$ implies that x_1 and x_2 are of the same priority level, but x_2 is twice as important as x_1.

The problem with archimedean ordering is that knowledge is required of the decision maker, (the weights), which is often, simply not available. There are many situations where the decision maker cannot say: x_2 is twice as important as x_1; all that one can say is that x_2 is more important. This sort of problem is very common in situations where one is evaluating multiple objectives, of which some are incomparable or incommensurable.[1]

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[1]Incommensurable goals are one which are not measured via the same unit of measure. Examples are cubic feet of timber, and visitor days of recreation or hunting.

One approach to the multi-objective-incommensurable-goal problem is where one minimizes the weighted deviations from specified goals. Although this approach (this approach, called goal programming, will be thoroughly discussed later) shows promise, one still is confronted with the difficulty of determining weights for the goal deviations.

Field (1973) has noted that the decision maker may not be willing to value deviations from goals on an equal basis. This would require one to weight deviations from goals within a particular priority level in order to express the relative loss associated with one unit deviation in comparison with another. In forest multiple use management, the decision maker does not even know the market value of some of his goods and services. How can he then be expected to weight deviations from these goals in a cardinal sort of way?

2. Pre-emptive ordering

Pre-emptive ordering, or ordinal ordering, as it is generally called is very different from the cardinal ranking procedure. Ordinal ranking separates outcomes into different orders of magnitude. Mathematically, this implies a relationship among outcomes such as the following:

$$P_j >>> P_i$$

where the P_j priority factor means that the associated outcome must be achieved as much as possible before any attempt is made to meet the outcome associated with the P_i priority factor. In addition, when meeting lower ranked outcomes, the pre-emptive ranking procedure prevents any diminishing of previously achieved, higher ranked outcomes.

Admittedly, this sort of ranking is very strict, however, according to Lee (1972), it seems to parallel the mode of thinking of the multiple use decision maker of today. The parallelism is even more striking when the complexity of the situation increases. The multiple-use resource decision maker is much more capable of stating ordinal preferences for outcomes rather than cardinal preferences.

Multiple use resource management, with its multiplicity of conflicting and incomparable goals, requires a ranking system which is compatible with the decision makers capability.

3. Approach of study

Multiple-use resource decision making involves both value judgements and facts. Bentley and Davis (1967) discuss the importance of separating facts and value judgements in analysis and decision making. They mention that resource decision making is concerned with both market valued and nonmarket valued goods in addition to institutional issues such as tax revision and private uses of public land. Value judgements are a necessary part of resource decision making, especially public resource decision making.

Bentley and Davis (1967) emphasize the difference in the role of the analyst and the policy maker in resource decision making. The roles are not to be confused; they should be entirely separate. The analyst should present available facts to the decision maker, who, in turn makes value judgements in developing resource policy.

This study is concerned with helping the analyst do a better job by providing the policy maker with as much relevant information as possible.

The approach of this study has been to develop an analytical framework which is capable of meeting the needs of the USFS in applying multiple use forest management. Essentially, alternative techniques to multiple use decision making were studied with the aim of identifying a technique well suited to the decision making circumstances in the USFS. A major criterion in identifying the technique will be its ability to handle resource allocation problems which have multi-dimensional objectives. The decision makers' capability in ranking goals or objectives will also be an important criterion.

In studying alternative approaches, two basic categories were delineated:

1. Subjective approach;
2. Economic/Quantitative approach.

It is felt that there is a need for both the subjective and quantitative/economic approaches due to the varied circumstances affecting public forest management decision making.

The federal government is concerned with both economic (efficiency) objectives and noneconomic (employment, societal well being, etc.) objectives. There is an important role for each approach in the decision making process. That role will now be discussed as the two approaches are presented.

B. Subjective Approach (Heuristic Approach)

The subjective approaches have developed over the years as an alternative to the more quantitative approaches. This development probably came about due to the very demanding nature of the data needs of the quantitative approaches. Many people believe the decision making problem facing the multiple use resource decision maker is so large and complex that quantitative approaches are rendered inadequate.

These same people suggest a more general approach to decision making, an approach which is not as demanding in terms of data needs.

The subjective approaches can be grouped into two categories:

1. Verbal;
2. Mapping.

1. Verbal techniques

The verbal approaches begin with the intuitive technique whereby the forest manager, wildlife biologist, grazing expert, etc. walk out onto an area and, decide among themselves, what the management strategy should be. They might take with them information in the form of type maps, compartment maps, stand inventories, etc. and prescribe, on the spot, a management plan for the area. This is probably the simplest of the verbal approaches and was probably adequate for decisions concerning management direction in the past.

Hewlett and Douglass (1968) have extended the verbal approach to incorporate more objectivity into the decision making process. They use a qualitative rating of management practices in a study involving a watershed in the Coweeta Basin in North Carolina. They have developed a working model of a multi-purpose watershed. In order to evaluate conflicts among uses, they have developed some qualitative ratings on the basis of comments by visiting specialists, day to day observations on the site, and research results. The effect of management practices is rated by pluses, minuses, and zeros to indicate favorable, unfavorable and no appreciative influence respectively, on resource or resource use. In their study, no attempt was made to put dollar values on the resources.

An overall summary of management practices can be developed by adding the pluses and minuses to determine the percentage of interaction, complementary or supplementary use.

Clawson (1974) has used a similar approach to describe the degree of compatibility among various forest uses. He described the interaction among forest uses via a verbal description such as the following (p. 115): Interaction between "maintaining an attractive environment and;

a.) wildlife -- "compatible to most wildlife, less so to others"

b.) wilderness -- "not inimical to wilderness, but does not insure"

c.) natural watershed -- "fully compatible"

d.) wood production and harvest -- "limited compatibility, often affects the amount of harvest".

An approach by Mack and Myer (1965) is an example of a combination verbal-analytical technique. Their approach is actually an application of the social account[1] format in evaluating decisions in outdoor recreation. They develop a "merit weighted user-day" technique to measure recreation benefits of alternative park locations. A social account format of data is presented to the policy maker for his use in decision making. There are both monetary values and subjectively determined merit weighted user days in the analysis.

The social account framework seems to have some potential for analyzing problems where nonmarket goods are involved. In addition, the use of social accounts allows for the separation of facts and values in decision making as noted by Bentley and Davis (1967).

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[1]Social account, described by Kuhn (1962, p. 13), is a technique whereby one views the economy in accounting terms. One has benefits and costs (both internal and external) listed in tabular form in order to present the policy maker with all facts available concerning policy consequences.

2. Mapping techniques

The use of mapping techniques is yet another attempt to incorporate some objectivity into the decision making process. Mapping techniques can be very helpful in visually depicting the very complex interrelationships among resource use.

Webster and Meadows (1973) mention the use of mapping procedures as being useful to land use planning, which is basically what multiple use is all about. They mention specifically the use of overlay techniques which allow one to superimpose a set of cultural and natural features suggesting patterns of land use.

These overlay techniques have proven to be very useful for certain stages in resource and land use planning. They are particularly helpful in identifying and displaying resource capabilities for an area. The determination of resource capabilities for the Ozark Highlands, the subject area of this study, was developed via the mapping and overlay technique. Webster and Meadows cite the extensive use of mapping techniques in the acquisition of new recreation land in Wisconsin.

Another mapping approach by Streeby (1970) has applied Litton's (1968) classification scheme to a sixteen mile strip of highway along the Sierra National Forest in California. This is basically another mapping approach, whereby, areas are classified via Litton's classification scheme in order to evaluate aesthetic attributes of the landscape and as a means of evaluating the impact of increased scenic production in terms of other goals. The purpose of the approach is to give the land manager keener insight into the alternatives for scenic management.

The use of the computer has added yet another dimension to the mapping approaches. The computer allows the resource planner to incorporate voluminous amounts of data in developing his information display system. There are many systems available, differing mainly in the types of information handling capacities and techniques. Essentially these systems accept a variety of information, store it according to geographical location, correlate the information to determine interrelationships, and display the information in map form and, in some cases, summarize the information in report form. Row and Schmelling (1971) summarize the information display systems available through the USFS.

The various systems make use of such information as area type maps, aerial photos, resource statistical data, field surveys and administrative documents.

3. Discussion

The subjective approaches discussed can play a very important role in the multiple-use resource decision making process. Their usefulness lies in their ability to display and somewhat categorize conflicts in complicated situations. They are potentially useful in partially bridging the gap between the analytical techniques and the political concensus concerning resource management goal priorities. This is an area where there are many serious problems according to Webster and Meadows (1973). The analytical techniques are better adapted to analyzing economic objectives, however, many objectives of public forest management are noneconomic in nature.

The verbal and mapping techniques could be very useful to the decision maker in another respect; that of soliciting support for programs. A visual or verbal description of the situation, depicting possible conflicts in resource use, is much easier to understand than a table of figures with the same message. Goals of the public land manager are often, and rightly so, determined via political consensus. This is necessary due to the nature of public goals which often defy analysis via conventional analytical techniques. There is a need to keep legislators and the public informed as well as possible. It is the feeling of this writer that the subjective approaches can play an important role in this goal identification and ranking process.

For purposes of this thesis, however, we are assuming the goals are already determined and one must therefore answer the question; how can one meet these goals? It was felt that a more analytical technique was needed to analyze this question, hence the emphasis on analytical techniques.

C. Quantitative/Economic Approaches

The qualitative techniqes do not, in general, provide the type of information desired from this study. Specific information was desired such as: what are the trade-offs involved in selecting one management strategy over another?; how well one can meet a set of goals with existing resources? It was felt that there was a definite need to quantify decisions. The subjective approaches did not seem to have much potential for answering these types of questions. They are specific questions requiring specific answers to problems facing the contemporary multiple-use decision maker.

The economic/quantitative approaches are better suited to the needs of this study for several reasons:

1. They are much more repeatable than the subjective approaches, hence one can question and revise them more freely and fully;

2. Alternative strategies are much easier to analyze due to the greater quantification of decisions;

3. Information is transformed into a more usable form; i.e. basic information can usually be condensed into a form which the decision maker can evaluate in a more objective way;

4. It was felt that the major objectives of managing forest land, for this study, were economic and hence could be best analyzed via economic approaches. The actual goals for the unit were already specified; the next question was how

best to meet the specified goals. The noneconomic objectives of management were already incorporated via the goal setting process itself;

5. In addition, the quantitative/economic approaches can be helpful in analyzing the consequences of management decisions, thus enabling a check on the consistency of goal setting. As mentioned previously, due to the institutional arrangement of our government, goal setting, which includes both economic and noneconomic objectives, is best determined via the political arena where noneconomic objectives are more adequately taken into consideration. The quantitative/economic approaches could be useful in determining whether or not the goals specified are reasonable or feasible from the point of view of economic criteria. Also, some of the economic/ quantitative techniques such as linear programming are especially helpful in delineating feasible and nonfeasible goals from a physical constraint point of view.

Therefore, the quantitative/economic technique was chosen as the most appropriate for the problem stated in the beginning of the thesis. A next step was an analysis of the quantitative/ economic techniques previously used in resource management in order to identify a technique well suited to handling the multi-dimensional goal problem.

The investigation of the quantitative/economic techniques indicated that such approaches could be separated into three principle categories:

1. Simulation techniques;

2. Maximizing techniques;

a.) investment criteria such as internal rate of return (IRR), present net worth (PNW), and benefit/cost analysis

b.) classical economic theory with emphasis on the joint production model (JPM)

c.) linear programming models

3. Satisficing techniques;

a.) goal programming.

1. Simulation

Simulation is a modeling technique which has been expanding in use quite rapidly due to recent developments in computer technology. It is a systems approach which attempts to look at the whole management picture rather than just one phase of it. It is not generally viewed as an optimizing technique.

In order to study a system[1], models are developed. The

[1]There are many definitions of a system. A simple and basic one given by Gordon (1969, page 1) is: "...an aggregation of objects joined in some regular interaction or interdependence." The movement of cars through a city is aided by a traffic system for example.

models[1] are used as part of the system simulation as a technique in solving problems by following the changes in the model over time (Gordon, 1969). The models actually simulate responses to changes in the system over time.

Row and Schmelling (1971) describe the various types of response simulation systems used by the USFS. Some of these systems are dynamic (dealing with more than one time period), while others are probabilistic (as opposed to the deterministic models).

Simulation, as it has been applied to forest management, has been primarily as a prediction device. Clutter and Bamping (1965) discuss the use of simulation to predict future events in order to carry out intelligent planning in a forestry enterprise. They mention the very important fact that: "...if we cannot predict the future outcomes that will result from various programs, the selection of an optimum program is essentially impossible" (Clutter and Bamping, 1965, p. 180). Prediction is used in this thesis, as in the study by Clutter and Bamping (1965), to mean simulating forest management operations, via models, over time. This is done in order to determine what the operation will look like as it moves through time. Essentially, one can lay out consequences

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[1]The model is a representation (usually an abstraction) of the system and includes the important relationships in the system.

of alternatives by allowing parameters of the model to change in order to determine effects on the system. It should be noted that, for purposes of this study, prediction will not mean forecasting in the usual econometric sense. Econometric techniques are used to forecast, for example, that the average price of stumpage will be "x" dollars in 1985.

The Clutter and Bamping study, typical of many simulation applications to forestry, was applied to a hypothetical industrial forest of some 300,000 acres, located in Georgia and South Carolina. The model simulated the actual biological and economic characteristics of the forest over a period of years. By properly adjusting the parameters of the model, one could evaluate forest responses to various changes over time. Specifically, they were trying to predict responses of the forest to changes in growth rate, cutting regimes, and cutting practices. They used the model in order to compare two specific management regimes; an area regulation harvesting procedure, and the financial maturity procedure.

Morgan and Bjora (1971) used simulation techniques in a similar manner, however, the model was aimed at the problems of corporation planning. They mention that a particular concern of corporate planning is the process of identifying alternative medium and long range strategies, evaluating them with respect to one or more criteria, and presenting them to managers of the enterprise so that they may decide on the most suitable course of action for the enterprise to follow.

Simulation has shown to be very helpful in the second problem: that of evaluating alternative strategies.

The model developed by Morgan and Bjora (1971, p. 104) "...takes the enterprise in its initial state, as described by the input variables (which include cutting and new planting plans) and simulates, year by year, the physical program and financial results which follow from the initial state".

The model, as developed, has been shown to be primarily useful in evaluating cutting and planting plans, which are certainly part of ones needs in developing an overall multiple use plan for an area.

A similar study by Sayers (1971) is a fairly elaborate simulation study comparing plans of management on private forestry estates in Scotland.

There have also been many applications of simulation to yield and growth studies. A typical example by Bella (1971) is a simulation model examining new approaches for evaluating inter-tree competition effects; representing actual tree spatial arrangement, defining interactions between increments of height and DBH, and representing random components of variation in tree growth and mortality. The purpose of the study was to simulate aspen stand growth and productivity under varying site conditions in order to determine the optimum rotation age for volume or weight. This sort of study has also been useful in predicting effects of changes in parameters on the stand; or predicting stand response to different treatments. This sort of information is needed by the decision maker in order to evaluate alternative management strategies.

a. Discussion Simulation offers an alternative to the linear programming techniques often used in forest management planning. There are advantages to the simulation approach such as providing more detailed information to the decision maker according to Sayers (1971). In addition, the simulation practitioner is not constrained by model assumptions such as the additivity, linearity, and proportionality assumptions of the linear programming model. The simulation technique allows one to simulate forest responses to changes in parameters over time, i.e. to simulate the effects of present conditions and proposed changes in management activities over time.

This forecasting feature of simulation is significant due to the importance of management planning projections in the decision making process. Simulation could be a very useful tool to the resource manager by helping him to remove some of the uncertainty from the decision making process.

The simulation approach is not without its disadvantages such as the significant data requirements. In addition, there is the complaint that it does not force the decision maker to look at values as does the optimizing linear programming models.

The simulation model does not have an objective function and hence, does not have a system for weighing values that must be taken into account. In place of a formal objective function, simulation relies on the decision maker to look at possible consequences of courses of action thus allowing the decision maker to make decisions on a more subjective basis.

It is the feeling of this author that there is a place for simulation in multi-objective planning. It might be best used in conjunction with an optimizing technique which will allow the decision maker to compare, via an appropriate criterion (preference function), the alternative management strategies. The Resource Capability System (Dyrland, 1973) is a good example of the case in point. Simulation is used to depict the effects of various management activities on outputs such as streamflow, forage, fish, wood, and recreation. These effects are then used as inputs in a linear programming model which is designed to evaluate different management strategies in order to efficiently allocate scarce resources.

Simulation has a particularly useful value in a very practical sense for situations where existing optimization models are not feasible. Optimization models require some form of objective function thus presenting difficult valuation problems, especially in the realm of forest management. The simulation model could be useful in presenting consequences of alternative actions, thus allowing choice to be made by a policy board or legislative committee (as often really happens).

In the future, there will be increasing competition for the use of the land base in addition to the increasing demand for forest products such as recreation, forage, hunting, water, and timber products. The competition for the land base will come, both from nonforest users such as industrial and residential developers, and competition from within the forestry ranks. This intense competition calls for greater skill in using the land base now available. Simulation can play a very important role in this process by providing the decision maker with necessary information concerning the effects of various management activities on forest outputs. This information can then be used as an input into an optimizing model such as linear programming in order to evaluate various management strategies.

2. Maximizing approaches

The maximizing approaches are classified as such because they attempt to find an optimum solution to a problem. They vary in the type of criteria used to identify the optimum solution and the type of problem to which they are most applicable.

The maximizing techniques, as have been applied to multiple use resource management, are generally concerned with the application of certain models of Classical Economic theory, namely, the joint production model (JPM); investment criteria[1] such as internal rate of return (IRR), present net worth (PNW) and the benefit/cost criterion; and mathematical programming models, in particularly the linear programming model.

Before discussing individual maximizing approaches, it should be pointed out that they have one common, serious, deficiency in application to multiple-objective decision problems. Each is a single criterion technique which attempts to combine all relevant information into one criterion, whether it be present net worth; discounted net revenue divided by discounted cost; profit; etc. In some situations, this practice is feasible as in the case where there exist a market mechanism to determine prices and costs for the various inputs and outputs in question. However, there are many realistic situations where the market mechanism cannot be relied on to determine accurate values for inputs and outputs. This is especially true when dealing with production by the public sector of our economy.

a. Investment criteria models Investment criteria have been used by forest managers for many years. The basic investment criteria used are: benefit cost analysis, PNW, and IRR.

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[1]The reader interested in the theory behind these three criteria should consult McKean (1958) for benefit cost theory; and Hirshleifer (1970) for PNW and IRR.

The three techniques are similar in that they provide criteria which one may select from alternatives. The criteria are:

a.) benefit cost analysis -- if the benefit cost ratio is $\geq$ 1, accept;

b.) IRR -- if IRR $\geq$ alternative rate of return, accept;

c.) PNW -- if PNW $\geq$ 0, accept.

Of course, if the budgets are limited, and they generally are, the three criteria can be used to rank alternative investments.

The traditional analytical base for evaluating the production of public goods has been the benefit cost analysis. There are many examples of its use; ranging from the frequent use and abuse[1] by the US Army Corps of Engineers to use by forest managers in evaluating alternative management practices.

Gieske and Boster (1971) suggest the use of benefit cost analysis, IRR, and PNW as viable techniques in multiple use management. They mention the fact that multiple use resource management produces several differing benefit and cost flows over time. Then, in order to determine alternative project efficiencies, year to year benefit cost variations should be aggregated to single values. Once this is done, one can rank projects via their ratios, selecting from the highest to the lowest as the budget permits.

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[1]Leopold and Maddock (1964) discuss the typical abuses in applying benefit cost analysis to water resource projects.

Chappelle (1969) has developed a computer routine called "IVST" which allows the user to select IRR, PNW, or the benefit cost ratio depending on the criterion best suited to his firm's goals. It is similar to other investment analysis computer routines in that it is designed to help the decision maker decide whether or not to pursue certain productive activities or alternatives.

Webster (1965) has analysed the practicality of various investment criteria in the area of forest management. Twenty-three timber management opportunities were ranked according to different criteria including IRR, contribution to PNW, value response per cost dollar, and pay-out period. The study suggests the circumstances under which a particular criterion is best by answering the question: "what profit criterion should be used by forest managers and forest economists to evaluate the relative profitability of timber management opportunities?" (Webster, 1965, p. 264).

There have been many other applications of benefit/cost analysis, IRR, and PNW to forest management. The IRR, in particular, was used by Marty and Newman (1969) to rank forest management opportunities throughout the United States. They found that management intensification will return 3% or more on seventy two million of the ninety-six million acres of un-reserved forest land within the USFS system.

In addition, the IRR and PNW have been used to introduce the time element into the other quantitative/economic techniques which will be discussed later.

<u>1.) Discussion of investment criteria</u> Benefit cost analysis, IRR, and PNW usually assume that a single criteria, national income, is to be maximized when applied to public projects. They also assume that one can convert benefits and costs to comparable values. These techniques really do not allow the simultaneous consideration of multiple objectives. Castle (1964) mentions that each are single criterion techniques making it very difficult to handle multi-objective goals.

Resource valuation presents an almost insurmountable problem to the person trying to apply any one of the investment criteria as mentioned by Duerr (1963) and Whaley (1970).

The investment criteria require resource valuation, and costs of production to be known. Many of our forest products, as mentioned previously, are not ordinarily bought and sold via the market mechanism; hence one does not have a clear idea as to their value to society.

Researchers have done considerable work in recent years to develop value indicators for nonmarket goods and services, however one still has some way to go before they are reasonable approximations to the real values. Most of the research has been in the areas of outdoor recreation by Clawson and Knetch

(1971), Pearse (1968), Lloyd (1969), the Water Resources Council (1964), the Outdoor Recreation Resources Review Commission (1962); and water resources management by Stewart (1964), Castle (1964) and others (Freund and Tolley, 1964; Brewer, 1964). In addition, the Federal Water Resources Council (1970) has done much research in developing procedures for determining pseudo-market values for water resources.

Even when one does have market values of the various forest goods and services, they are not always comparable. For example: the stumpage values for timber usually expressed value in $/Bd. Ft.; water charges are expressed in acre feet; and grazing values expressed in animal unit months.

The problem with using investment criteria is that they require values to be transformed to a uniform measure before application of the technique. Most applications use dollar value as the uniform measure, however this presents problems when some goods are basically incomparable in these terms. Investment criteria are essentially single criteria techniques and work best when one is dealing with market goods.

b. The joint production model   The joint production model (JPM) is that part of Classical Economic Theory which has been suggested by Gregory (1955, 1973) as a possible framework from which one can study the multiple use management problem.

Recent interpretations by Muhlenberg (1964) suggest that Gregory meant the JPM be used as a theoretical approach as opposed to a more applied approach. In any event, it would be useful to study the approach and see what the possibilities are for application to multiple use forest management problems.

The JPM as defined by Gregory (1955, p. 6) is: "The production of more than one product from the same plant or through use of the same process." Some examples are mutton and wool; pulpwood and wood chips; wheat and straw; etc.

In theory, the JPM looks very promising. Gregory (1973) has shown how the model can be applied to a small sawmill operation in order to determine the profit maximizing point of production (Fig. 2). The products of the sawmill are pulpwood chips and sawn wood. The question posed is: what is the profit maximizing combination of wood chips and sawn wood to produce? Gregory then goes through the following steps in applying the JPM:

1. Develops production possibility curves[1] and iso revenue curves for all of the various combinations of products and services from the forest;

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[1]Henderson and Quandt (1972) define production possibility curves to be that combination of products that can be produced from some specified amount of input.

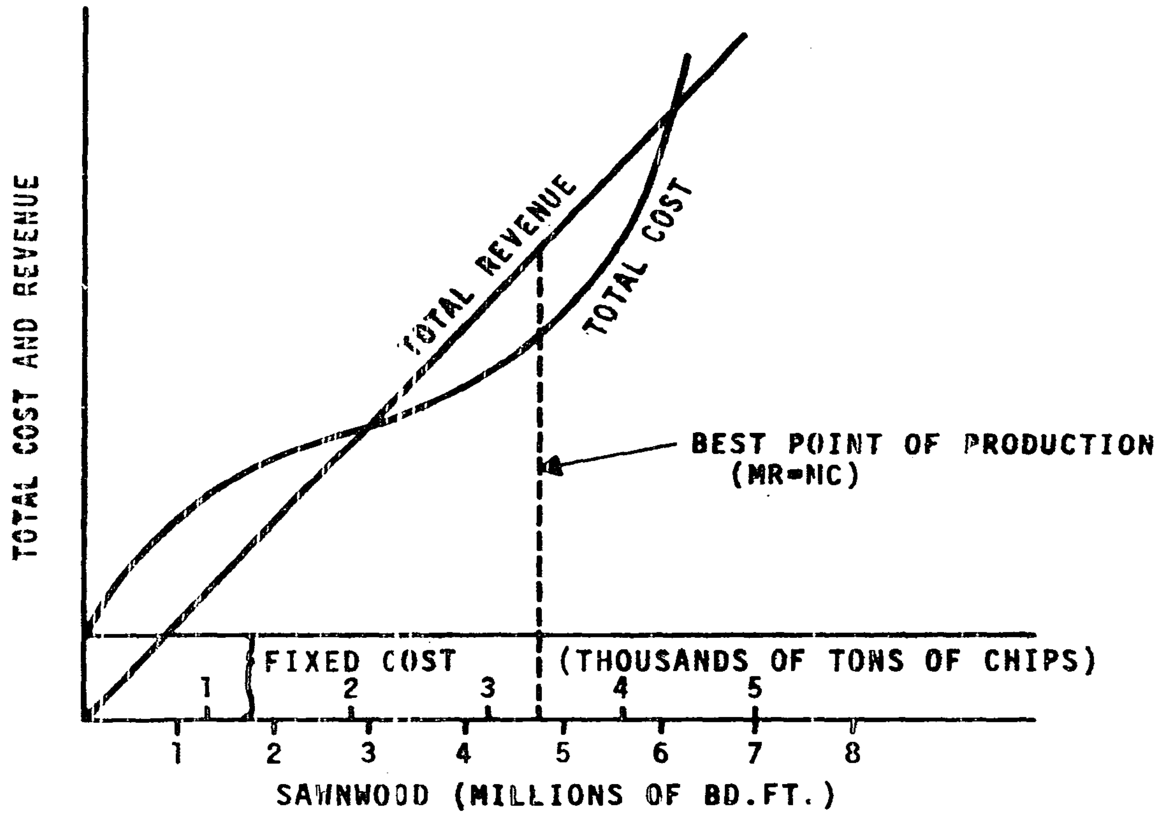

Fig. 2. Joint production model with fixed proportions, i.e., for every 1400 bd. ft. of sawn wood produced, one ton of pulpwood chips are also produced (From Gregory (21, page 257))

2. Determines the location of the output expansion path[1];

3. Develops total revenue and total cost curves for the various product combinations.

4. Combines the production possibility curves, expansion path, total revenue and total cost curves to determine the best point of production.

The best point of production will be, of course, where marginal revenue = marginal cost. This will be the profit maximizing point on the expansion path.[2]

As one studies the procedural steps in carrying out the application of the JPM, one can see plainly the very specific data needs such as information on production possibility curves and iso-revenue curves. This type of information requires intimate knowledge of resource interactions, and the interaction between resources and products produced in the forest. It also requires knowledge of costs and revenues of the various goods and services produced by the forest. Production costs must be known in order to determine the total cost curve. Revenues, or values must be assigned to products produced in

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[1]Henderson and Quandt (1972) define the output expansion path to be the points of tangency of the production possibility curve and the iso-revenue curves. They are the revenue max. levels of output for a given level of input; they are the most efficient production points for the given level of inputs.

[2]The interested reader should see Gregory (1955) for a graphical presentation of the concepts of JPM; or see Henderson and Quandt (1972) for a mathematical analysis.

order to determine the total revenue curves. At present, this type of information is sadly lacking in the area of forest management as noted by numerous sources such as Streeby (1970), Muhlenberg (1964), Clawson (1974) and Lundgren (1963).

Muhlenberg (1964) has acknowledged some of the drawbacks in applying the JPM to forest management and has therefore made some amendments to the purely theoretical approach of Gregory. He has relaxed the condition of continuous expressions for the production possibility curves and iso-revenue curves. In place of the continuous functions, he provides point data from which to determine the location of the function itself.

Muhlenberg's approach is certainly more applicable than Gregory's theoretical approach, and is a start in the right direction. More than anything else, the two articles point out the very sizable research needs of the forestry profession. The JPM, at present, does not seem to be applicable to multiple use forest management as a "hands on" approach. However, it does provide a useful theoretical framework from which one can study multiple use management. The work by Gregory and Muhlenberg certainly indicate the tremendous data needs of the model itself. This is an important piece of information in itself and can provide needed direction in forest management research.

<u>1.) Discussion</u> The joint production model, like other models of classical economic theory, usually require one

to combine all relevant information into one criterion such as profit maximization or cost minimization. This can be a serious handicap when dealing with public production where so many of the goods and services have poorly operating market mechanisms, if any at all. Uniform value measures are difficult to determine.

Recently, there has been substantial concern over the applicability of the models of classical economic theory to multiple use decision making, including decision making in forestry. The basic concern of many including Simon (1959), is the feeling that the theory is too demanding in its data requirements and assumptions with respect to consumer and producer behavior. Appendix "B" deals with the major complaints of the classical theory; complaints from individuals who believe the satisficing approach to decision making is more appropriate in today's complex world.

c. Linear programming model[1] The Linear Programming Model (LP)[2] is another optimizing approach which has been applied quite frequently to resource management decision making. The model itself, is actually of the constrained

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[1]Chance constrained programming and interative programming are discussed in Appendix A as sometimes useful modifications of the general linear programming model.

[2]A comprehensive coverage of LP theory can be gleaned from several sources such as Hadley (1963), or Charnes and Cooper (1961).

optimization variety and is an extension of the LaGrangian[1] models of classical economic theory. The discussion will include the general linear programming model and an extension to multi-objective linear programming models.

1.) General linear programming model The linear programming model can be represented via mathematical form as follows:

(matrix format)

Max(Min) $Z = CX$	objective function
subject to:	
$AX \lesseqgtr b$	constraints (system)
$X \geq 0$	nonnegativity constraints

Legend:

C -- 1xN vector of objective function coefficients
X -- Nx1 vector of activities
A -- MxN matrix of production coefficients
b -- Nx1 vector of constraints

Essentially, one attempts to maximize or minimize an objective function, subject to a set of constraints. The object is to determine the set of activities (the X's) which maximize or minimize the objective function while adhearing to a constraint matrix ($AX \gtreqless b$). The activity variables are the

[1]The LaGrangian model is a mathematical optimization technique which allows one to maximize or minimize a constrained or unconstrained objective function via the calculus. The interested reader should consult Henderson and Quandt (1972) for a thorough explanation.

ones over which the decision maker has some control such as management practices, cutting regimes, etc. In manipulating the variables, the manager must adhear to constraints such as the budget levels, available acerages, and time. In order to decide on various levels of activity variables one needs a criterion to judge how well objectives are being met; hence the objective function.

Linear programming has been applied to most phases of forestry, ranging from its use in determining optimal mixes of products to produce at a plywood mill by Bethel and Harrell (1957); determining least cost logging transportation systems by Donnelly (1962); farm wood lot planning by Coutu and Ellertsen (1960); forest regulation problems such as planning and scheduling cutting and planting activities by Kidd et al. (1966), Curtis (1962); Loucks (1964); and multiple use resource management by Navon (1971), Putman et al. (1971); Dyrland (1973) and House (1971).

Early applications of linear programming to decision making in forest management dealt with farm wood lot planning such as the one by Coutu and Ellertsen (1960). Their study used linear programming to determine the most profitable combination of agricultural and forestry activities for various farm resource situations. The study was applied to two farms sizes: a small farm of 4100 acres and a large farm of 35,000 acres. Results of the study indicated that maximum revenues can be obtained through development of the agricultural rather than the forestry enterprise on the small farm whereas on the large farm, the most profitable enterprise would require an increase in forest area.

The next application area to be developed was the area of forest regulation; that is, the scheduling of various forest harvest operations over time. Curtis (1962) applied linear programming to the operation of the Buckeye Cellulose Corporation in order to schedule cutting and regeneration activities on 22,000 acres of company leased lands. In scheduling the activities, constraints such as: making 11,000 acres available annually for site preparation and planting; creating an even distribution of age classes within management units; and maximizing profits for the company had to be followed. The linear programming model proved to be very useful in developing optimal cutting and regeneration schedules for the company.

Related to the study by Curtis (1962) is one by Loucks (1964) where linear programming was used to develop sustained yield cutting schedules. Two models were run: (1) volume to be cut is maximized subject to the various conditions imposed by nature and required by the management plan; (2) area to be cut is minimized while assuring a specific yield for each cutting period. The linear programming model was quite useful to the company in determining forest cutting schedules.

A study be Leak (1964) discusses the possibility of using linear programming to analyze yield tables in order to help provide estimates of: (1) maximizing yields under specific conditions; (2) areas to be cut or thinned by age classes, operating cycles and other categories so as to achieve maximum yield; (3) the effects of different restrictions or cutting policies upon the established allowable cut.

The forest regulation models became more sophisticated over time. A study by Kidd, Thompson, and Hoepner (1966) applied linear programming to the regulation of timber harvests in order to determine the optimum harvest schedule to maximize the net worth of a forest property. The study by Kidd et al. (1966) was especially interesting in that it enabled the forest manager to see how much one can increase present net worth of the property by omitting the sustained yield constraint. The model presented a trade-off to the manager; whether or not to include the sustained yield constraint which is considered by many to be necessary for stable employment, supplying markets, etc. versus the fact that removal of the constraint allowed an 40% increase in present net worth of the property.

An example of a nonscheduling application of LP is one by Davis (1967) who used parametric linear programming to analyze the behavior of deer populations. He developed a mathematical model for a specified deer herd, ecological environment, and management resource situation in order to determine information such as estimates of the optimum size and structure of the annual harvest and leave herd. Timber management was also introduced into the model as a specific management alternative in order to determine the problems of joint deer and timber production on the same acreage. One objective of the model was to determine an imputed value for deer; what a deer would have to be worth before one should manage for them.

More closely related to the multiple use management problem are applications by Navon (1971), Putman et al. (1971), the Resource Capability System by Dyrland et al. (1973), and the study by House (1971).

The Putman study, called Forest Range Environment System (FRES) is an application of LP to help develop a new program for range management and research. The purpose of the study was to suggest a more efficient combination of land management alternatives to be used in attaining Forest Service goals for the range resource. A series of LP runs were structured around two variables; production levels of various management strategies, and constraints on land use. Each LP solution gave a least cost investment and land management solution for achieving a goal. They developed a series of LP solutions to produce evidence of interrelationships within the whole range system. The results of the study suggested that wood output decreases little as grazing levels increase, however storm runoff and sediment increase with higher grazing levels.

House (1971) has developed a modified LP and PNW approach. The approach, which House called Polyperiod Programming, maximizes PNW of various timber management regimes over twenty year periods. House tested the operationality of the model on the Big Quilicene watershed on the Olympic peninsula. This approach analyses three timber management regimes used for each of the 37 land units in the watershed. Two regimes use the clearcutting method, but differ in management intensity. The third regime permits limited timber harvest but protects the aesthetic qualities of the forest for recreational viewing (via landscape cutting regimes).

Navon (1971) has developed an elaborate model specifically aimed at solving multiple use management problems. The Resources Allocation Method (RAM) was developed to provide an analytical framework for drawing long-range forest management plans and for evaluating wildland management multiple use policies. The TIMBER RAM, a subsystem of RAM, was developed to generate cutting and reforestation schedules for commercial forest land under multiple use management. The objective of TIMBER RAM is to maximize discounted net revenue from an area by scheduling forest treatments over time. Various management practices call for different treatments hence the opportunity to evaluate the results in terms of net revenue of each forest management policy.

Probably the latest, substantial, LP approach to forest multiple use is the Resource Capability System (Dyrland, 1973). The system was developed to assist in evaluating the capabilities and limitations of our basic soil, water, and climatic resources; to simulate and quantifiably evaluate their response to management alternatives; and to assist in identifying their role in interdisplinary analysis of resource allocation alternatives. The result of analysis by the Resource Capability System is the identification of an optimum product output and use levels for each resource using the management objectives and constraints provided.

The Resource Capability System attempts to determine the capability of the land, water, and climate to sustain various levels of use and growth without impairment of the basic capacity of the land (environment). This is quite different from traditional approaches which attempt to maximize the utility of a particular program.

The Resource Capability System uses both LP and simulation techniques. Similation is used to predict the effects of present conditions and proposed management practices. It is also used to help evaluate management effects over time. The LP is used to develop strategies, i.e. once the management alternatives are developed for an area, they are then utilized along with information on demand, both social and economic, and management constraints relating to the area being evaluated, to develop optimal alternative management strategies.

2.) Multi-objective linear programming (MOLP) model

The MOLP model is an extension of the general LP model. It was developed to solve LP problems requiring several, simultaneous objective functions. This was necessary due to the difficulty experienced in trying to tie several objectives together via one unique objective function such as PNW, cost minimization, or profit. Often times an organization such as the USFS, will have several, conflicting objectives which they would like to meet and the general LP model, with its uni-dimensional objective function, does not provide an adequate analytical framework to analyze these problems.

The general mathematical form of a typical MOLP model is presented by Zeleny (1974) as follows:

Model C2. Maximize (Minimize)

$$Z^1 = \lambda^1 \sum_{i=1}^{n} C_i^1 X_i$$

$$Z^2 = \lambda^2 \sum_{i=1}^{n} C_i^2 X_i$$

$$\vdots \qquad \vdots$$

$$Z^k = \lambda^k \sum_{i=1}^{n} C_i^k X_i$$

subject to:

$$\sum_{j=1}^{m} A_{ij}X_j \leq b_i \qquad i = 1,\ldots,n$$
$$j = 1,\ldots,m$$

$$X_j \geq 0$$

$$\sum_{i=1}^{k} \lambda^i = 1 \qquad \lambda^i \varepsilon (\ell_i, \mu_i)$$

Legend:

λ_i = ith objective weight

ℓ_i, μ_i = lower and upper bounds respectively for the ith objective weight

C_i^k = objective function coefficient for objective (k) and activity (i)

Z^k = value of the kth objective function

X_i, A_{ij}, b_i, are same as stated before. (Section IIC)

The above model allows the treatment of several (k) simultaneous objectives. One solves for the set of efficient extreme, nondominated solutions (efficient set) instead of a single optimal solution as in the general linear programming model (Zeleny, 1974).

One of the major drawbacks in using MOLP is the difficulty in solving the model. Roy (1970) discusses this problem and possible approaches to the problem.

Two of the approaches discussed by Roy (1970, p. 239) are:

1. "Aggregation of multiple objective function into a unique function defining a complete preference order";

2. "Progressive definition of preference together with exploration of the feasible set".

a.) Exploration of feasible set The full vector maximum problem and solving algorithms are discussed by Phillip (1971) as an approach to solving MOLP problems whereby one solves model C2 for all possible efficient[1] extreme points. (i.e. one explores the entire efficient feasible set of solutions to a particular problem.) The decision maker is then assumed to be able to select the solution he likes best. The advantage of this approach is that more information is made available to the decision maker in the form of alternative efficient extreme points (solutions) to the problem. The general LP model, conversely, yields only one solution per computer run.

However, as noted by Steuer and Oliver (1974), the number of efficient extreme points can become very large for relatively small sized problems. In fact, when the number of objectives becomes greater than five, the problem often becomes computationally infeasible (Steuer, 1974).

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[1]A point $\bar{X}$ is said to be efficient if and only if $C\bar{X} \geq CX$ for all $X \in \delta$. C and X have same meaning as stated before.

In an effort to alleviate the above problem, Steuer (1974) has developed a technique, called Interval Criteria Weights Programming (ICWP). This approach develops neighborhoods of efficient extreme points in contrast to the complete set developed by the full vector maximum algorithms. This is accomplished by specifying subintervals for the weights[1] in the objective function. The result is that fewer efficients points are generated, yet enough are developed to allow the decision maker considerable choice in selecting the "best" solution.

b.) Aggregation of multiple objective functions into one unique function Essentially, this is what was done in the forestry applications discussed previously in section cl. The objectives were tied together via a common denominator such as PNW, profit or cost minimization. However, a common denominator cannot always be found. This is often the case in forest resource management where some of the forest products are essentially nonmarket goods (recreation and hunting for example).

A modification of the aggregate objection function technique is an approach called goal programming (GP). The GP approach is a technique whereby deviation from multiple goals

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[1]Weights (λ_i) are Archimedean type weights and fall in prespecified intervals: $0 \leq \ell_i \leq \lambda_i \leq \mu_i \leq 1$.

are minimized in the objective function. This approach does not require one to tie various objectives together via a common denomination. In addition, it has the advantage of not requiring difficult information concerning the product values (the (C_i) coefficient in the objective function). More will be said of the GP model in later sections as this was the approach used in this study.

3.) Discussion The LP applications in forest resource management have one common major drawback in terms of applicability to multiple use management problem. Each evaluated alternatives with respect to a uni-dimensional objective function. The scheduling applications maximize PNW or minimize cost of the scheduling system; TIMBER RAM maximizes discounted net revenue of a forest area by properly scheduling harvesting operations and the Resource Capability System also evaluates alternative strategies via a uni-dimensional objective function.

The general linear programming approach does not allow for the proper interaction of the multiple goals which cannot be tied together via a common denominator.

Some MOLP models essentially solve the multi-dimensional goal problem by allowing for various objective functions to be represented. However, there is still the difficult problem of determining weights to be used for the various objectives. Steuer and Oliver (1974) mention the serious problem in the media selection area where the weights are very subjective in nature. Discussion with Forest Service personnel by this author indicate a similar problem in the forest resource management area.

Interactive linear programming models (see Appendix A) have been suggested as an approach to solving the weighting problem. The interactive models allow for diminishing marginal rates of substitution (Dyer, 1972) within the solution process. However, effective use of the interactive procedure requires special, high level analytical capabilities within the organization. This is an unrealistic assumption for many organizations, especially when talking about individual forest level management in the Forest Service.

In view of these quantification problems, the goal programming model was selected as an appropriate technique to study multiple-use forest management problems. Goal programming models are less demanding in terms of data requirement than the standard linear programming models. In addition, they are better adapted to handling the multi-dimensional objective problem so prevalent in multiple-use forest management.

4.) Note on assumptions of the LP model In discussing the application of LP models to resource management, one must certainly consider the implicit assumptions of the LP model. They are, of course, the assumptions of proportionality, additivity, and divisability.

1. Proportionality -- This assumption implies that the objective function, constraints, and goal relationships must be linear. For example; if one can achieve four visitor days of recreation with one acre of land, then two acres will provide eight visitor days of recreation. This type assumption is made in order to simplify the production function requirements of the model.

2. Additivity -- The activities themselves must be additive in the objective function and the constraints. There can be no joint interaction among the various activities. Mathematically, this means that the functions must be expressed thus:

where Y = a particular goal, and X_1, X_2, and X_3 are inputs to the goal;

$$Y = f_1(X_1) + f_2(X_2) + f_3(X_3)$$

and not: $Y = f(X_1, X_2, X_3)$.

3. Divisability -- This assumption simply means that the appearance of fractions of the activity variable in the solution must be acceptable and feasible to the circumstances.

If one chooses the LP model, there should be some evidence to support the assumptions (1 - 3) which are being implicitly made.

D. Satisficing Versus Optimizing Approaches

The very severe demands made on the decision maker by the Classical Theory (see Appendix B) has lead many people to question the applicability of these models to the very complex type of decisions that face contemporary decision makers.

According to Simon (1955), there is a definite lack of evidence to indicate these computations (reference the marginal conditions mentioned in Appendix B) are, in fact made. This is especially true in most actual human choice situations of any complexity.

Due to lack of evidence, Simon feels that individuals might behave in a manner quite different from that predicted by economic theory. Simon has suggested the use of a two-valued preference function which includes a satisfactory and nonsatisfactory region. This theme is depicted quite well in graphical terms by Lane (1972) in Fig. 3.

The satisficing approach is an iterative one; if an outcome is unsatisfactory, then the individual will either institute a search for a satisfactory alternative or reduce his aspiration level. If a satisfactory outcome is encountered the individual may revise his aspiration level upwards according to Simon (1959).

The satisficing approach seems to be better suited to the type decision making that "rational man" is capable of performing. Simon (1955, p. 114) points to the paradox of economic theory in dealing with human behavior in an

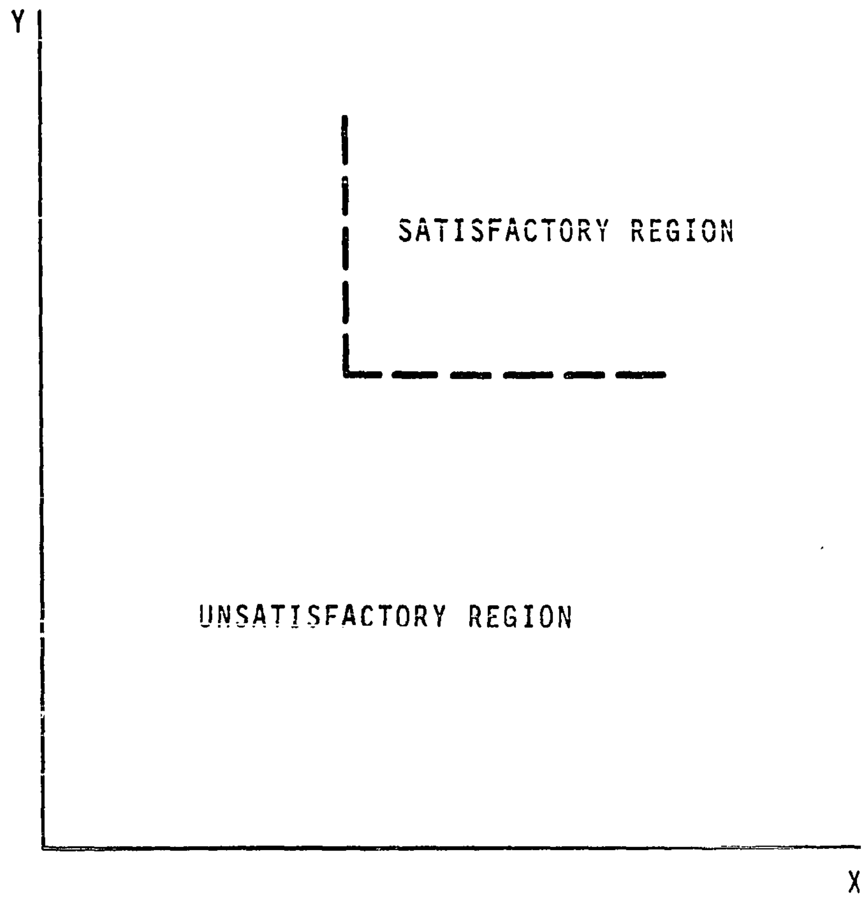

Fig. 3. Satisficing preference map

organizational context: "... the theory of the firm and administrative behavior attempt to deal with human behavior in situations in which that behavior is at least "intendedly" rational; while, at the same time, it can be shown that if we assume the global kinds of rationality of classical theory, the problem of internal structure of the firm or organization largely disappears."

He further goes on to say "...the paradox disappears and the outline of theory begin to emerge when we substitute for "economic man" or "administrative man", a choosing organism of limited knowledge or ability."

The main advantage of the satisficing approach is that the preference function is such that a man with limited knowledge and ability can make decisions in very complex situations. The preference function is more in tune with the realities of the decision making environment.

In addition, when comparing the satisficing approach with the optimizing techniques discussed earlier, one must consider the type of information needed in order to optimize. For example, in LP, one must first determine a feasible solution. One must determine whether or not the model can be solved and the specified constraints adhered to. This part of LP can be compared to the satisficing approach. However, the LP model then goes on to determine an optimum solution from among the set of feasible solutions via an objective function. The optimum solution is the one which maximizes a given payoff function. The problem is in determining a realistic payoff, function, i.e. a function which is simple enough to work with for the decision maker. Often, these payoff functions require information which is just not available, even to the more knowledgeable forest managers.

Optimizing techniques require one to deal much more specifically (in contrast to satisficing techniques) with the weighting or ranking problem. Most optimizing techniques require a uniform measure of value for the activities. For instance if ones objective is profit maximization, then the activities used to achieve profit maximization must, somehow, be tied together. However, there does not seem to be any fully acceptable unifying criterion, thus creating critical weighting problems for the activities. This problem is especially severe in the cases where the objectives are completely incomparable such as "apples and oranges". The optimizing techniques require one to develop a scalar payoff function which will allow one to put "apples and oranges" on common value terms.

To this author, the incomparability of some goals is a major stumbling block in using the classical optimizing techniques.

A more acceptable approach to multiple use management would be one that combines the good aspects of the satisficing approach and the optimizing techniques, yet does not include the major disadvantages; an approach that utilizes a pay off function that can realistically deal with the type of data which is currently available in the forest management area; one which can handle the problem of incomparable goals; an approach that will allow a meaningful analysis and evaluation of alternative management strategies with the express purpose of providing sound management decisions.

1. Goal programming in general

One of the latest techniques which has been applied to multiple use decision making in forestry is a type of mathematical programming called goal programming (GP). GP lies somewhere between the optimizing LP techniques and the satisficing approach discussed by Simon (1955).

Goal programming is a type of MOLP model. The term GP was probably first coined by Charnes and Cooper (1961) in their monumental two volume work, Management Models and Industrial Application of LP. The technique was developed primarily as an extension of the general LP model in order to handle management problems involving multiple objectives and to overcome other basic problems inherant to the general LP model.

The general LP model and the GP model are actually quite similar in perspective. Both contain the same basic parts: a set of linear constraint equations and a linear objective function(s) which serves as a criterion to evaluate various feasible solutions. They differ in the <u>formulation</u> of the objective function itself. Briefly, the GP objective function is primarily a satisficing type whereby deviations from specified goals are minimized (more will be said on this in the next section).

There are two major problems with the linear programming model which the GP formulation attempts to overcome: (1) unsolvable problems; and (2) uni-dimensional objective functions.

<u>a. Case of unsolvable LP problems</u> Unsolvable LP problems arise when the set of constraint equations cannot be solved simultaneously for the set of X's (activities). This happens quite frequently when one is trying to model a very complex situation. Of course, when this happens, it might be due to a specification error on the part of the user and he might analyze his constraint matrix in order to determine the ones which are causing the infeasibility.

An example used by Charnes and Cooper (1961, p. 216) to depict an infeasible solution[1] is the following:

$$\text{Max. } Z = \$1X_1 + \tfrac{1}{2}X_2$$

subject to:

$$3X_1 + 2X_2 \leq 12$$

[1] Infeasible solutions are ones where the equation system cannot be simultaneously solved (Charnes and Cooper, 1961).

$$5X_1 \leq 10$$

$$1X_1 + 1X_2 \geq 8$$

$$-1X_1 + 1X_2 \geq 4$$

$$X_1, X_2 \geq 0$$

In this case, the constraints represent the available resources. The object is to allocate the resources to the two activities (X_1 and X_2) in such a way as to maximize the value of the objective function. (The graphical solution to the problem is shown in Fig. 4)

As one can see from Fig. 4, there is no region in the northeast quadrant (from the constraints; X_1, $X_2 \geq 0$) which satisfies all of the constraint equations simultaneously. There There is no set of X's, that when plugged into the equation system, will satisfy all of the constraints at the same time.

This infeasibility problem is an especially serious handicap to decision makers wishing to make long range plans. Often, they desire to set goals or targets, which they know are not achievable, but would like to know how close they can come to achieving them.

The GP model has no such limitation. The objective or goals are approached as closely as possible, but need not be met completely. This sort of flexibility allows the specification of a problem in terms of multiple conflicting goals and

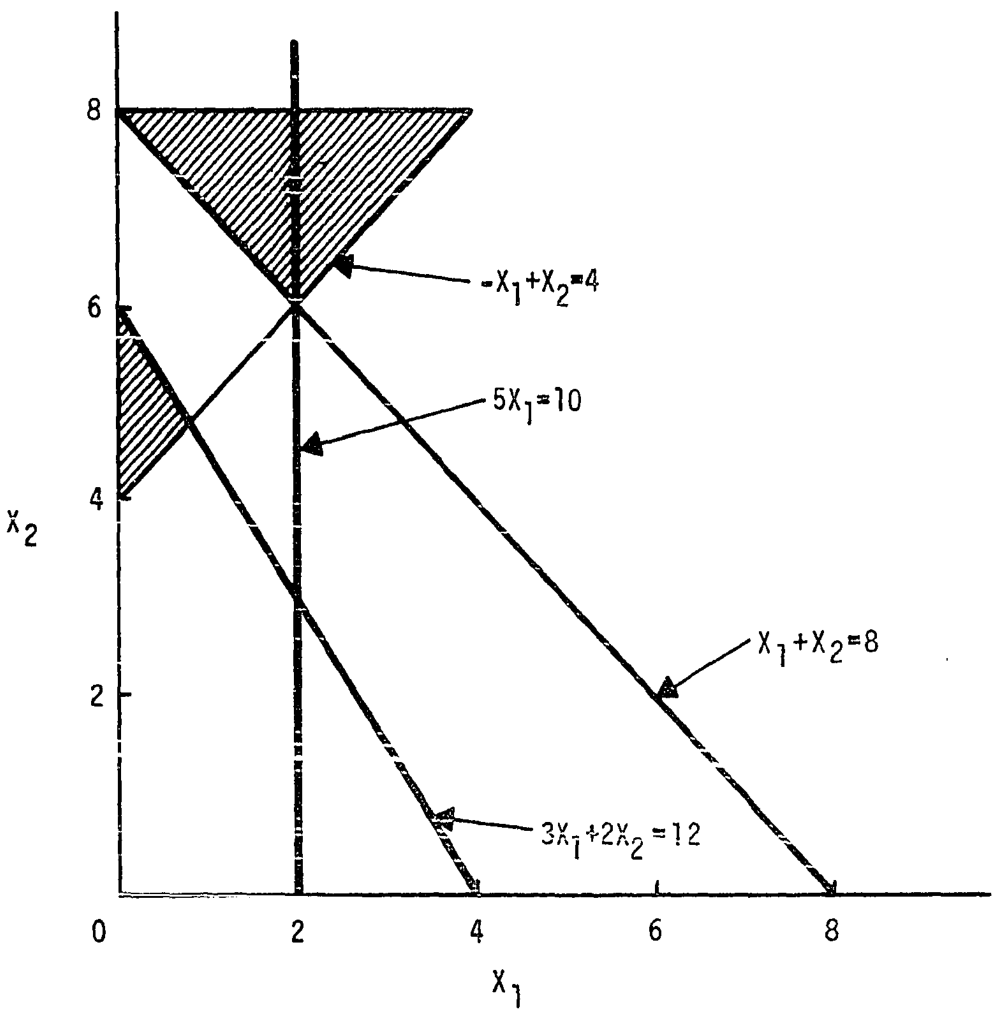

Fig. 4. Graphical representation of unsolvable problem (From Charnes and Cooper (80, page 216))

the allocation of resources according to an agreed upon priority scheme.

b. Uni-dimensionality of objective function As expressed by Kornbluth (1973), a major fallacy with most LP applications is the insistance on one, all important objective function (with the exception of some MOLP models). Most applications (including forestry) try to tie everything together via some common denominator. The forestry applications mentioned previously use PNW maximization and cost minimization as all inclusive objectives. However, several studies suggest that profit maximization is only one of many objectives of management. Personnel relations, consumer needs, stockholders interests have been shown to be desired goals of management in an important study by Schubik (1964).

A study by Charnes and Stedry (1964, p. 150) suggest that: "assumptions of long run profit or utility maximization are nonoperational (even) if logically, or tautologically, they can be shown to be valid". Kornbluth (1973, p. 194) suggests that: "in corporate long term planning, exercises, it is much more usual to make projections covering a whole range of statistics (profit, sales, growth, return on capital employed, return on sales, etc.) and to attempt to organize a coherant strategy to meet the desired projections."

The multiple use forestry practioner has basically the same problem. The resource manager has a multiplicity of goals, some of which are comparable, and some noncomparable. Profit maximization is not necessarily the major goal of National Forest management as expressed in the MU-SY act of 1960. Noneconomic goals such as sustained yield, maintaining environmental quality, and aesthetic considerations are to be incorporated into the decision making process.

Some MOLP models allow the simultaneous treatment of multiple, conflicting goals and is a significant improvement over the uni-dimensional LP applications. However, the MOLP model has serious problems of its own. As mentioned before (Section IIC), there is considerable difficulty in solving the model. In addition, there are the serious problems in determining the objective function coefficients (the C_i).

As noted by Lee (1972), the GP approach allows the simultaneous solution of a system of complex objectives or goals rather than requiring a single objective. In addition, the objectives may be composed of nonhomogeneous units of measure such as AUM, cu. ft. and visitor days.

It should be remembered that one must still deal with the weighting problem when using goal programming, however it becomes a problem of weighting deviations from goals in contrast to weighting activities as in linear programming models. The nice part about this technique is that the goals themselves do not need to be measured in the same units, hence incomparable goals can be considered simultaneously.

One possible drawback to multi-criteria programming models is the loss of some analytical power, particularly sensitivity analysis. A multi-dimensional objective function limits the amount of information one may glean from a sensitivity analysis procedure.

2. The linear goal programming model

The general form of the linear GP model is:

$$\text{Min. } Z = \sum_{i=1}^{n} w_i (d_i^+ + d_i^-)$$

subject to:

$$\sum_{i=1}^{m} A_{ij} X_j + d_i^- - d_i^+ = b_i$$

$$\sum_{j=1}^{m} B_{sj} X_j \quad \gtreqless r_s$$

$$X_j,\ d_i^+,\ d_i^- \quad \geq 0 \quad j=1,\ldots,m \quad i=1,\ldots,n$$

$$d_i^- \times d_i^+ \quad = 0 \quad s=1,\ldots,k$$

Legend:

w_i = weighting function

d_i^+ = overachievement from goal (i)

d_i^- = underachievement from goal (i)

A_{ij} = input-output coefficient expressing the relationship between the jth activity and the ith goal

X_j = activity variable

B_{sj} = input output coefficient expressing the relationship between the jth activity and the s st system constraint

r_s = system constraints

b_i = goal constraints.

a. Model segments The model consists of three segments: objective function; system constraints; and goal constraints.

1.) Objective function The objective function, is always a minimization type whereby one attempts to minimize the weighted or unweighted sum of deviations from the specified goals. The activity, or structural variables, in contrast to conventional LP models, do not ordinarily appear in the objective function of GP models.

There are several variations of the objective function which prove to be very useful in allowing the user greater flexibility in evaluating goal performance. The variations as described by Ijiri (1965, p. 40) are:

a.) min. of $(d^- + d^+)$ - this variation attempts to solve for the set of activities (X's) which will exactly satisfy the equation: AX = b; i.e. just satisfy the constraint or meet the goal exactly.

b.) min. of (d^-) - this formulation will attempt to solve for the (X) that will minimize the (b - AX) to the extent possible. i.e. to minimize the goal underachievement.

c.) min. of (d^+) - attempts to identify the set of (X's) which minimizes (AX - b) to the extent possible. A minimization of overachievements is the objective.

d.) min. of $(d^- - d^+)$ - this variation, which is rarely used, attempts to maximize (AX) itself.

e.) min. of $(d^+ - d^-)$ - this is equivalent to finding the set of (X's) which minimize (AX).

In this particular study, minimization of goal underachievement will be the primary concern, hence the (b) variation will be used in formulation of the objective functions.

2.) System constraints The system constraints, sometimes called subgoals, or technological constraints, are similar in nature to the constraints in the conventional LP models. These constraints are imposed by the actual environment in which the decision maker is operating. Usually, these restrictions will define the feasible region of the solution space. Examples of these constraints are: limited budget, acerage constraints, etc. One can put priorities on these constraints to force the solution procedure to meet these constraints before going on to the goal constraints. Ordinarily, this is the procedure which is followed, however in the case of infeasible solutions, one can relax this procedure in favor of a more flexible one; one which allows the solution procedure to overide the physical constraints (in a computational sense only) by actually treating them as goal constraints (It should be cautioned that the physical constraints should always be met before any attempt is made to meet goals if the model is to remain realistic).

3.) Goal constraints Goal constraints are the inequalities or equalities with the deviational variables attached to them. The goal constraints specify the relationships between goals or targets of the decision maker, and the activities or choice variables. This type of constraint is not usually found in conventional LP models, at least not in the same form they are found in GP models. It is the deviational variables, (d_i^- and d_i^+) in the goal constraints which are minimized during the solution procedure in the GP models.

b. Solution procedure The solution procedure in GP models is quite different from that found in LP models. In the LP models, the values of the activity variables, via the objective function, drive the values of the slack variables[1]. In the GP the deviational[2] variables tend to drive the values of the activity variables as noted by Lee (1972). The degree to which they do this will be determined by the relative

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[1]Slack variables are simply a means by which inequalities are converted to equalities, a necessary step in solving a set of simultaneous equations. The slack variables also play an important role in the solution procedure by allowing the process to start at zero.

[2]The deviational variables take the place of the slack variables in the goal constraint equations. Essentially, they have the same function.

importance assigned to the deviational variables in the objective function. Generally, minimization of the objective function implies the desire to get the deviational variables as close to zero as possible.

The solution procedure in LP is essentially a cardinal solution procedure whereas the GP procedure as described by Lee (1972) is a ordinal procedure, although all GP models are not ordinal in nature.

3. Applications of goal programming

As indicated previously, this study is concerned with applications of decision making techniques to multiple use forestry, specifically the use of goal programming. Hence, discussion of the GP literature will emphasize applications rather than theory.

Kornbluth, in a recent survey article (1973, p. 195), has listed the general type of situation where GP can be applied. It can be applied where:

1. "Objectives can be expressed as desired values for goal variables;

2. The attainment of these objectives depends on values taken by the activity variables under control of the decision maker;

3. The activity variables are constrained by a series of linear relationships;

4. The decision maker has made some subjective (or objective) weighting concerning the importance of his goals in terms of the constants (M_k)."

As stated by Lee (1972), there are three major application areas of GP:

1. Allocation Problems;
2. Planning and Scheduling Problems;
3. Policy Analysis.

This study will be concerned primarily with the 1st; allocation problems, although the other areas will be covered because they are the areas where most of the applications have been made to date.

a. Planning and scheduling problems   Planning and scheduling problems present a very fertile area for GP applications. In fact, most of the previous work in GP has been in this area. Planning and scheduling problems are ones such as manpower planning, production scheduling, financial planning, personnel planning, and market strategy planning.

One of the first applications of goal programming was the one by Charnes et al. (1955) where the technique was used to estimate optimal executive compensation plans. The objective of the study was to arrive at an optimal compensation "formula" for executives, while adhering to company goal constraints such as: not violating the ranked position hiarchy of the company; meeting competitive conditions so valuable people are not lost to other companies; etc. The optimal compensation formula was the one which minimized ranked deviations from the goal constraint, and minimized salary paid to the executives.

Charnes and Cooper also applied goal programming techniques to other manpower planning problems. One study by Charnes et al. (1972), was designed to provide a choice among all possible alternatives in filling vacancies from within the organization, from training, and from outside sources, within stated constraints (goals). The goals were types of manpower required per period, and the activity variables and physical constraints described recruitment and career advancement of personnel during planning periods of the model.

Related to the manpower studies by Charnes and Cooper is one by Gibbs (1973) who used goal programming in developing a training program for computer analysts belonging to a corporate systems group. Although hypothetical in nature, the study indicated the usefulness of goal programming in the manpower training area.

Charnes and Cooper et al. (1968) have also used GP for media planning. The model was designed to select optimal media plans for a particular user such that the users product received maximum exposure for a specified advertizing budget.

Jaaskelainen (1969) provided one of the first applications of pre-emptive goal programming to production planning problems. His study uses a goal programming model to schedule production, employment and inventories to satisfy known demand requirements over a finite time horizon. There are three separate, incompatible goals: the level of production; employment; and inventories. This study is different from the Charnes and Cooper studies mentioned previously in that the goals in the Jaaskelainen study are ordered so that goals in a lower rank are satisfied only after those in a higher rank are satisfied, or have reached points, beyond which no improvements are possible under given constraints.

In a similar vein to the Jaaskelainen (1969) study, Lee (1972) has applied goal programming (using pre-emptive weights) to financial planning, marketing decisions, academic planning and medical care planning. In each case, Lee (1972) found the pre-emptive approach to be useful in handling goals which are both multi-dimensional and incompatible.

The above list of goal programming applications to planning and scheduling problems is not meant to be exhaustive, but to give the reader some appreciation for the versatility of the approach.

b. Policy analysis Policy analysis is another area where goal programming could be very useful. Policy analysis includes the determination of priorities for various goals and developing a program to meet these goals. There is a strong possibility of using goal programming to ascertain the soundness of governmental policies. One could analyze this soundness by determining how closely the goals can be met, given the existing constraints. In this way one could analyze whether or not a particular goal set is realistic. If they are not, then the goals must be altered to reflect the true condition of the environment. In this way, goal programming could help in developing management strategies which are most compatible with government objectives.

An example of the use of goal programming in policy analysis might be the Forest Service in their effort to determine whether or not a set of specified goals for one of their management units is obtainable with existing resources and management strategies. The goal programming solution will indicate the degree of goal attainment and which strategies to follow. If a particular goal, recreation for instance, is seriously underachieved, this might suggest the goal itself is unrealistic for that unit and should be scaled down, or possibly the goal priority should be changed. The goal underachievement might also suggest that current management strategies are outmoded and need revision.

The policy analysis use of goal programming is actually closely related to its use in allocation problems. In fact, it would be a logical thing to do, once one has used goal programming to help solve allocation problems.

<u>c. Allocation problems</u> Allocation problems present another area, closely related to policy analysis and planning

and scheduling problems, which could benefit by goal programming. Allocation problems, for purposes of this study, will mean resource allocation such as allocating land, labor, capital to various activities.

It is in the resource allocation area where the only known, (to this author) published, goal programming application in forest management exists. Field (1973) applied the preemptive goal programming model to the management of a hypothetical woodlot. The study by Field attempts to solve the problem of a small woodlot owner who has several goals in acquiring his property:

1. Provide recreational facilities for his family;

2. Provide a supplementary source of income for his family.

There are several constraints that had to be adheared to in managing the woodlot, namely:

1. Practice sustained yield management;

2. Provide so many summer and fall recreation days;

3. Provide a certain amount of income from timber harvest and rental of the cabin on the property.

The overall objective of the owner was to come as close as possible to meeting the ordinally ranked goals, yet abide by the physical constraints. The GP model allocated available days to various activities in order to come as close as possible in meeting the goals.

The study by Field, although hypothetical in nature, indicated the very definite possibilities in applying GP to real multiple use management problems in forestry.

d. Discussion The applications of goal programming in the areas of planning and scheduling, policy analysis and resource allocation certainly indicate the versatility of the model. The application could also be grouped into categories such as pre-emptive models and cardinal ranking models. The selection, would of course, depend on the situation facing the decision maker.

There are applications of stochastic goal programming by Contini (1968) and interaction goal programming by Dyer (1972). (The drawbacks of these approaches are discussed in Appendix A.)

The deterministic goal programming model (section IID2) was felt to be well adapted to handling complex decision making problems of unit planning in the Forest Service. Investment models such as benefit cost analysis, present net worth and internal rate of return are not well suited to handling multi-dimensional goal problems. In addition, due to the mode of thinking of the public land manager, the goal programming model was felt to be more in tune with his capabilities.

4. Algorithm evaluation

Once the decision maker selects an approach to a problem that seems satisfactory to him, there is still the very substantial problem in actually applying the approach. In the case of mathematical programming models such as GP, ones biggest aid is the computer; in fact, without it, there probably would not be any such thing as operational mathematical programming models.

The computer makes the solution of goal programming problems feasible both in terms of timeliness and cost. However, without well-established algorithms, even the computer would not make practical the solution of numerous small problems. Algorithms take advantage of the speed and accuracy of the computer in solving problems involving repetitive or iterative calculations such as occur in mathematical programming models. Algorithm selection is thus an important matter of concern for "manager sorts" (analysts). Often several algorithms will be available for doing the same type of job, however one may have advantages over others in special situations. For instance: one algorithm may have a cost advantage in some situation and be in applicable in others; another algorithm may have an advantage in being able to handle bigger models than other algorithms; and another algorithm might be easier to work with, in general, than others. Knowledge of this sort of information is very useful to applied "manager sorts". The purpose of discussing algorithms in this thesis is to make the algorithms more usable to potential "manager sorts". A knowledge of the available algorithms with their advantages and disadvantages should prove helpful to potential goal programming users.

This study looked at three algorithms which were developed to handle pre-emptive goal programming problems. The algorithms are similar in that each is a variation of the Simplex Algorithm originally developed by Dantzig (1963) for application to LP models. The algorithms differ with respect to the method used to force the ordinal solution to the model. Two of the approaches use existing LP computer packages while the other is a separate Fortran program.

a. Lee approach S. M. Lee (1972) has developed an approach which modifies the simplex calculation. There are two major changes:

1. The objective function consists of weighted and ordered deviations from goals instead of the traditional activity variables.

2. The simplex criterion[1] is a matrix instead of a row vector as in the Dantzig algorithm. This is of course, a direct result of the multi-dimensionality of the objective function. The matrix is MxN where M = number of priority levels and N = number of columns in the model. Essentially, the matrix is used in the algorithm to iteratively check each priority level in order to determine the incoming column in much the same way the $Z_j - C_j$ row in Dantzig's algorithm determines the incoming column.

[1]The simplex criterion refers to the $Z_j - C_j$ row which is used to determine which will be the new incoming column in the updated tableau via the iterative procedure.

As with Dantzig's technique, the initial tableau starts at the origin with the d_i^- in the basis. The incoming column is determined on the basis of the value of the per unit contribution rate of each variable in achieving the most important goal (P1). In Table 1, X_2 initially comes into the basis and d_1^- leaves. The remainder of the calculations are similar to the Dantzig technique.

Illustration:

As an illustration, Model 1.1, below, is used to demonstrate the first tableau of the Lee algorithm.[1]

Model 1.1

$$\text{Min } Z = P_1\, d_1^- + P_2\, d_2^- + P_3\, d_3^+$$

s.t.

$$x_1 + x_2 + S_1 = 65 \quad \text{(physical constraint)}$$

$$x_1 + 2x_2 + d_1^- = 100$$

goal constraints

$$x_2 + d_2^- - d_2^+ = 75$$

$$3x_1 + 4x_2 + d_3^- - d_3^+ = 210$$

$$x_1,\ x_2,\ d_1^-,\ d_2^-,\ d_3^-,\ d_2^+,\ d_3^+ \geq 0$$

[1]The P_i indicate ordinal priority levels; S_1 is a slack variable in the physical constraint; and $d_i^{+,-}$ are deviational variables used in the goal constraint equations.

Table 1. Initial tableau via Lee algorithm for Model 1.1

C_j	V	C			P_1	P_2			P_3	
			X_1	X_2	d_1^-	d_2^-	d_3^-	d_2^+	d_3^+	S_1
	S_1	65	1	1	0	0	0	0	0	1
P_1	d_1^-	100	1	2	1	0	0	0	0	0
P_2	d_2^-	75	0	1	0	1	0	-1	0	0
	d_3^-	210	3	4	0	0	1	0	-1	0
	P_3								-1	
	P_2	75		1						
	P_1	100	1	2						

b. <u>D. B. Field approach</u> D. B. Field (1973) has developed an approach which utilizes existing LP computer packages. Field's approach requires the calculation of pre-emptive coefficients for use in the objective function. He has developed an algorithm called the "Priority Factor Algorithm" which performs these calculations. The Priority Factor Algorithm computes the minimum number which will allow a higher ranked goal to be achieved as much as possible before any attempt is made at achieving the next highest goal.

As described by Field (1973), the calculation of the coefficients is as follows:

1. Calculate the maximum possible activity level of each deviational variable;

$$*d_i^- = \underset{(x_j)}{\text{MAX}} \quad b_i - \sum_{j=1}^{n} a_{ij}\, x_j$$

$$*d_i^+ = \underset{(x_j)}{\text{MAX}} \quad \sum_{j=1}^{n} a_{ij}\, x_j - b_i$$

n = no. of structural variables in the model

x_j = feasible values of the structural variables

b_i = goal level

a_{ij} = input-output coefficient

2. Let $P_k = 1$

where k = lowest priority level

3. Calculate $P_j = n^* \, [P_{(j+1)}] + 1$

where $n^* = \text{MAX}\ \{W_i\ *d_i^{+,-}\}$ over (j + 1)

w_i = within rank weight associated with each variable

Illustration:

Illustrating the Field calculation via Model 1.1

1. $*d_1^- = 100 - 1(0) - 2(0) = 100$

   where $x_1 = x_2 = 0$

   $*d_2^- = 75 - 1(0) = 75$

   where $x_2 = 0$

   $*d_3^+ = 4(65) + 3(0) - 210 = 50$

   where $x_2 = 65$

   $x_1 = 0$

2. Let $P_3 = 1$

   then: $P_2 = ((50)\ (1)) + 1 = 51$

   $P_3 = ((75)\ (51)) + 1 = 3{,}825$

After calculating the P_j, it is a straightforward matter to use existing LP computer packages to solve Model 1.1 via Field's approach.

c. Charnes and Cooper approach Perhaps the first approach to goal programming is the one listed by Charnes and Cooper (1961). Their approach is similar to Fields' in that existing LP packages can be used. The difference is in the way they handle the goal ordering problem. The Charnes and Cooper technique has the unfortunate effect of enlarging the model itself and of forcing a given level of deviation to all lower ranked goals.

Illustration:

In order to convert Model 1.1 to a pre-emptive GP model using the Charnes and Cooper technique, one must do the following:

1. Let all $P_i = 1$ (unit deviations)
2. Add constraints such as:

$$d_2^- - d_1^- \geq 0$$

$$d_3^+ - d_2^- \geq 0$$

These constraints force the model solution such that $d_2^- \geq d_1^-$ and $d_3^+ \geq d_2^-$ must be met. This sort of pre-emptive solution is even more strict than the Lee or Field models.

E. Specifics of Goal Programming

The goal programming model was applied to a particular unit on the Mark Twain National Forest in Missouri. The application was essentially at the "conceptual" level and attempted to test the feasibility of the approach for contemporary multiple-use management problems on public forest land. Some background information on the Forest Service land use planning system would be helpful in understanding the role of goal programming in this system.

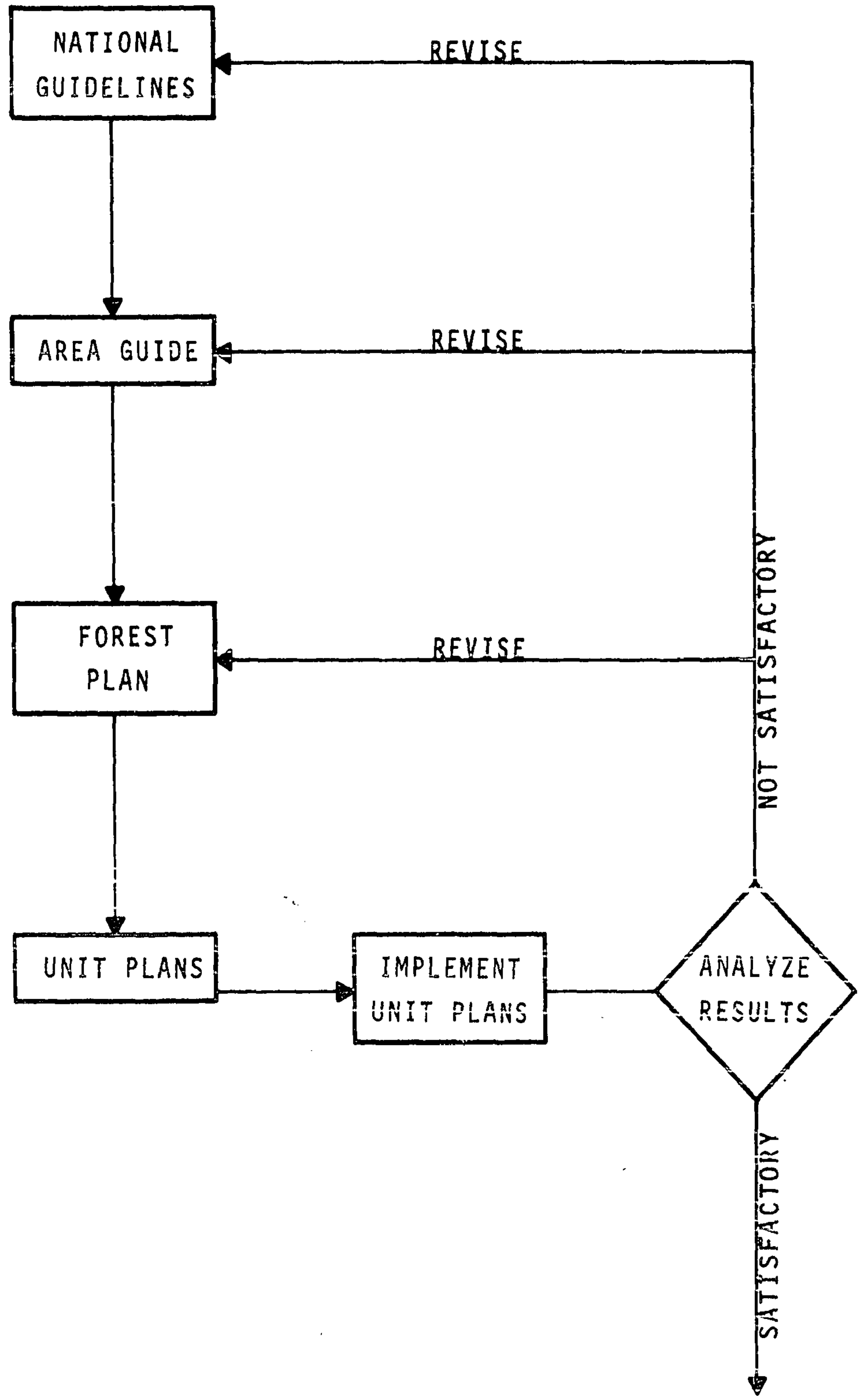

Fig. 5. USFS Planning System

1. Forest Service land use planning system overview

Land use planning is used by the Forest Service to develop ways to achieve National Forest System objectives effectively and efficiently. The land use system (Fig. 5) is composed of four, hierarchial levels of direction (Forest Service Manual, Title 8200):

a. Chief of Forest Service - At this stage, national objectives and targets are established via a process of consultation and negotiation between the Chief of the Forest Service and the Secretary of Agriculture.

b. Area Guides - Definite planning areas are established on the basis of population makeup, physiology, climate, problems and needs. The Area Guide provides broad direction to be followed by all National Forests in the planning area. The Area Guides are issued by the Regional Foresters.

The following considerations are taken into account in developing an Area Guide:

(1) The economic, social and environmental situation within the area;

(2) Projections and assumptions concerning population growth, levels of income and unemployment;

(3) Institutional considerations such as lows and regulations;

(4) Objectives and targets reflecting individual National Forests' share of area objectives and outputs.

c. National Forest Plans - The supervisors of individual National Forests must combine the planning direction received from the Regional Forester (via the Area Guide) with specific information about their National Forest. The Forest Land use plan provides day to day guidance for the management of the individual forests.

d. Unit Plans - The units are geographic areas of land, varying in size, that are characterized by particular patterns of topography, climate and land use (Forest Service Manual, Title 8200). These units may occur as one major drainage or several drainages. According to the Forest Service Manual (Title 8200, Section 8226): "the purpose of the unit is to provide a focus for planning activities in a small enough area to be workable and large enough to enable the planning team (Forest) to envision or predict the cause and effect relationship of management alternatives". The Forest Supervisor is responsible for developing the Unit Plans on a Forest.

The Unit Plans provide more specific, "on the ground" direction for meeting Forest objectives. In fact, the Forest Plan itself is actually made up of individual Unit Plans.

Some of the important steps in developing Unit Plans are:

(1) Evaluate the current situation in terms of land capability, current resources and public needs;

(2) Determine resource activity possibilities;

(3) Determine alternative plans which resolve various

activity conflicts and achieve varying levels of contributions to the planning objectives;

(4) Analyze the trade-offs of various plans in meeting planning objectives.

Goal programming will be used in this thesis to help in the development of Unit Plans, particularly steps (3) and (4) above. Development of alternative plans and analyzing trade-offs among plans is an integral part of the Forest Service land use system, hence the interest in this application.

Before going on to a discussion of the specific land area of application for this study, it should be mentioned that the Forest Service uses an interdisciplinary planning approach to its land use planning system. This means that a team of individuals, representing two or more areas of knowledge will focus on the same subject, that subject usually being multiple use management. The interdisciplinary team assembles the required data, identifies opportunities for action and forecasts benefit and costs of various possible actions. i.e. the interdisciplinary team provides the background information for the Area Guide and the individual Forest plans.

2. The Ozarks Highlands Area Guide[1]

The Ozark Highlands Area, the area of concern for this thesis, includes the mountainous and hilly portions of southern Missouri, northern Arkansas and eastern Oklahoma (Fig. 6). Within the Area are four National Forests; the Clark and Mark Twain in Missouri, the Ouachita in Oklahoma, and Arkansas; and the Ozark-St. Francis in Arkansas.

The Ozark Highlands were relatively isolated from the rest of America for much of its early existence. The Ozarks were settled by people from Tennessee, Kentucky, Virginia and the Carolinas. These people, mostly farmers, were very independent.

Today, however, the role of the Ozarks seems to be changing. This is due inpart to increased demand for recreational opportunities in our country. The Ozarks, with their abundant supply of natural resources, and their unique area characteristics, will play an increasingly important role in meeting the Nations' need for natural resources. The advent of the Interstate Highway System has made the Ozark Highlands much more accessable than in the past. For instance, there are

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[1]The Ozark Highlands Area Guide (U.S.D.A., 1974) is a part of the Forest Service land use planning system. The information contained in the Guide was collected by the Ozark Highlands Task Force, and interdisciplinary team of five members headed by Richard Hull. The task force study report (U.S.D.A., 1973b) contains the findings of the team in much more detail than the summary found in the Area Guide.

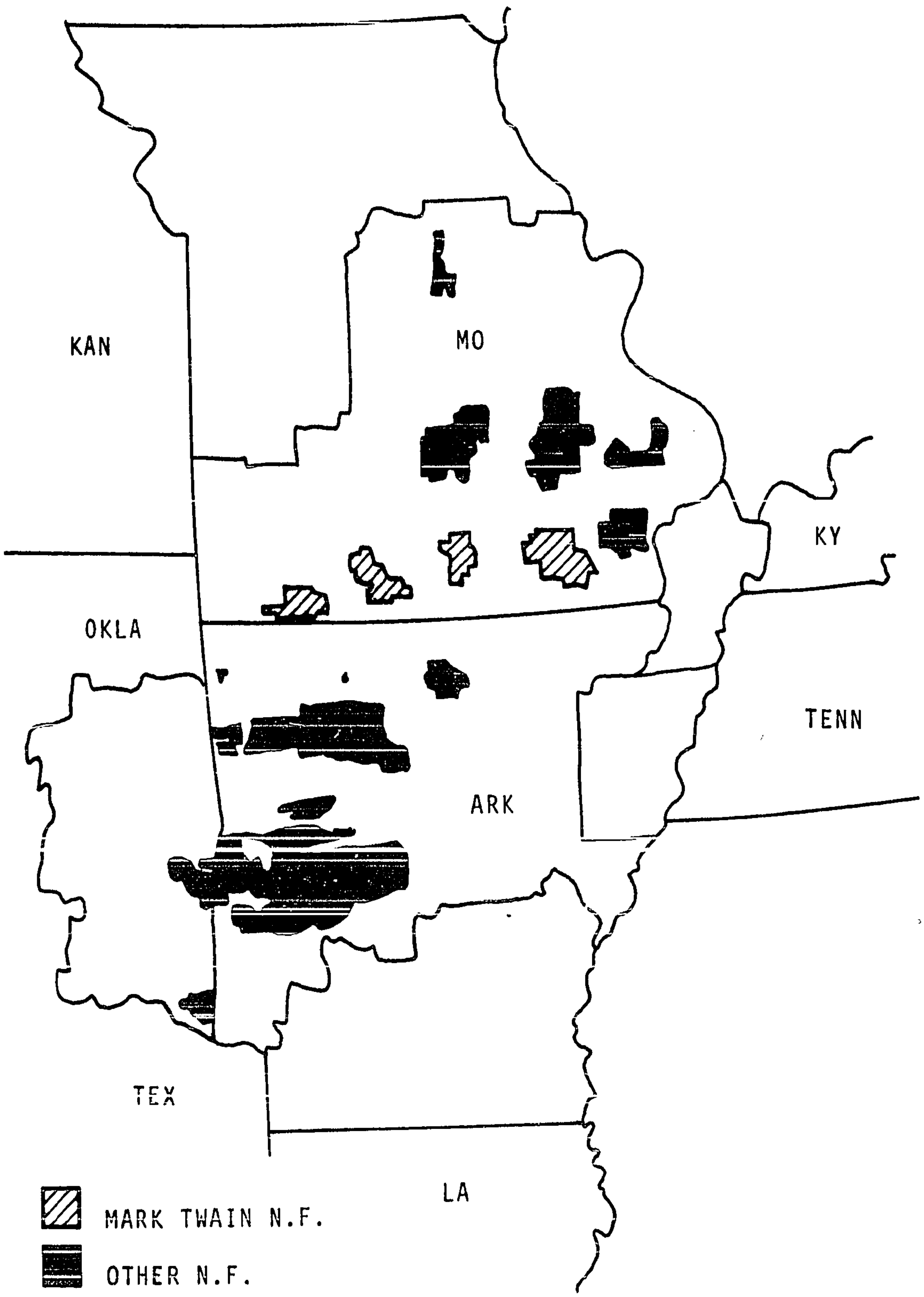

Fig. 6. Ozarks highlands planning area

approximately 40 million people residing within a day's driving distance of the Clark National Forest in the northern Ozark Highlands. The National Forests are very important to the area with current programs directly or indirectly responsible for over 2,500 jobs (U.S.D.A., 1974).

The role of the National Forests in the Ozarks will only increase in the future. It is this author's view that recreation will become a major use of the National Forests in the area. The Ozark Highlands provide the one area where people from the prairies and agricultural lands (Mid West) can enjoy a mountainous environment. With only 12 per cent of the land of the area in public ownership, the National Forests provide the only sizable acreages necessary for quality dispersed recreation (hiking, sightseeing, nature walking, etc.).

The Area Guide (U.S.D.A., 1974) stresses the need to manage the National Forests effectively and efficiently. This is due to the increasing demand for timber, recreation, wildlife, forage; etc. from the National Forests in the Area. Demand for dispersed recreation has been projected to increase by 117 per cent by 1980; it is estimated the wildlife habitat capability must be doubled in order to provide the increased demand for wildlife (hunting); hardwood saw timber demand will increase by 600 per cent, hardwood pulpwood by 2500 per cent, softwood saw timber by 20 per cent and softwood pulpwood by

25 per cent.

3. The Mark Twain[1] National Forest

The Mark Twain National Forest is within the boundaries of the Ozark Highlands Area (Fig. 6). As part of the Forest Service land use planning system, a Forest plan was developed by the Forest Supervisor and his staff. The Forest Plan for the Mark Twain describes how the management of the Forest will be carried out in order to implement national objectives set forth by the Chief of the Forest Service. The Forest plan will combine specific information on the Mark Twain with the planning direction received from the Area Guide for the Ozark Highlands.

The Mark Twain itself is in the northern portion of the Ozark Highlands Area. The forest is made up of approximately 600,000 acres of land on the Ozark Plateau, an area known as Missouri's southwestern Ozarks. Thirty-two per cent of the area is in pole timber stands; 31 per cent in saw timber; 30 per cent in seedlings and 7 per cent is nonstocked (Ostrum and Hahn, 1974). The black-scarlet oak type is the major forest type on the Forest followed by the post-blackjack oak type. These forest types include a considerable amount of the Southern Pine species (primarily Loblolly).

[1]The Mark Twain and Clark National Forests were joined in 1974 and are now known as the National Forests in Missouri.

4. Swan Creek unit

The Swan Creek unit is located in Christian county, Missouri, on the Ava Ranger District (Fig. 7). The unit is bounded on the south and west by State Highway 125; on the east by State Highway UU; and on the north by the District boundary. The unit includes some 10,000 acres of National Forest land, the majority of which is oak and oak/pine, and cedar/hardwood. Swan Creek is the primary natural feature and drains the unit from north to south. The unit is approximately 15 miles southeast of Springfield, Missouri (population 180,000), and includes National Forest land closest to that population center.

Past uses of the Unit include dispersed recreation, timber production, hunting and grazing. Dispersed recreation on the Unit includes sightseeing, hiking and nature walking as the primary activities. Timber production has included hardwood saw timber, cordwood for charcoal production; and cedar saw timber production. The great majority of the stands are young growing trees, and, at present, there is limited opportunity for additional timber harvest (beyond the present allowable cut). The Unit is not currently being used as a water shed, however, there is potential for this use.

The Unit plan for the Swan Creek Unit, an integral part of the Forest Service land use planning system, contains the specific management direction to be followed on the Unit. The

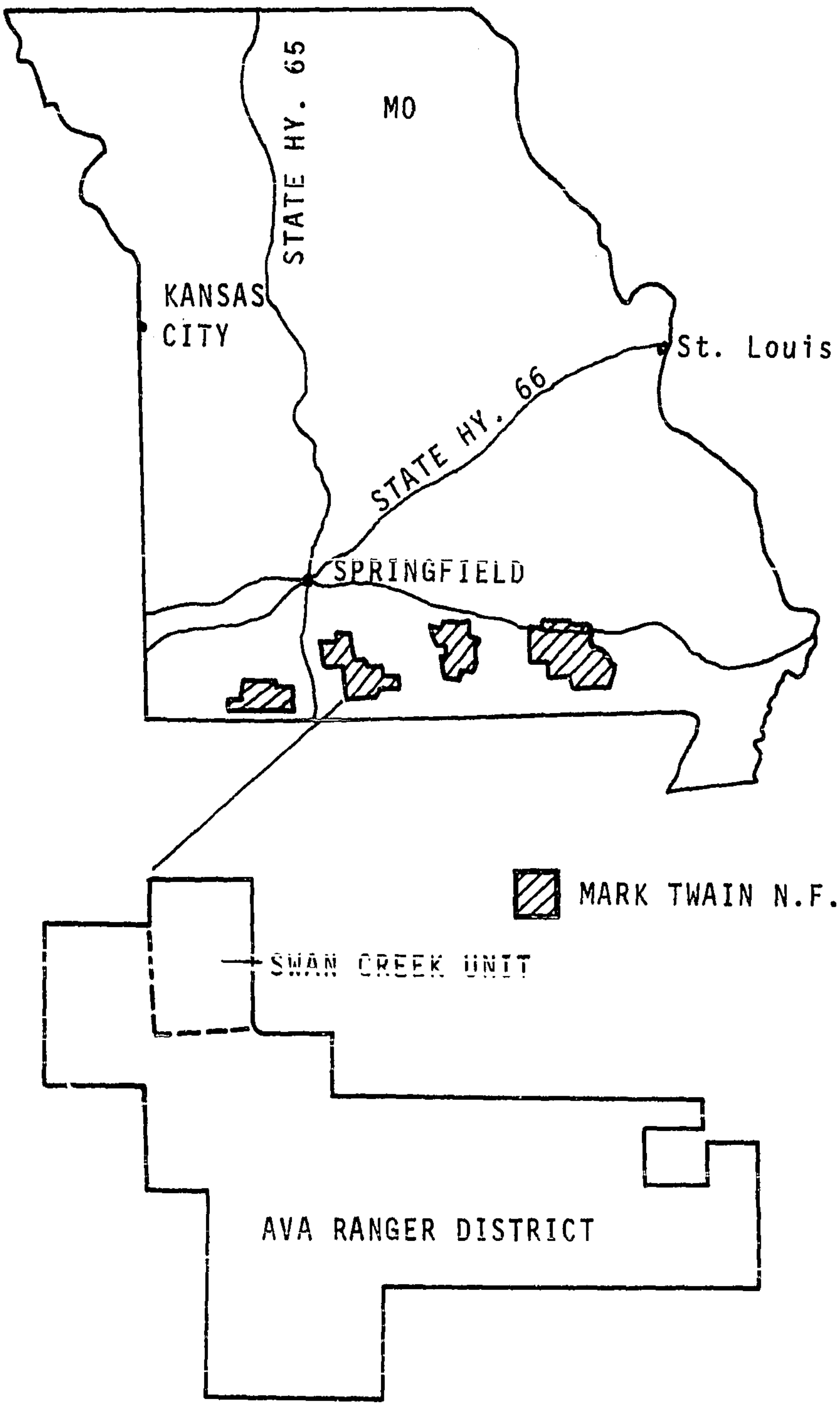

Fig. 7. Location of Swan Creek unit

Unit plan is actually part of the Mark Twain Forest plan. The plan includes many items of importance such as:

(1) a complete inventory of the Unit including vegetative cover type maps, stand tables, acreages in various cover types etc.;

(2) a wildlife habitat management plan which includes an inventory (different from (1) above) of present cover conditions, and management prescriptions for improving the habitat;

(3) a project work listing which enumerates various items to be accomplished such as crop tree release, developing savannahs, protection and management of existing fields, water developments (ponds) and timber stand improvement (TSI) work. Also included are estimated costs of these operations;

(4) a series of statements concerning Unit policy direction on various topics. In many cases, Forest level policy provides needed direction, however in some cases, Forest policy is altered to take into consideration special circumstances which may exist on the Swan Creek Unit.

The goal programming approach was applied (at the "conceptual level") to Unit planning in this thesis. Specifically, the approach will deal with the evaluation of alternative management strategies with the purpose of determining effective means of meeting <u>Unit</u> goals. In addition, the efficacy of various goals will be evaluated. Are the goals reasonable? Is the Unit capable of meeting the goals?

5. Data for the study

Several years ago (1972), the author became interested in the problems of applying multiple use concepts to public forest land. Consequent to this interest, a working relationship between the author, Dr. John Meadows and the Planning Team of the Mark Twain National Forest (particularly Ron Olsen) developed. Mr. Olsen and his associates were very much interested in exploring possible approaches to multiple-use management. Multiple-use management is very much a part of their jobs.

The data used in the study is "rough" and not refined to the point where one could apply the results (allocation of acres) without careful review. However, the data serves to illustrate the potential of goal programming as applied to unit level planning in the Forest Service and, in addition, serves to identify information requirements. Considerably more detailed data would be required to convert this study to an approach which could be applied without considerable interpretation. However, current budget and time limitations made this detailed type of study infeasible.

The data actually used in the thesis came from two main sources: The Ozark Highlands Took Force Report; and the Mark Twain planning team.

a. Ozark Highlands Task Force Report (U.S.D.A., 1973b) The Task Force Report is the result of a six month study undertaken by an inter-disciplinary team (Robert Hull, leader). The purpose of the Task Force was to collect relevant information on the Ozark Highlands Area in order to facilitate the development of the Area Guide and the individual Forest plans. The Task Force report includes such items as: a demand allocation study which identifies the contribution of the Ozark Highlands area to National needs, and estimating the amount which must be provided by each National Forest in the Area; a suitability analysis which determines the suitability of the land to supply specific resources; a production coefficient study which determines the input-output relationships between forest management practices, resources, and forest products; an economic analysis (carried out by the Economic Research Service) which determined the impact of the National Forests on jobs, incomes, etc.; a public involvement study which attempts to involve the public in forestry policy and program formulation.

The Task Force Report was used by the Mark Twain Planning Team as a guide in developing production coefficients and goal levels for the Swan Creek Unit.

b. The Mark Twain planning team The planning team provided specific information for the Swan Creek Unit. (Recall that the Ozark Highlands Task Force Report (U.S.D.A., 1973b) dealt with the entire Ozark Highlands Area, hence the data is quite general and does not apply directly to specific National Forests and certainly not to a Unit within a National Forest.) The planning team essentially "converted" information, provided by the Task Force Report, to a form that was applicable to the Swan Creek Unit. For example, production coefficients developed by the Task Force for the Ozark Highlands Area are just too "gross" to apply specifically to the Swan Creek Unit. The planning team provided information such as: goal levels for the Unit; goal priorities; activities (management practices); production coefficients; and costs for the various management practices. The specifics leading to the development of this information will now be discussed.

1.) Goal levels The Swan Creek Unit goal levels were developed with dual consideration for the suitability of the Unit to produce goods and services, and the actual Mark Twain National Forest goal levels as specified in the Area Guide. The suitability of the Unit to provide goods and services is considered because the Forest Service is concerned with maintaining forest productivity on a sustained yield basis for all products. Setting goals which require the Unit to be over-utilized is considered as being contrary to good stewardship of the public land. Each unit is expected to provide its "share" of the Forest level goals; the particular contribution to be determined by Forest staff personnel. A particular Units' contribution or share is based primarily on an area proportional allocation of the Forest goals to individual Units, and then adjusted upward or downward depending on the individual Units' suitability. The Swan Creek Unit has four characteristics which differentiate it from the "average unit" on the Mark Twain National Forest:

(1) Swan Creek runs through the entire unit from north to south greatly enhancing the units' ability to provide dispersed recreation due to the increased stream frontage;

(2) access is much better on the unit due primarily to the fact that the unit is encircled by State and county roads;

(3) the forest stands in the unit are relatively young in comparison with the rest of the Mark Twain stands. This was due primarily to excessive cutting in the past, hence the allowable cut on the unit is considerably less than on the average unit;

(4) the unit is very close to Springfield (15 miles), hence the demand for recreation and hunting will be greater than on the average unit.

The above, special characteristics were used to adjust the goal levels as determined by the area allocation scheme. For example: The dispersed recreation goal for the Mark Twain National Forest is 600,000 visitor days[1] as stated in the Ozark

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[1]A visitor day is defined (U.S.D.A., Forest Service, 1973b) as 12 hours of recreational or hunting use, individually, or collectively in a dispersed area. This can be interpreted to mean one person for 12 hours or 12 persons for one hour.

Highlands Task Force Report (U.S.D.A., Forest Service, 1973b). The Swan Creek unit, with 10,000 acres, is expected to provide approximately (10,000/600,000) x 600,000 = 10,000 visitor days of dispersed recreation. However, the Swan Creek unit was decided to be twice as capable of supplying dispersed recreation[1] as the average unit on the Mark Twain, hence, the goal was increased to 20,000 visitor days.

The remainder of the goal levels for timber, hunting and grazing were determined in a similar manner.

Table 2 summarizes the goal levels for two points in time: 1974 and 1985. These particular points in time were used for two reasons: (1) Looking at demands now (1974) and in the future (1985) gives some recognition to the time horizon in planning decisions. Although not dynamic in the sense that dynamic programming models would look at more frequent points in time, the approach used here is an improvement over looking at simply one point in time; (2) The Ozark Highlands Task Force Report (U.S.D.A., F.S., 1973b) and The Ozark Highlands Area Guide (U.S.D.A., F.S., 1974) lists the demands for forest goods and services for these two years. This thesis study wanted to take advantage of the data which was available.

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[1]Dispersed recreation includes such activities as hiking, driving for pleasure, etc. They are events which take place over an area rather than occurring in one place such as picnicing.

Table 2. Goals for the Swan Creek Unit

Goal	Units	1974	1985[a]
Dispersed recreation	Visitor Days	20,000	27,000
Hunting			
Forest species[b]	"	30,000	40,000
Open land species[c]	"	2000	4000
Timber			
Hardwood sawtimber	CU.FT.	10,000	25,000
Hardwood pulp	"	20,000	50,000
Softwood sawtimber	"	360	380
Softwood pulp	"	160	180
Grazing	AUM[d]	2000	2000

[a]Projected goals (from the Ozark Highlands Task Force Report (U.S.D.A., 1973b) and Ozark Highlands Area Guide (1974)). The Task Force Report and Area Guide give percentage increases in demand over 1974 levels. These percentages were then adjusted for conditions on the Swan Creek Unit.

[b]Forest species include deer, turkey, fox, squirrel, and raccoon.

[c]Open land species include quail and rabbit.

[d]Animal Unit Months (AUM) refers to the carrying capacity of an acre. For example: one AUM means the acre can support one unit (1000 pounds) for a period of one month without incuding a downward trend in forage production, quality, or soil (Stoddart and Smith, 1955, Page 2). The animals referred to in this table are cattle.

2.) Goal priorities As directed by the Multiple Use and Sustained Yield Act of 1960, the priorities were determined after careful consideration of the numerous factor involved. The goals were ranked, in this case, by the planning team of the Forest in order of relative importance.

The ranking of the various goals by the team was in an ordinal manner. A cardinal ranking scheme was simply not feasible in this situation. The rankings developed are the result of an application of a group interaction technique whereby various experts (in this case timber managers, wildlife biologists, silviculturists) were involved in an interdisciplinary approach to deciding on a proper ranking scheme. Each of the experts were involved in a "give and take" discussion over the relative importance of the various goals. Guidelines for the experts were provided via the management direction developed in the Forest plan and the Ozark Highlands Area Guide (U.S.D.A., Forest Service, 1974).

Public involvement, via public hearings, played an important role in the group decision process. Citizens were asked to present their views concerning proposed resource management actions. During the hearings, the public was given ample opportunity to develop arguments for various courses of action they felt were important.

Due to the mixture of market goods and nonmarket goods, the planning team felt the best ranking they could specify was of an ordinal nature. Forest Service objectives are goal oriented and reflect primarily a political concensus of opinion

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[1]The group decision process is described by Collins and Guetzkow (1964) as a very effective problem solving technique.

as to what is most important and least important. Goal priorities are determined, in large degree, via the political process where nonmarket goods and other intangible considerations are more adequately represented in the decision calculus. The planning team specified ordinal priority levels for each of the four major goal classifications. Some categories are further broken down using Archimedian weighting within a particular category.

There was unanimous agreement that dispersed recreation was the most important goal and should receive primary attention. This was due to the unit's close proximity to Springfield and the above average capability of the unit to provide this service.

Hunting was considered the next most important goal with both types of hunting (forest species and open land species) weighted equally. The hunting goal was considered very important again due to the unit's proximity to Springfield and the large wildlife population supported by the relative young forest stands.

The timber harvest goals for this unit were considered third in order of importance. The poor condition of the stands and the relatively poor markets were important considerations in this decision. Within the third priority level, the various timber products were weighted via product values as determined from recent timber sales in the area.

The grazing goal was ranked last for the Swan Creek unit. A major reason for providing <u>any</u> grazing at all is due to the long standing tradition of providing unrestricted grazing use of public lands. A major problem with grazing is that most forest managers feel timber management (especially hardwood management which is the major commercial timber species in the unit) and grazing are incompatible.

A listing of the weighting scheme used in the study is presented in Table 3.

Table 3. Weighting scheme for goals on the Swan Creek Unit

Goal	Ordinal priority levels	Weight[a]
Dispersed recreation	1	
Hunting forest species	2	1.0
Hunting open land species	2	1.0
Timber harvest		
Softwood sawtimber	3	13.17
Hardwood sawtimber	3	10.61
Softwood cordwood	3	5.0
Hardwood cordwood	3	1.0
Grazing	4	

[a]Weights are used here to signify Archimedean weights in that they represent trade offs among goals at the same priority levels.

<u>3.) Management practices</u> A management practice, as it is used here will mean a set of varied operations which are performed in order to provide effective stewardship of the public forest land. The operations will vary with the management practice, however most field operations will be silvicultural in nature. In addition, management will include the necessary overhead operations such as timber sale administration and planning; providing public information; and other general operation which must be carried out.

Strategies are assumed to be practiced only on areas where they are highly suitable. Suitability is determined on the basis of cover type maps which identify major forest cover types throughout the unit. This will be explained in more detail in the section on production coefficient.

Fire protection, a major component of forest management is not included as a management activity for purposes of this study. Fire protection is provided via another budget source, entirely separate from the timber management budget.

There were eight major management strategies which were considered viable for the Swan Creek Unit by the planning team. Each major strategy had variations which ranged in number from one to five. The variations were essentially less intensive versions of the primary strategy.

(1) Even-age management for oak and/or oak pine. The even age management strategy consists of cultivating the even-

age stand via proper silvicultural cutting techniques such as pre-commercial thinning, intermediate thinning, sanitation cutting, and the harvest cut. The major harvest cutting practices are the shelterwood technique and clear cutting technique. The even-age strategy includes six variations ranging from very intensive (EAM11) to least intensive (EAM16). The purpose here is to put more points on the production function for each major strategy.

a. EAM11 - This is the most intensive of the even age strategies. Activities include a pre-commercial thinning at age 20; intermediate cuts at ages 40, 50, 60 and a harvest cut at age 80. Timber sale adm. and planning are included in this strategy.

b. EAM12 - This strategy is less intensive than EAM11 in that fewer intermediate cuttings are performed. The intermediate cuts at ages 40 and 60 are eliminated. Again timber sale adm. and planning are included.

c. EAM13 - This strategy is less intensive than EAM12 in that there is no pre-commercial thinning and only one intermediate cut at age 50 followed by a harvest cut at age 80. (Timber sale adm. and planning again are included.)

d. EAM14 - This strategy is essentially a pulpwood management strategy where one performs a pre-commercial thinning at age 20 followed by a pulpwood harvest cut at age 50. (Includes timber sale administration and planning.)

e. EAM15 - This strategy has only one activity, that of building one acre ponds per 150 acres of forest land. The purpose of the strategy is to improve the wildlife habitat in the absence of timber cutting practices.

f. EAM16 - This strategy is the least intensive of the even-age strategies. In fact this strategy is that of unmanaged land with no activities being performed. (No activities implies that timber sale administration and planning are not performed.)

It should be mentioned that no timber can be cut via this strategy because timber sale administration and planning activities must be implemented (as per Forest Service policy) before any timber sales are carried out. Hence, the only available products from this strategy are hunting, recreation and grazing when applicable.

(2) All age management for oak and/or oak/pine. All age management is very similar to even age management except the silvicultural practices and cutting schedules are adjusted to provide an all-age stand. The major difference is the use of selection cutting techniques for the harvest cut. As with the even-age strategy, there also exists six levels of intensity for the all age management strategy, in fact they are essentially the same in nature.

(3) Pine type management. Pine type management is essentially the same as even age management for oak and or

oak/pine, the major difference being due to the different rotation ages in the southern pine type. Pine type management is applied to stands which are predominantly made up of southern pine (primarily Shortleaf Pine). Again pine type management has six levels of intensity ranging from most intensive (PTM11) to least intensive (PTM16).

(4) Cedar and cedar/hardwood management. This type of management strategy consists primarily of a mixture of even age and all age management applied to the eastern red cedar, upland hardwood cover type. The activities performed are similar to even age management and all age management for oak and or oak/pine with the major difference being the timing of the cutting schedules. The timing is different due to the difference in rotation ages of the species involved. Again, the cedar and cedar/hardwood strategy ranges from very intense (CCH11) to unmanaged land (CCH16).

(5) Savannah[1] management. The absence of timber management activities distinguishes the savannah management strategy from the three previously discussed. Savannah management (SVM11) consists primarily of prescribed burning techniques and the application of herbicides to maintain the savannah condition. In addition, there is a less intensive

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[1]A savannah is defined here to mean an area of forest land (from the oak and oak/pine type) with less than 40% of the full stocking level.

savannah strategy where the prescribed burning and herbicide treatments are eliminated (SVM12). This strategy is the no management strategy applied to savannahs.

(6) Open glades[1] management. Open glades management is similar to savannah amangement in that prescribed burning and herbicide treatments are the major activities used in the strategy. These two activities are used to maintain the open glades condition, which is considered by many to be ideal open land wildlife habitat. In addition to the intensive strategy (OGM11), there is an unmanaged open glades strategy (OCM12), similar to the unmanaged savannah strategy.

(7) Open field management. Open field management consists of the same type of activities mentioned for savannahs and open glades. The only difference is that the prescribed burning and herbicide treatments are applied to areas designated as open fields. Open fields differ from open glades in that the soil is deeper in the fields and the vegetation consists entirely of brome sedge and various other grasses. Again, open field management has two intensity levels: intensive (OFM11) and no management (OFM12).

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[1]Open glades are noncommercial forested areas with less than 20% woody cover. They are landscapes characterized by thin soils and limestone out croppings with native grasses and cedar being the vegetative cover.

(8) Old growth[1] management. Old growth management (OGM) is actually no management. One simply leaves the stand as it is. This strategy is applied to areas which are designated as old growth.

Table 4 presents a summary of the various management strategies used in the study. The table also illustrates the types of activities which make up each of the management practices.

4.) Management costs The costs for the 31 management activities used in the study consisted of four major categories:

(1) Contract costs[2] - The contract cost is that cost associated with carrying out the various silvicultural operations such as pre-commercial thinning, intermediate cutting and harvest cutting. These operations are carried out at various stand ages (depending on the species and rotation age), hence these costs were converted to an annual equivalent cost per acre. A four per cent discount rate was used in conjunction with standard discounting procedures to determine the

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[1]Old growth stands are defined here to be stands consisting primarily of saw timber size trees or size class 7 and 8 via the Forest Service terminology. Old growth can also be described as stands held beyond their normal economic rotation.

[2]The silvicultural operations are usually accomplished via contracts issued to individual people or companies by the Forest Service.

Table 4. Management practices and their activities

Mgt. practice	Activity							
	PCT	IC	IC	IC	SHC	SHC	HT + PB	POND
	Stand age when activity carried out							
	20	40	50	60	60	80	annual	1/10 years
EAM11	X	X	X	X		X		
EAM12	X		X			X		
EAM13			X			X		
EAM14	X		X					
EAM15								X
EAM16								
AAM11	X	X	X	X		X		
AAM12	X		X			X		
AAM13			X			X		
AAM14								
AAM15								X
AAM16								
PTM11	X	X	X		X			
PTM12	X	X			X			
PTM13		X			X			
PTM14	X		X					
PTM15								X
PTM16								
SVM11							X	
SVM12								
CCH11	X	X	X		X			
CCH12	X	X			X			
CCH13		X			X			
CCH14	X		X					
CCH15								X
CCH16								
OGM								
OGL11							X	
OGL12								
OFM11							X	
OFM12								

PCT - pre-commercial thinning; IC - intermediate cut; SHC - sawtimber harvest cut; HT - herbicide treatment; PB - prescribed burn.

annual equivalent cost for each management strategy. The costs are listed in Table 17 of Appendix C.

(2) General overhead costs - The general overhead costs were primarily those associated with timber sale planning, supervision, and other Forest planning activities. The overhead costs were assumed to vary directly with the intensity of silvicultural operations being performed. They were assumed to be a percentage of the labor costs stated above in (1). Table 15 in Appendix C indicates the schedule used to calculate the overhead costs.

(3) Building ponds for wildlife purposes - The ponds are one acre in size and cost approximately \$375 to build. One pond is to be built per 150 acres hence per acre cost is \$375/.50 acres = \$2.90/acre. This cost was converted to an annual equivalent cost (with n = 10 being the average life of pond before major main tenance is required) of \$.35/acre/year.

(4) Annual maintenance costs for savannahs, open fields and open glades — These are costs associated with operations performed to maintain certain areas as open fields, glades and savannahs. The operations are primarily prescribed burning and herbicide treatments. Table 16 in Appendix C lists the annual maintenance costs for these operations.

The above costs were added together to determine the total annual equivalent costs per acre for each of the 31 management activities. Table 17 in Appendix C lists the total cost/acre for each activity.

5.) Production coefficients[1] The production coefficients were developed jointly by the Mark Twain planning team and the author. The coefficients apply specifically to the ecological cover types occurring on the Swan Creek Unit and should not be applied to areas quite different in ecological make up. Due to a general lack of recorded information, somewhat subjective guidelines were used at times, in developing the coefficients. The Mark Twain planning team was made up of people knowledgeable on timber, wildlife, recreation, soils, and grazing. These experts provided guidelines and other helpful information in developing the coefficients. Information provided by the experts was used specifically by the author in developing many of the coefficients.

The coefficients vary in degree of accuracy with the timber product coefficients being the most accurate and recreation and wildlife (hunting) and least accurate. This

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[1]A production coefficient is defined (for this study) to be the input-output relationship between a management practice and an output. An example from the basic model used in this study will help to clarify the definition. The input-output equation showing the relationship between the product, grazing, and the various management practices is:

$$0.0EAM11+...+0.0EAM16+0.0AAM11+...+0.0AAM16+0.0PTM11+...+0.0PTM16+0.0CCH11+...+0.0CCH16+0.7SVM11+0.17SVM12+0.80GL11+0.2OGL12+1.80FM11+0.45OFM12>2000A.U.M.$$

This equation implies, for example, that for every acre of land which is managed via the old field management practice (OFM11), 1.8 A.U.M. of grazing product will be provided; for every acre managed via the savannah management practice (SVM11), 0.7 A.U.M. of grazing will be provided, etc.

is due simply to the fact that more information is available concerning timber production.

The development of the coefficients was influenced by Pearsons' (1943) concept of multiple use. It was assumed that areas highly suitable[1] for a particular activity would be used primarily for that activity. For example: savannah management would be practiced on areas determined to be highly suitable for savannah management. This practice does not preclude the production of more than one product on an area, it simply means that areas highly suitable for providing recreation (savannahs for example) will have a higher coefficient than areas less suitable for recreation (open fields or a pine plantation). The same holds true for timber production, grazing and wildlife (hunting).

The general procedure used in developing the coefficients followed in two stages[2]:

(1) Coefficients were developed for the eight major management activities (AAM11, EAM11, PTM11, SVM11, OGM, CCH11, OGL11, and OFM11). Many assumptions were used in this stage

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[1]A suitability analysis was conducted by the planning team. The analysis identified areas highly suitable for the various management activities. Table 18 in Appendix D lists the cover types which were determined to be highly suitable for the management activities used in this thesis.

[2]Specific information concerning the development of the production coefficients can be found in Appendix D. The development is explained in much more detail than in the text.

and are listed in Appendix D. Essentially, timber product coefficients represent the allowable cut on a particular cover type, assuming a particular management activity; dispersed recreation coefficients represent carrying capacity estimates made by the planning team; wildlife hunting coefficients also represent the carrying capacity of an area under a particular management strategy (estimated by the wildlife specialist); and the grazing coefficients represent the carrying capacity of ranges in terms of Animal Unit Months.

(2) Coefficients were then developed for the less intensive management activities (AAM12, AAM13,...,AAM16; EAM12,...,EAM16; etc.). Essentially, these coefficients were adapted from the above coefficients via a large set of assumptions. Tables 19-25 in Appendix D lists the specifics of the conversion process.

6. The basic model

The basic model used to test the conceptual use of GP to unit level planning on the Swan Creek unit will now be discussed.

The model is an attempt at depicting the various components of the multiple use resource allocation problem existing on the Swan Creek unit.

Essentially, the model allocates acres of forest land to various management strategies in order to meet a set of ranked and weighted goals. In allocating the acres of forest land, the model must conform to a set of physical constraints (system constraints) and goal constraints. The physical constraints are two types: a budgetary type where the management practices must not cost more than $8000 to perform; and an acreage availability type constraint where one forces management practices to be performed only on areas determined to be highly suitable for those practices.

If a goal cannot be met, the model will minimize the weighted negative deviations from the goals.

Basic Model ('R1-74')

$$\text{Min} \sum_{s=1}^{4} \sum_{i=1}^{8} W_s \, d_i^- \qquad i=1,\ldots,8 \quad s=1,\ldots,4$$

subject to:

$$\sum_{i=1}^{8} \sum_{k=1}^{31} A_{ik} X_k + d_i^- - d_i^+ = b_i \qquad \text{(goal constraints)}$$

$$\sum_{j=1}^{12} \sum_{k=1}^{31} B_{jk} X_k \quad \gtreqless r_j \qquad \text{(system constraints)}$$

$$j=1,\ldots,12 \quad k=1,\ldots,31$$

Legend:

W_s = weighting function

d_i^- = underachievement from goal i

d_i^+ = overachievement from goal i

B_{jk} = input-output coefficient between activity X_k and system constraint (j)

X_k = management activity

A_{ik} = input output coefficient between the goals and the activities

b_i = the goals

r_j = system constraints

a. <u>System constraints</u> There are acreage availability constraints which limit the number of acres which may be allocated to each management strategy category. It is through this constraint set one forces a management practice to occur only on areas highly suitable for it. The constraints are as follows:

EAM11 + ... + EAM16	=	1600 acres
AAM11 + ... + AAM16	=	900 acres
PTM11 + ... + PTM16	=	136 acres
SVM11 + SVM12	=	800 acres
CCH11 + ... + CCH16	=	3558 acres
OGM	=	1052 acres
OGM11 + OGM12	=	1706 acres
OFM11 + OFM12	=	776 acres
Total acreage	=	10,522 acres

In addition, there are two other system type constraints. The budget constraint is used to prevent one from using more money than is available for management of the unit. There is a $8000 timber management budget which must be adhered to.

Also, some models run for this study, include a constraint which prohibits cutting more hardwood products than the goal calls for. This constraint focuses on two problems: (1) one must be conscious of the possibility that the market usually will absorb only a certain amount of timber products (there was no such problem with the other forest products in this study). This constraint prohibits overachievement of the hardwood timber goals simply by cutting off the appropriate management practices; once the goal is reached; (2) Due to the joint product nature of saw timber and pulpwood, there is the possibility one will be overachieved in order to meet the other goal. This happens when the two goals are quite different in scale. Preliminary "computer runs" indicated this possibility for the hardwood saw timber and pulpwood products, with saw timber being achieved long before the pulpwood goal. Hence, there was a need to allow a shift from a strategy which manages jointly for both saw timber and pulpwood to one which is strictly pulpwood management.

b. Goal constraints The goal constraints essentially indicate the relationship between the activities and the goals. The goals are the ones specified in section IIE3a and listed in Table 3. The production coefficients are the ones developed in section IIE3e.

III. RESULTS

The results will be divided into two sections:

1. Algorithm selection;
2. Management activity analysis.

A. Algorithm Selection

The three pre-emptive goal programming algorithms discussed previously were compared using variations of the Basic Model ('R1-74') in order to determine the advantages of existing algorithms and disadvantages with respect to:

1. Problem formulation;
2. Solution statistics including run cost.

The models were run using the IBM 360-65 computer at the ISU Computation Center. The objective was to determine the best algorithm to use for this study. A second objective was to present some useful information to prospective GP practioners.

1. Problem formulation

Each algorithm has the advantage of being able to handle resource planning problems of a multidimensional nature. The algorithms require a minimum of goal priority specification by the decision maker. The decision maker need only specify: timber is more important than grazing; dispersed recreation is more important than hunting; etc. It is not required that the decision maker specify cardinal weights for the various goals, although this information could be easily incorporated into the algorithms.

a. Size of problem The reader will recall that in Section IID4 (Algorithm evaluation), problem size was discussed. Both the Lee (1972) and Field (1973) approaches do not enlarge the size (matrix size) of the problem whereas the Charnes and Cooper (1961) approach increases the size of the problem by requiring the addition of constraints to force the pre-emptive ordinal solution to the problem. Size of the problem is important as a cost consideration in most cases.

b. Priority coefficients A distinct disadvantage of the Field algorithm is in the calculation of the priority coefficients. Depending on the magnitude of the right hand sides, (goal levels), the number of goal constraints, it will not take long before the (P_j), the priority coefficients, become very large. Ultimately, the size of the problem one can handle with Field's approach will depend on:

a.) the degree to which one can scale the model;

b.) the largest number (P_j) the LP computer package can handle. (The IBM package used for these comparisons has a limit of 12 digits.) The P_j values calculated for the comparisons ranged from one to approximately 21,109,209., even after the models were scaled by 100.

2. Solution statistics[1]

The algorithms using the IBM computer package (MPSX) had a definite advantage in this comparison category. Table 5 summarizes the results of these runs with respect to CPU time, number of iterations and run cost.

The major reason for the large difference in central processing unit times (the Lee algorithm was, on the average, for this study, 4 times as expensive) and run cost between the algorithms is due to the different matrix inversion techniques used. The IBM LP package, used by the Field algorithm, utilizes the "revised simplex"[2] whereas Lee's algorithm uses the "Gaussian elimination" technique. Revised simplex requires substantially fewer calculations in going from one iteration to the next, hence it is a much more efficient inversion technique, especially when using the computer.

In addition, the superior flexibility of MPSX allows "similar problems"[3] to be solved at reduced costs. Model

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[1]There are no figures for the Charnes and Cooper approach because all runs made with this algorithm resulted in infeasible solutions. This was due to the fact that the forcing constraints added, were too restrictive.

[2]The revised simplex method was developed by Dantzig, Orchard-Hays, and others at the Rand Corporation. It is a very efficient computational procedure for solving linear programming problems on the computer. See Chapter 17 in Hadley (1963) for a thorough explanation of the procedure.

[3]Similar problems are ones in which one vector or a right hand side (RHS) element is all that changes in going from one model to the next. Referring to model R1-74: several runs are made with the only change being made is a shift in the management budget itself.

Table 5. Algorithm comparisons for the Lee and Field algorithms

Run no.	CPU time (sec)	Main core time (2-K sec)	Iterations	Run cost
Lee IA	5.84	1978	41	$1.71
Lee IB	6.11	1991	43	$1.74
Lee IC	6.35	2008	48	$1.76
Lee IIA	4.59	1900	24	$1.60
Lee IIB	5.32	1945	33	$1.67
Lee IIC	5.52	1956	33	$1.68
Average	5.62	1963	37	$1.69
Field IA[a]			24	
Field IB	5.47	1507	26	$1.43
Field IC			30	
Field IIA[a]			28	
Field IIB	3.31	1392	28	$1.23
Field IIC			28	
Average	1.46	483	27	$0.44

[a]Run as a group using IBM's parametric routine.

groups IA, IB, IC; IIA, IIB, IIC; differ only with respect to the budget element in the right hand side vector. MPSX, with its superior flexibility, can solve these "similar problems" at greatly reduced costs. Lee's algorithm, conversely, does not have such flexibility at present.

3. Other considerations

The MPSX routine and thus the Field (1973) algorithm are more flexible in that one has the option of "range analysis" and "parametric programming". The sensitivity analysis is not currently available with the Lee (1972) algorithm, although the simplex solution is outputed allowing one the option of manually working out a sensitivity analysis. However, it should be noted that a lack of sensitivity analysis is not as serious a problem as might be suspected. The multi-dimensional objective function used in the pre-emptive GP model greatly limits the value of the range analysis option of MPSX.

4. Discussion

When working with relatively small models (less than 15 - 20 goal constraints), the best pre-emptive algorithm seems to be the one developed by Field. It is much cheaper (¼ as expensive) to run than Lee's algorithm, yet gives the same solution. Major problems would be models which have large right hand side values which could conceivably result in prohibitively large P_j values in the objective function. As previously mentioned, this can be overcome to the degree one can scale the model. The capacity of the computer to handle the P_j values will ultimately determine whether or not one can use the Field algorithm.

Another possible disadvantage of Field's algorithm is in determining the d_i^- and d_i^+. It should be remembered that one must be able to specify values for the (X_j), the structural variables, in order to calculate the $*d_j^-$ and $*d_j^+$.

The Lee algorithm is somewhat easier to program due to the simpler technique of specifying the priority coefficient in the objective function. The Lee method simply requires the priorities to be specified by integer number (P1 = 1; P2 = 2; etc.) in contrast to the calculations involved in the Field algorithm. The remainder of the input information for each algorithm is relatively similar.

A major advantage of the Lee algorithm over Field's is its ability to handle much larger models (greater than 20 goals), however, run costs are approximately four times as much.

The major problem with the Charnes and Cooper approach is the possibility of a solution somewhat less than the obtainable optimum due to the forcing effect of the added constraint equations. In some cases, as in this study, infeasible solutions result.

The algorithm selected for this study was the Field approach because the models which must be run to analyze the various management strategies had only four pre-emptive priority levels, well within the 20 goal limit, and the ever present cost factor. Approximately 75 computer runs had to be made in order to fully develop the alternative management strategies. In addition, there was a desire to perform some parametric programming on various models in order to estimate model stability.

B. Management Strategy Analysis

Variations in the basic model ('R1-74') were used to evaluate different management strategies. The objective was to determine whether or not the goals could be met with the available budget and how this could best be accomplished. If a goal could not be met, the management strategy that would allow one to come as close as possible to meeting the goals was sought.

The model variations used included budget level changes from the current level of $8000; goal priority changes from those given originally in Table 3; changes in some of the physical constraints; and changes in the goal levels themselves. Table 6 summarizes the fifteen models which were run for this study. In addition, the results of the individual runs are found in Tables 26-40 in Appendix E.

1. 1974 goal levels

Several important results were made as a result of running the 15 models.

a. Goals in general All of the 1974 goal levels can be met with the existing budget of $8000 with the exception of the hunting forest species, hardwood cordwood, and the grazing goal (Fig. 8). There does not seem to be any problem in

Table 6. Model variations

Models	No rank	Max rev.	Given priority	Hunt #1	Timber #1	NO OG	WOG	WHOC	WOHOC	1974	1985
R1-74			X				X		X	X	
R1-85			X				X		X		X
RR1-74			X				X	X		X	
RR1-85			X				X		X		X
R10-74			X			X			X	X	
R10-85			X			X			X		X
R100-74			X			X		X		X	
R2-74					X		X		X	X	
R2-85					X		X		X		X
RR2-74					X		X	X		X	
R3-74				X			X		X	X	
R3-85				X			X		X		X
RR3-74				X			X	X		X	
P1-74		X					X			X	
R11-74	X						X		X	X	

Legend: NO OG - no old growth constraint; WOG - with old growth constraint; WHOC - with hardwood overcut constraint; WOHOC - without hardwood overcut constraint; No rank - goals are not ranked; Max rev. - maximize revenue.

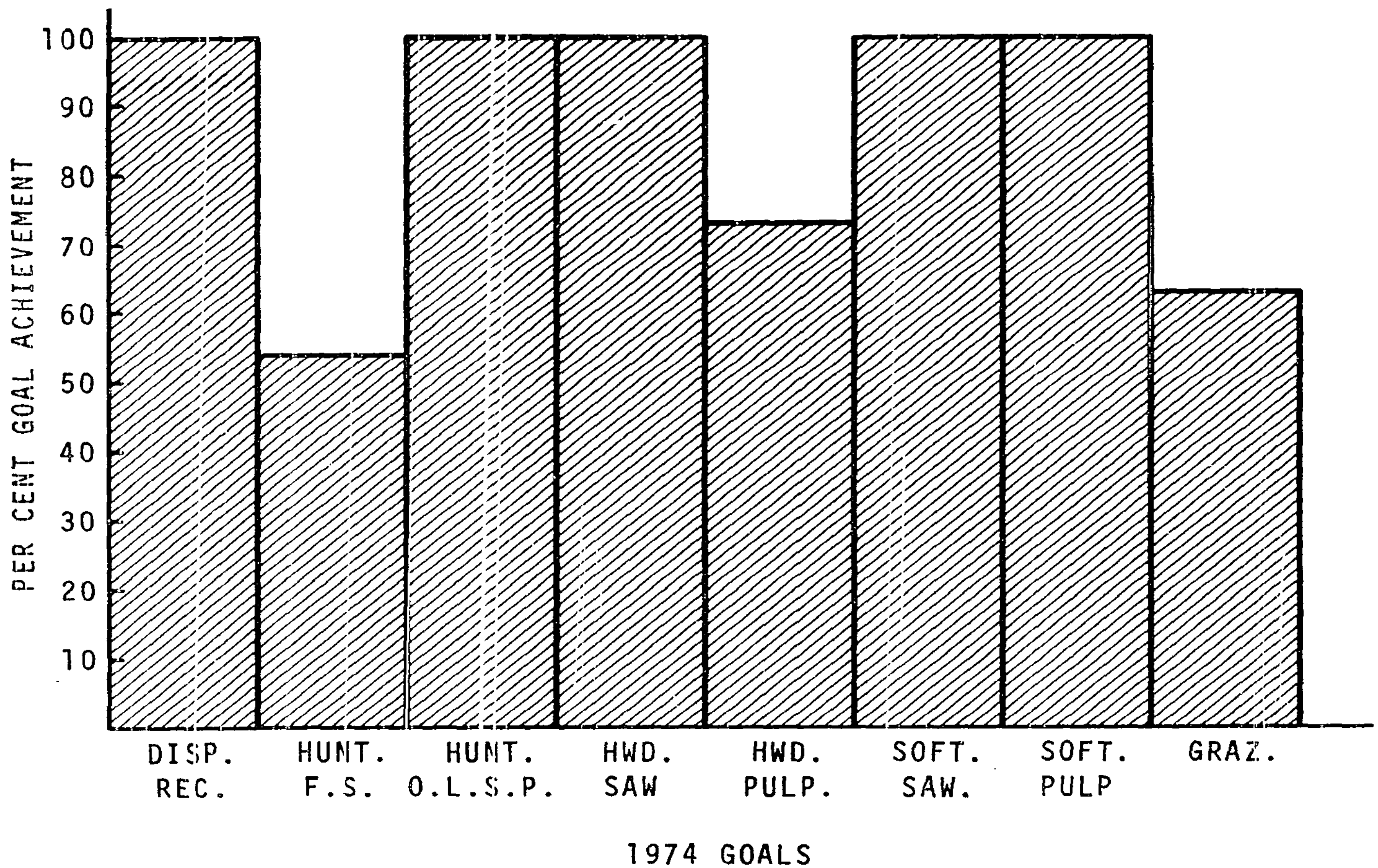

Fig. 8. Per cent goal achievement at $8000 budget level via basic model 'R1-74'

meeting the dispersed recreation, hunting open land species, hardwood saw timber, and softwood timber goals. These goals are met with an $8000 budget, regardless of the management strategy used. In fact, one really does not need to "manage" land to provide these goals on the Swan Creek unit.

Meeting the grazing and hardwood cordwood goals can be achieved by either increasing the budget or by adjusting the goal priorities. Table 8 illustrates this point for the hardwood cordwood goal.

b. Wildlife forest species goal   The major problem is presented by the wildlife forest species goal. This goal is very insensitive both to changes in the budget level and adjustments in management strategies as evidenced by Table 7. Table 7 indicates that underachievement of the wildlife forest species goal only ranges from 42% (basic model R1-74 and unlimited budget of $21,000) to 54% (maximum revenue model P1-74, and a $6000 budget). By contrast, the hardwood cordwood goal is very responsive both to changes in the budget level and changes in management strategies as seen in Table 8. The underachievement ranges from 0% (via several models) to 67% (max. revenue model P1-74).

The wildlife forest species goal cannot be met via increases in the budget level as applied to the management strategies used in this study. The management strategies are

Table 7. % Underachievement of wildlife forest species goal of 30,000 visitor days (1974 level)

Model	$6000	$8000	$10000	$ unlimited[a]
R1-74	48	46	44	42
R11-74	52	49	46	42
RR1-74	48	47	46	46
R10-74	51	48	46	-[b]
R100-74	51	49	48	-[b]
R2-74	50	47	45	-[b]
RR2-74	50	48	46	-[b]
R3-74	48	46	44	-[b]
RR3-74	48	47	46	-[b]
P1-74	54	51	49	-[b]

[a]Unlimited budget refers to that amount necessary to manage all acres in an optimal manner.

[b]Not determined.

Table 8. % underachievement of hardwood pulpwood goal of 20000 cu. ft. (1974 goal levels) at various budget levels

Model	$6000	$8000	$10000	$ unlimited
R1-74	51	27	18	0
R11-74	0	0	0	0
RR1-74	51	32	0	0
R10-74	53	28	6	0
R100-74	54	46	5	-[a]
R2-74	0	0	0	0
RR2-74	0	0	0	0
R3-74	50	26	18	-[a]
RR3-74	50	30	0	-[a]
P1-74	67	39	24	-[a]

[a]Not determined.

primarily oriented toward timber production, with other goods and services being assumed a by-product of good timber management. This practice is adequate for most of the goods and services such as recreation, grazing and hunting open land species. However, it is not adequate for meeting the forest species hunting goal, even at 1974 goal levels.

The problem presented by the inability of the Swan Creek Unit in meeting the forest species wildlife goal can be further analyzed via two questions. Number one is the possibility of developing other management strategies which are aimed specifically toward maximum development of the wildlife potential of the land. Number two is the distinct possibility that the goal itself is unrealistic. Diversity of habitat is the key to managing land for wildlife purposes (Gabrielson, 1936 and Leopold, 1930). Several management practices are quite effective in providing habitat diversity:

1. Reduce the size and increase the number of harvesting operations. This practice will increase the amount of the forest area in a highly productive stage for wildlife. Gabrielson (1936) estimates most of the wildlife on a given unit is located on areas cut over within the past 20 years. A reduction in the size of the harvesting operation will create a better distribution of the younger age classes. The disadvantage of this approach is of course that hogging costs will increase.

2. Modify existing timber stand improvement programs. One can modify timber stand improvement programs to sacrifice timber trees on poorer quality sites in favor of trees and shrubs having game value. In addition, one could leave "wolf trees" (have for squirrels and other wildlife) when carrying out timber stand improvement work. Both Gabrielson (1936) and Chapman (1936) suggest that many species of food bearing trees can be favored, along with favoring margins (edge effect) and openings at relatively no loss to the commercial product of timber.

Recent related research by the Michigan State Department of Natural Resources is encouraging (Bennet, 1974). They are conducting a pilot project to determine how much of each forest stage of succession we should maintain in order to provide the desired goods and services from the forest. The first step of the project involves clear cutting large areas (1000-5000 acres and larger) in order to get regrowth of the intolerant stage trees and brush. This is felt necessary to prevent the loss of wildlife associated with the intolerant stage of a forest stand such as deer, grouse, birds and other mammals. They are collecting information on recreational uses that are gained and lost, reactions of past and present users of the areas, responses of the vegetation and wildlife and costs of different treatments.

3. Maintain old growth areas in the unit. Old growth stands provide a unique cover for some forms of wildlife such as the nesting species.

4. Reduce stocking level of the stand. The lower stocking level will delay the "crowding out" of low growing plants which are desirable forage for many species of wildlife. In addition, low stand densities encourage large crowns and fruit production in the crop trees.

5. Develop food plots on areas to supplement the normal forage producing capability of the unit. The development of food plots would consist of clearing acre-size areas at an initial cost of $100 per acre with annual maintenance costs of $10 per acre. This would be followed by the planting of perrenial clovers, wheat and oats.

6. Incorporate prescribed burning practices on the area. This practice could prove helpful in opening up the understory, thus setting back plant succession.

There are formidable problems associated with the implementation of the practices mentioned above. The major p roblem is a serious lack of information concerning input-output relationships of wildlife populations. One needs to know what acceptable foods can be produced in a given stand and how much would be utilized by the wildlife populations. The ecology of lesser forest vegetation is still practically an untouched field over much of the United States (Society of

American Foresters, 1942). More recently, Jordan (1970) stresses the need for more work on developing production functions describing the relationship between various management practices and their effect on game populations. To date, the best general statement that can be made about the relationships is that most of the above mentioned practices (modification of timber stand improvement, reduce size of harvesting operations, and reduce stand density) increase the yield of woody browse plants (Jordan, 1970).

Related to the production function problem is the apparent lack of specific cost information on the various practices. Without cost information, it is difficult to determine the most economical method of improving wildlife habitats.

The other question one must ask is whether or not the forest wildlife species goal is realistic for the Swan Creek Unit. This is a difficult question to answer due to the general lack of input-output information and cost information for alternative management practices. The author, in conjunction with Roger Kivkmans (wildlife biologist on the Mark Twain National Forest) attempted to derive a rough approximation of the degree to which wildlife habitat could be improved on the Swan Creek Unit. In order to provide the best habitat, Kirkmans estimates that 20% of each compartment should be in productive forage. Normally, on an 80-90 year rotation, in an ideally balanced size class situation, 10-15% of a planning area may be expected to be in a productive forage condition as a result of normal harvest and cultural operations. This can be increased to 20% by: (a) improving the balance of size classes via harvest and cultural operations; (b) direct habitat management practices such as prescribed burning and establishment of food plots. There will be little effect on areas where site index is < 45, which, by the way, is approximately 35-40% of the Swan Creek Unit.

Maximum production of wildlife forest species on the Swan Creek unit would therefore be approximately 24,000 visitor days if the remaining 6200 acres (acres with site index > 45) were managed at maximum capability. The significance of this calculation is that 1974 goal levels (20,000 visitor days) could be met, however the 1985 level (40,000 visitor days) would still be underachieved by 40 percent. Therefore, it seems the wildlife forest species goal is unrealistic for the Swan Creek unit.

c. Acreage allocations The management activities which seem to be most effective in meeting goals are all-age management for oak and or oak pine, and savannah management. These two activities consistently come into the goal programming solution at close to their maximum allowable levels. They are the first activities to come into the solution in each model as seen in Table 9.

Table 9. Acreage allocations for AAM11 and SVM11 for the various models run at $8000 budget. (AAM11 maximum= 900 acres; 1058 for R10-74 and R100-74 models; SVM11 maximum = 800 acres)

Model	AAM11	SVM11
R1-74	900	800
R11-74	900	800
RR1-74	900	800
R10-74	1058	800
R100-74	1058	800
R2-74	900	800
RR2-74	900	800
R3-74	900	800
RR3-74	900	800
P1-74	484	800

The activities which consistently come into the solution only at relatively high budget levels (greater than $10,000) are old field management (OFM11) and open glades management (OGL11). The only exception to this rule (Table 10), is the P1-70 model which maximizes revenue.

Table 10. Acreage allocations for OGL11 and OFM11 for the various models run at the $8000 budget level (OGL11 maximum = 1701 acres; OFM11 maximum = 776 acres)

Model	OGL11	OFM11
R1-74	0	0
R11-74	0	556
RR1-74	0	0
R10-74	0	0
R100-74	0	0
R2-74	0	0
RR2-74	0	0
R3-74	0	0
RR3-74	0	0
P1-74	1701	776

d. Ordinal solution vs no ranking solution   There is a definite trade-off which must be evaluated if one is going to use an pre-emptive ordinal solution process as was used in this study. The ordinal solution is often times a very restrictive solution. This point can best be illustrated via an example which compares the results of an ordinal model (R1-74) and Model R11-74, one which treats each goal equally (rank of one), and minimizes total goal underachievement

(Table 11).

Table 11. A comparison between an ordinal solution and an equal priorities solution (no ranking solution)

Goal underachievement	Units	R1-74	R11-74	Difference #[a]
Disp. rec.	V.D.	5661[b]	4838[b]	-[c]
Hunt. FS	V.D.	13892	14616	2%
Hunt. OL Sp.	V.D.	2879[b]	3435[b]	-[c]
Hard. Saw	CU.FT.	4476[b]	3206[b]	-[c]
Hard. Pulp	CU.FT.	5363	0	27%
Soft. Saw	CU.FT.	1213[b]	754[b]	-[c]
Soft. Pulp	CU.FT.	94[b]	75[b]	-[c]
Grazing	AUM	750	0	38%
Total		20005	14616	6.4%

[a]Difference measured in % using 1974 goals as a base.

[b]Goal overachievement.

[c]Both models fully achieve these goals.

The model which does not rank goals has a 6.4% improvement in total goal achievement. The important item to note in Table 11 is that the ordinal solution (R1-74) more completely satisfies the second most important goal (wildlife forest species hunting) by 724 V.D. (2%), but this is at the expense of underachieving the hardwood pulpwood goal by 5363 CU.FT.

(27%) and the grazing goal by 750 AUM (38%).

The decision maker may want to alter his goal ranking scheme in light of this type of information. In some cases, providing 2% more hunting will be more important to the manager than providing an additional 27% hardwood pulpwood and 38% grazing. It is a trade-off which the manager must evaluate carefully.

e. Maximizing revenue solution The worst strategy, in terms of meeting goals, is the model which maximizes revenue (P1-74). There is a trade-off here between meeting goals and maximizing revenue. Model P1-74 provides $21,430 additional revenue over model R1-74, but at the expense of providing 1405 fewer V.D. of hunting forest wildlife and 2440 fewer CU.FT. of hardwood pulpwood as shown in Table 12. However the maximum revenue model does meet the grazing goal whereas the R1-74 model underachieves that goal by 750 AUM.

These results must be interpreted with caution due to the nature of the product values used in the calculations for each management activity. The values for timber products and grazing are relatively accurate in that they reflect current market values, however, values for dispersed recreation and hunting are estimates made by the Mark Twain personel. The values used can be found in Appendix G.

Table 12. Comparison between the maximum revenue model (P1-74) and the R1-74 model which minimizes goal underachievement at the $8000 level

Goal underachievement	Units	P1-74	R1-74	Difference[a]
Dispersed Rec.	V.D.	10433[b]	5661[b]	---
Hunt. FS	V.D.	15297	13898	5%
Hunt. OL Sp.	V.D.	4506[b]	2879[b]	---
Hard. Saw	CU.FT.	696	4476[b]	7%
Hard. Pulp	CU.FT.	7703	5363	12%
Soft. Saw	CU.FT.	516[b]	1213[b]	---
Soft. Pulp	CU.FT.	5	94[b]	---
Grazing	AUM	1317[b]	750	38%
Total Revenue	$	285,387	263,957	8%

[a]Difference measured in % using 1974 goal levels as a base.

[b]Goal overachievement.

f. Effect of the old growth constraint The reader will recall the old growth constraint which forces 10% of the unit's acreage to be allocated to old growth management (OGM). The major effects of the constraint can be determined via a comparison between basic model (R1-74) and (R10-74) which eliminates the old growth constraint. The major effect, at 1974 goal levels, is the worsening of the wildlife hunting forest species situation via the R10-74 model. The old growth management strategy has a high production coefficient for forest species wildlife because it provides a unique habitat for some species which is not provided via stands which are "managed". Surprisingly, the constraint does not affect achievement of timber product goals at the 1974 levels. However, this changes when one refers to the 1985 timber products goal levels. The R10-85 model (the 1985 goal level counterpart to the R10-74 model) does not provide any timber products at the $8000 budget level while the R1-85 model (the 1985 goal level counterpart to R1-74) provides 6000 CU.FT. of timber products at the $8000 budget level.

g. Effect of the hardwood overcut constraint The hardwood overcut constraint was included in some models to allow for the possibility that the timber markets will not always be able to absorb timber products beyond the stated goal level. The author compared models R1-74, the basic model with no overcut constraint, with model RR1-74 which included the overcut constraint. The most obvious difference is at the $10,000 budget level where the R1-74 model overachieves the hardwood saw timber goal by 6174 CU.FT., but underachieves the hardwood pulpwood goal by 3664 CU.FT. The RR1-74 model, conversely, allows one to shift to a pulpwood management strategy (EAM14, AAM14, CCH14) in liew of the more expensive strategy which manages for both pulpwood and saw timber products (EAM11, EAM12, AAM11, AAM12, CCH11, CCH12). The result is that both the pulpwood and saw timber goals are achieved with the same budget level as the less effective R1-74 model.

2. 1985 goal levels

Most of the comments made with respect to 1974 goal level achievement hold in the 1985 goal level case. The most interesting additional observation that can be made is that most of the projected 1985 goals cannot be met using the current $8000 budget level (Fig. 9). At this level, only the hunting open land species and softwood saw timber goals are consistently achieved under each management strategy. The hunting forest species, hardwood saw timber and pulpwood goals are seriously underachieved regardless of the management strategy used. Table 13 summarizes goal underachievement at the $8000 level for various management strategies.

Table 13. Underachievement of hunting wildlife forest species, hardwood, saw timber and pulpwood goals at the $8000 level (1985 goal levels)

Model	Hunting FS	Hardwood saw.	Hardwood pulp	Grazing
R1-85	65%	91%	93%	34%
RR1-85	65%	91%	93%	34%
R10-85	67%	100%	100%	--
R2-85	68%	20%	48%	49%
R3-85	62%	58%	79%	38%
Average	65%	72%	83%	33%

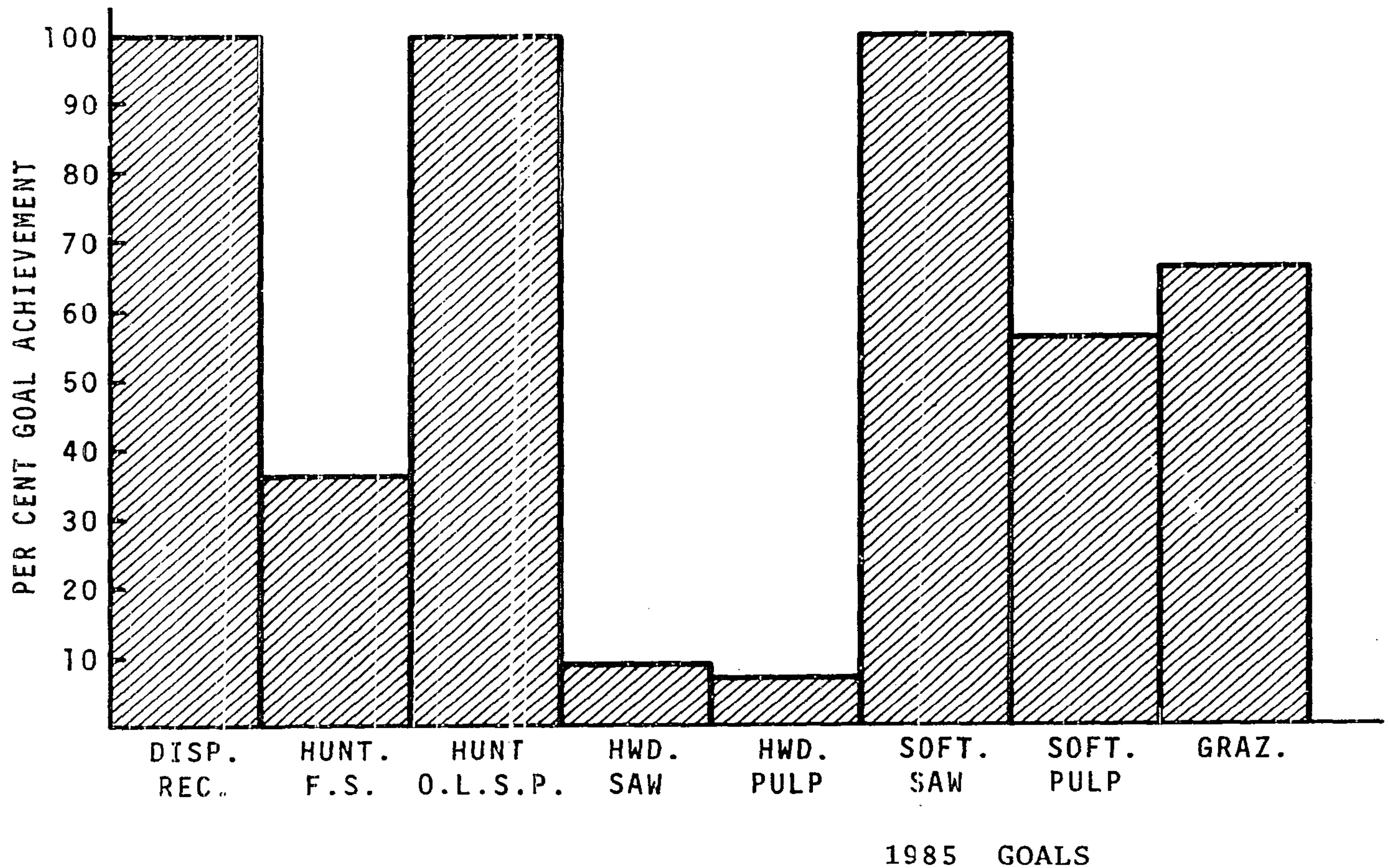

Fig. 9. Per cent goal achievement at $8000 budget level via basic model R1-85

Possible solutions to this problem would be changing the budget level and/or changing management strategies.

a. Changing budget levels   Using Model R1-85 (basic model), the budget was varied from $4000 (50% decrease) to $24,000 (300% increase) in order to determine the effect on goal achievement. Figure 10 is a summary of the comparisons made.

Generally speaking, the hardwood timber goals are sensitive to budget changes whereas grazing and hunting wildlife forest species goals are not. In fact, increasing the budget beyond the $10,000 level (25% increase) does not affect either the wildlife forest species or the grazing goal. Conversely, the timber product goals, (particularly saw timber) are sensitive to the budget level, especially in the $7000 to $14000 range.

b. Changing management strategies   The effect of changing management strategies was determined for the wildlife forest species goal, hardwood pulpwood and saw timber goals.

1.) Wildlife forest species   Changing management strategies has little effect on this goal as was noted earlier. The R3-85 model (hunting no. one priority) has the best track record as far as achieving the hunting goal, however, it is only a 3% improvement over the basic model (R1-85) at the $8000 budget level. Figure 11 compares Model R1-85 and R3-85 with respect to achieving the hunting goal. Beyond the $10000

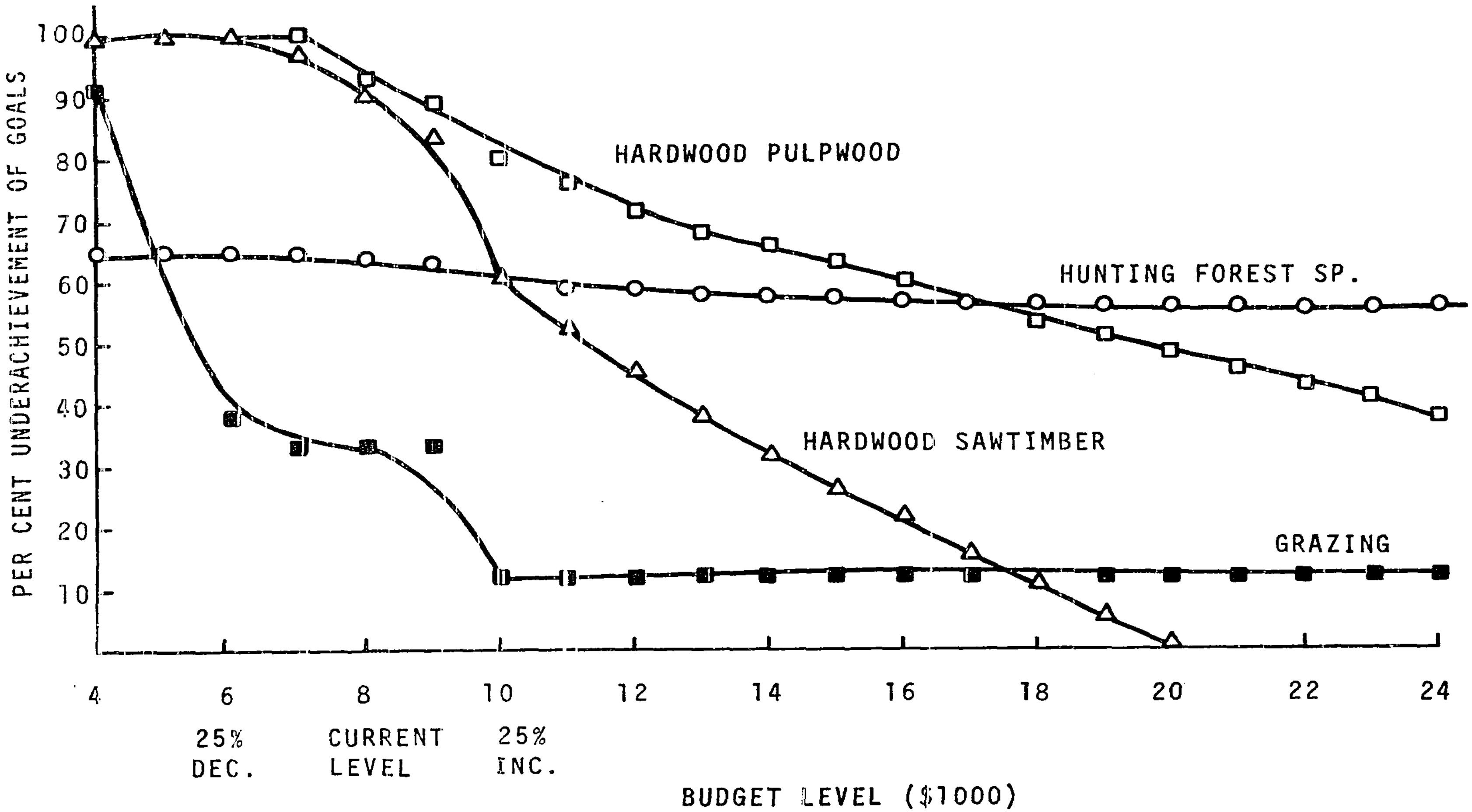

Fig. 10. Per cent underachievement of critical goals for various budget levels (1985 goals and model RI-85)

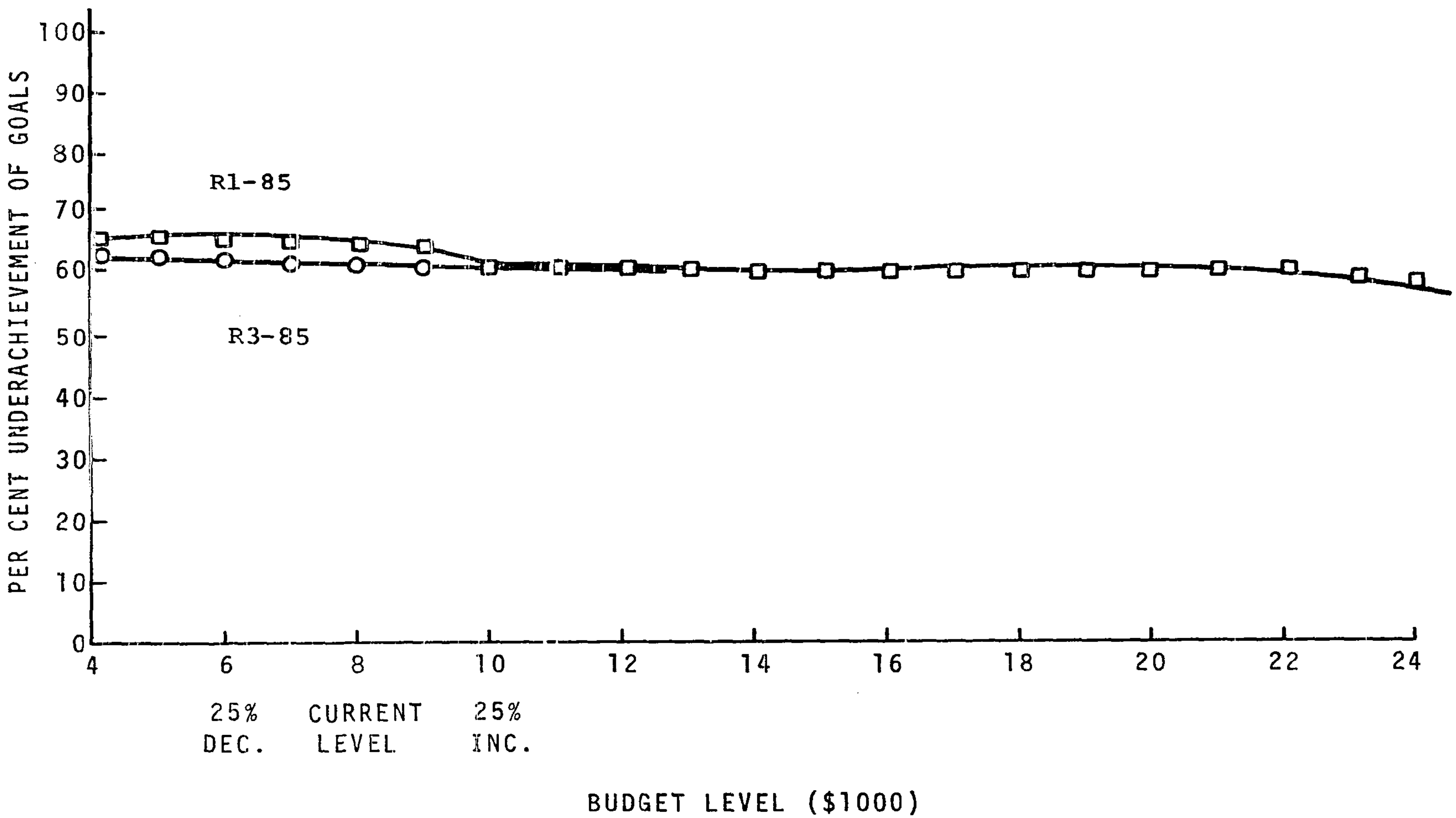

Fig. 11. Per cent underachievement of hunting wildlife forest species via maximum hunting strategy (R3-85) and basic model (R1-85)

budget level, the two strategies are identical.

2.) Hardwood pulpwood Achieving the hardwood pulpwood goal although impossible to achieve totally, is very responsive to management strategy changes. It is particularly responsive at the lower budget levels as shown in Fig. 12. The maximum timber production strategy, model R2-85, is much more effective at the lower budget levels.

3.) Hardwood saw timber The hardwood saw timber goal is also very responsive to management strategy changes at the lower budget levels as noted in Fig. 13. This goal can be achieved at a budget level of $13,000, a 63% increase over the current level of $8000.

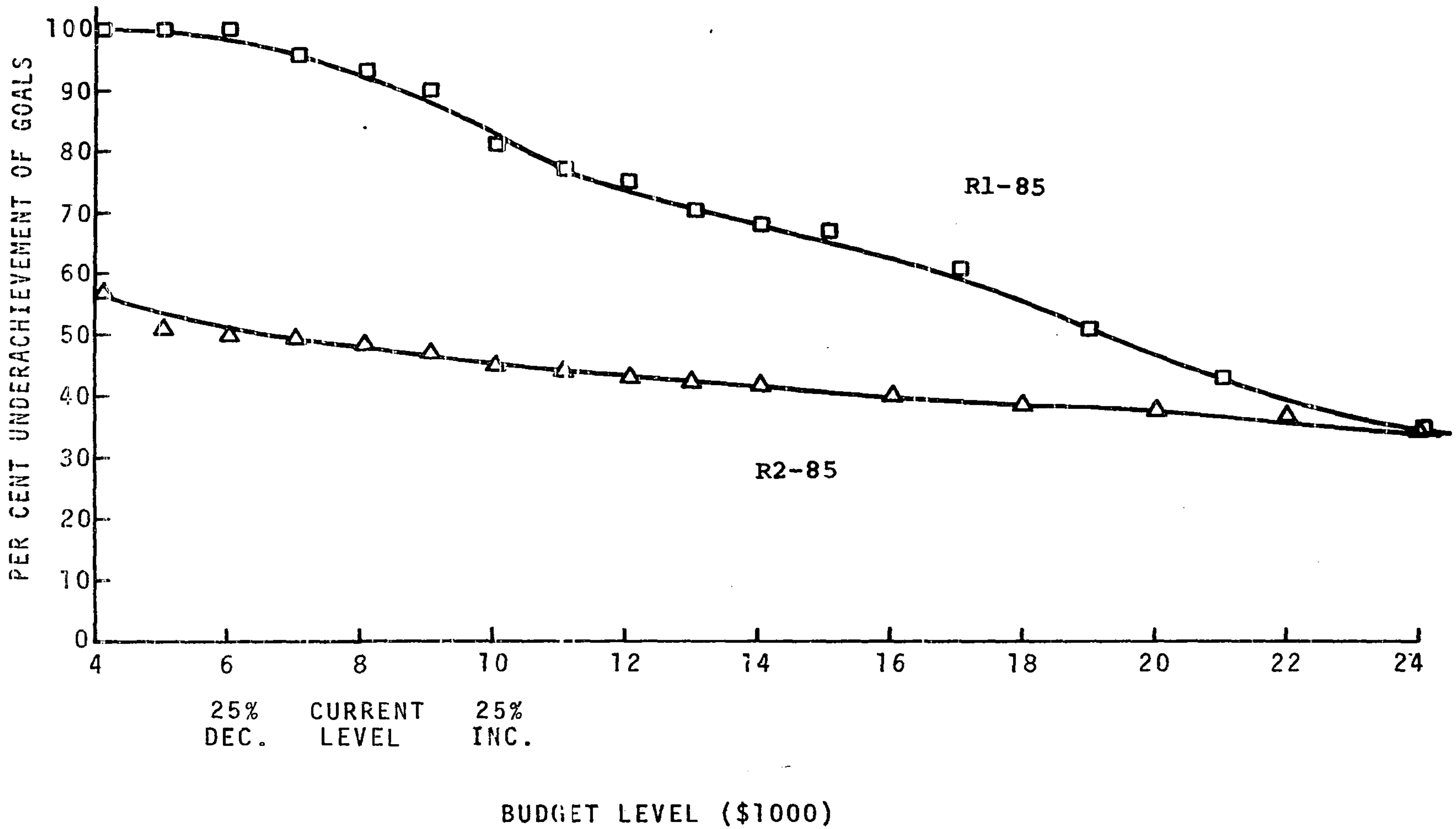

Fig. 12. Per cent hardwood pulpwood underachievement via maximum timber production strategy (R2-85) and basic model (R1-85)

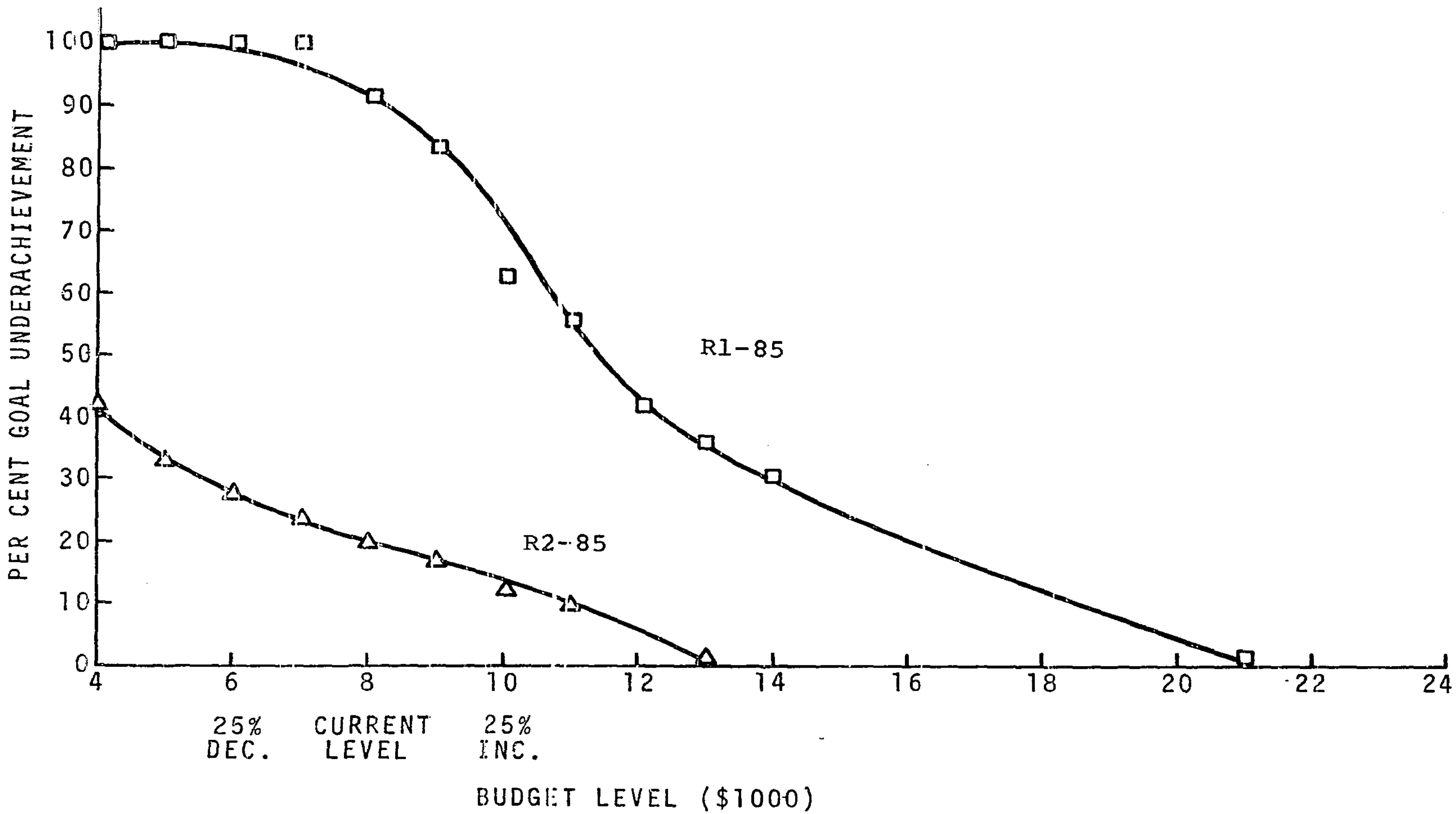

Fig. 13. Per cent hardwood saw timber underachievement via maximum timber production strategy (R2-85) and basic model (R1-85)

IV. CONCLUSIONS

The main focus of the study was to develop an analytical framework from which one can analyze multiple use, public forest management situations. The manager of a National Forest is dealing with complex overlapping and interdependent ecological and social subsystems which are not always understood. The manager is in need of a practical decision model which will allow him to integrate the available information in order to facilitate his understanding and evaluation of the effects of alternative decisions on the various subsystems.

Goal programming was selected as a possible decision model to help answer the question posed by the public multiple-use forest management decision maker: How can I allocate scarce forest resources to various management strategies in order to adequately achieve a set of prescribed goals? The goal programming model was tested, in a conceptual sense, via an application to the Swan Creek unit on the Mark Twain National Forest. This decision model was selected due to its ability in handling multi-criteria type problems, a common occurrance in multiple-use forest management.

A minor objective of the study was to evaluate available goal programming algorithms. It was felt knowledge concerning available algorithms would be very useful to "manager sorts". Applicability of the algorithms will vary with conditions in that one algorithm will be best under one set of circumstances while other circumstances will favor the use of another algorithm.

The algorithms which are currently available are both inexpensive and quite easy to use. In addition, use of the algorithms does not require an inordinate level of computer programming expertise.

The conclusion section will present findings which are of a more general nature than those found in the results section. The results section is concerned specifically with the Swan Creek unit, whereas the conclusions section will attempt to translate these results to a more widely applicable form. With this in mind, the author feels that possibly two types of conclusions can be drawn from this study:

a. Substance of resource management (e.g. points concerning the attainment of goals and the effect of various management strategies and budget levels on their attainment); and
b. Applicability of goal programming to multiple use forest management.

A. Substance of Resource Management

Several important conclusions can be made concerning the substance of resource management:

a. Currently used management strategies are primarily oriented toward timber production. These management strategies consist primarily of various silvicultural operations to promote timber growth. In the past, this was an adequate strategy as timber was the major product on National Forest lands. However, demand for other products such as recreation, and hunting is rapidly increasing to the point where a change in management direction seems advisable.

b. These strategies involve the following sorts of trade-offs among purposes of management. Several important trade offs can usually be expected when one emphasizes one purpose of management over another. These trade-offs become even more conspicuous as intensity of management increases. For example, the Swan Creek unit did not exhibit notable trade-offs using 1974 goal levels and the current $8000 management budget. However, when analyzing 1985 goal levels (which are considerably larger), several important trade-offs become apparent:

1. Maximizing wildlife hunting versus maximizing dispersed recreation -- One may maximize wildlife hunting and provide an additional 1282 visitor days of hunting over the strategy which maximizes dispersed recreation, but at the expense of providing 2600 fewer visitor days of dispersed recreation. There is a trade-off here, but it does not appear until one considers the

intensity of management needed to meet 1985 goal levels.

2. Maximizing timber versus maximizing dispersed recreation -- One may provide an additional 15,000 CU.FT. of timber products via the maximum timber strategy, but, at the expense of providing 2600 fewer visitor days of dispersed recreation than the maximum dispersed recreation strategy. The trade-off here is quite strong, as one would expect between two uses that can become incompatible as use intensity increases.
3. Maximizing timber versus maximizing wildlife hunting -- The timber maximizing strategy will provide 26,000 additional CU.FT. of timber products, but, at the expense of providing 2500 fewer visitor days of hunting forest wildlife than the maximum hunting strategy. This is not ordinarily what many people would expect due to the general feeling that timber and wildlife production are generally compatible. This particular finding on the Swan Creek unit suggests the possibility that, at very intensive levels of management, perhaps timber and wildlife production are not as compatible as once believed to be.

c. Strategies more directly focused on wildlife and other nontimber values are needed to more fully achieve stated objectives. The Swan Creek unit is a good example pointing out the need for developing new management strategies focused directly on wildlife and other nontimber values. Due to the current strategies' emphasis on timber production, the unit is quite responsive to changes in budget levels and management strategies in terms of meeting the timber product goals. However, other goals, such as hunting forest species and dispersed recreation are not significantly affected by these changes in budget levels and management strategies. It is this author's feeling that development of new strategies such as modified timber stand improvement practices, installation of food plots, prescribed burning and herbicide treatments to set back plant succession will make forest resource management more responsive to demand for nontimber products, particularly the wildlife values.

Recreational and timber use of forest land is compatible at the relatively less intensive levels of management. However, as use intensity increases, these two uses rapidly become conflictory in nature. At that point, perhaps the best strategy is to completely separate tracts of land such that one tract is primarily for recreational use with other tracts being devoted entirely to timber production.

As one can surmise, development of new management strategies may take the form of modifications of present practices in some instances whereas in other cases, more drastic changes may be necessary.

d. Some commonly prescribed goals may not be realistic, but a shift of strategies can make trade-offs more favorable. The Swan Creek unit of this study has a serious problem in meeting the hunting forest wildlife goal. This author made some rough calculations to determine what the unit could produce if each acre of land was optimally managed for forest species wildlife. The calculations revealed that 1974 goal levels could be met, however 1985 levels are still underachieved by 40%. Hence, there is a reasonably strong possibility that the 1985 goal is physically impossible to achieve.

In addition, it should be remembered that a shift to management strategies focusing on wildlife values is highly impractical at present. This is due to the current nature of the funding basis which is tied specifically to timber production.[1] A change in the finding procedure would be required in order to allow one to change current management strategies very drastically simply because there is little allowance (funds) for other than timber management practices on National Forests.

A change in budgeting procedures could very well alter the current trade-off relationships among forest goals. Funding which emphasizes wildlife values might very well shift the trade-off from giving up timber for wildlife, (as was the case in this study) to, exchanging wildlife for timber.

B. Applicability of Goal Programming to Forest Resource Management

There are several conclusions to be made concerning the applicability of goal programming to forest resource management:

a. Goal programming is applicable only if several technical conditions are reasonably well met.[2] These conditions relate to the decision makers' ability to:

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[1]The funding basis for management of the National Forests is quite complicated, however there is a definite bias in this funding procedure to favor management practices yielding the greatest amount of timber production.

[2]The technical conditions are similar to the ones described by Kornbluth (1973) in his survey article on goal programming.

1. state goals in some objective manner;
2. control variables which determine how well the goals are met (i.e. one should be able to define and facilitate management practices);
3. define some sort of subjective or objective weighting scheme for the goals[1];
4. define constraint equations and the objective function in linear form.

b. Goal programming should be applied only if decisions at hand have certain features. These features focus on two requirements:

1. There is a need for a multiple goal behavior type decision problem. A very persistent criticism of current decision making techniques is focused on the use of a single criterion to approximate multiple goal behavior. The goal programming model seems well adapted to handling this sort of problem because it does not require one to convert multiple criteria into one

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[1]In public resource management, the goals and priorities are often determined via the political arena. Due to the nature of this process the weights are of ten ordinal in nature with cardinal weighting being infeasible. This study found a potentially serious problem in using pre-emptive weight due to the very restrictive nature of the solution process. In some cases, an inordinate amount of resources can be channeled into a small improvement in one goal, but at the expense of seriously underachieving lower ranked goals (i.e. the marginal cost of additional improvement may be too high).

objective criterion. The unique nature of the objective function, where one minimizes deviations from goals (instead of maximizing profit as in many linear programming applications) allows a more practical interface between decision maker and model. This author believes the goal programming model is more in tune with the decision making capabilities of the contemporary multi-criteria decision maker.

2. Several courses of action should be viewed as viable alternatives. One advantage of the goal programming model is its ability to solve complex equation systems (models) efficiently. Solutions to the various models (alternative courses of action) can then be analyzed by the decision maker in order to select the best course of action. It is this author's feeling that the goal programming model becomes more useful as the complexity of the problem increases. Therefore, the model <u>might</u> be more usefully applied at a higher level of Forest Service decision making than the Unit level (as was the case in this thesis). As one advances up the hierarchial decision making ladder in the Forest Service, one finds more decision

alternatives are open. Fewer specified constraints on management exist at the Forest level than at the Unit level. By the time, one reaches Unit level decision making in the Forest Service, most of the decisions are already made. For instance, the budget level is already specified; goal levels are quite rigidly set; viable management strategies are pre-determined and priorities for the goals are quite rigidly formed. This set of circumstances is fine in that the technical conditions for applying goal programming to unit level decision making are met, however this is a form of suboptimization. This writer believes that possibly the goal programming model would prove more useful under more flexible circumstances. The approach could be used quite effectively in the area of policy analysis where one is evaluating various courses of action to meet policy objectives.

c. Additional research is needed to make more effective use of goal programming in resource management: Development of this study revealed several problem areas which would benefit from additional research. The problems are primarily practical in nature and tend to curtail useful applications of goal programming.

The goal programming model, similar to other mathematical programming models, has significant "data needs". The most pressing need is for reliable information on the relationship between forest resources (inputs) and the forest products (outputs). Much work has been done in the area of wildlife management, however more needs to be done. The efforts by the Michigan Department of Natural Resources are encouraging (Bennet, 1974). The recreation production coefficients are poor at best. Probably the most reliable information is that on timber production, however their quality deteriorates rapidly when one deviates from the most intensive management practice (EAM11, AAM11, PTM11, CCH11) to less intensive practices (EAM12, 13, 14, 15, 16, AAM12, etc.). They are essentially, two-point production functions with the two points being very intensive management and no management.

There is an urgent need to quantify forest resource input-output relationships. It is this author's feeling the additional information might usefully be collected in conjunction with current Forest Service surveys[1].

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[1]The Forest Survey is a continuing operation mandated by the McSweeney-McNary Forest Research Act of 1928. Its objective is to inventory periodically the nation's forest lands to determine their extent, condition, and volumes of timber, growth, and depletion (Ostrom and Hahn, 1974).

In addition, cost data is often times a scarce commodity when dealing with forest management practices. Cost information is often quite general and lacks the type of detail necessary for an economic analysis.

Determination of the "correct weights" for various goals can also be a very difficult problem. The goal programming model alleviates the difficulty somewhat by simply requiring ordinal ranking of goals. However, there is still considerable doubt even with ordinal weights. Perhaps, a better approach would be to ask the decision maker to determine a range or interval of weights for the various goals. Then, one might use Steuer's (1974) Interval Criterion Weights Programming Algorithm to determine the set of efficient extreme point solutions. The decision maker then is allowed to select the solution he likes best without actually deciding on a prespecified weighting scheme.

Another, related problem is the possibility the weights will change after the solution procedure commences. This would be a logical consequence of situations which exhibit diminishing marginal utility of goal achievement. The goal programming model, like most linear programming models, does not allow one to change weights once the solution procedure starts. Interactive goal programming (Dyer, 1972) has been suggested as a solution to this problem. The interactive approach requires interaction between the decision maker and the algorithm. Benayoun et al. (1971) have developed a multi-criteria interactive approach called STEP, whereby the decision maker and algorithm sequentially explore the feasible set of solutions. After each computer run, the decision maker decides whether or not a solution is acceptable; if not, a reduction in some criteria is necessary. The decision maker selects trade-offs which are acceptable to him.

Today, with the increased demand for all products produced on our National Forests, it is apparent that the NF must be managed as efficiently as possible. Multiple Use management would be a very good vehicle for meeting these demands.

This study demonstrates the potential of the GP model to transform the multiple-use concept from a philosophy to an "on the ground" practice. The major drawback of the model is its very substantial data requirements. However, these data requirements are not impossible to meet. They are, in fact, very logical and sensible requirements if one desires to intensively manage forest land and meet the projected demands for forest goods and services.

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VII. APPENDIX A. USEFUL MODIFICATIONS OF THE LINEAR GOAL PROGRAMMING MODEL

A. Chance-Constrained Programming

It would be remiss of this writer to omit a discussion of chance constrained programming while discussing the general topic of linear optimization models. The inclusion is primarily for sake of continuity in presenting the various ramifications of linear optimization models.

The motivation behind the development of stochastic programming (as it is sometimes called) is the complaint by many people (Waterman and Gee, 1966) that ordinary linear programming models, with their assumption of deterministic data, are unrealistic. However, it should be noted that there is some evidence to the contrary. Dzielinski et al. (1963) conducted an experiment to determine whether or not a deterministic linear programming model could give good results under stochastic conditions. Their conclusion was in the affirmative.

The chance-constrained model is one method for relaxing the deterministic assumption. The basic chance-constrained linear programming model is as follows (Charnes and Cooper, 1963):

$$\text{optimize} \quad f(c,x)$$

subject to: $P(Ax \leq b) \geq \alpha$

where: P = probability

f = linear function

A,x,b,c are same as previously described

α = a vector of constants that are probability measures of the extent to which constraint violations are admitted.

Putting subscripts on the constraints, and clarifying α to be: $0 \leq \alpha_i \leq 1$; one converts the deterministic form:

$$\sum_{j=1}^{n} a_{ij}x_j \leq b_i$$

to stochastic form:

$$P\left(\sum_{j=1}^{n} a_{ij}x_j \leq b_i\right) \geq \alpha_i$$

With the constraints rewritten as above, this implies that the ith constraint may be violated, but at most, $B_i = 1 - \alpha_i$ proportion of the time.

Chance constrained programming means that the variables (data such as input-output coefficients - A_{ij}; resource vector- b_i; and the objective function coefficient - C_i) are treated as random variables following a specific distribution, in contrast to being constants as in ordinary linear programming.

Most applications of chance-constrained programming have assumed the normal distribution (Sengupta, 1972). The normal distribution is easier to work with, hence, its popularity.

There are some serious questions as to the applicability of the chance-constrained programming in certain areas including the resource allocation problems. A major difficulty is in determining the correct distribution and its parameters as noted by Charnes and Cooper (1959) and Sengupta (1972). As previously noted, most applications assume normality, however Sengupta (1972) has noted that certain allocation problems (the topic of this thesis) require a strictly nonnegative domain. Negative prices and resource allocation schemes simply do not make sense. The Chi-Square distribution was used by Sengupta (1972) as an alternative, however this distribution is much more difficult to work with, especially in large resource allocation problems.

1. Discussion

In view of the difficulties in estimating correct distribution functions for variables; and in view of the fact there is evidence that stochastic situations can be reasonably approximated via deterministic models, this author decided on the use of a deterministic model for use in this thesis. The area of forest multiple use management is seriously lacking in basic data itself (input-output coefficients and value coefficients for the objective function), hence knowledge of distribution functions is likewise deficient.

B. Interactive Linear Programming Models

Interactive programming models are a modification of the usual linear programming model (previously discussed) and also can be modified to fit into the goal programming framework. Interaction with the decision maker is required in order to obtain information regarding his utility function defined over permissable values of the criteria. The purpose of the approach is to allow for the possibility of the diminishing marginal utility of goal achievement to be systematically considered in the decision making process. This is accomplished by allowing for changes in goal weights, after the solution procedure starts.

As noted by Dyer (1972) and Geoffrion et al. (1972), the interactive models require the decision maker to provide information regarding local trade offs among criteria at specific points in the iterative solution procedure. A series of computer runs are made, stopping each time after solution, to interact with the decision maker in an effort to determine whether or not one should stop or continue the iterative procedure.

Most applications of interactive programming deal with multi-criteria problems. Benayoun et al. (1971) have developed an approach, called STEP, which involves interaction between the decision maker and the algorithm. It was an adaptation of the multi-objective linear programming model, whereby the decision maker and the algorithm sequentially explore the various "optimal" solutions. (Recall that the usual linear programming model yields only one solution for a given computer run.) After each run, the decision maker decides whether or not a solution is acceptable, if not, a reduction in some criteria (the Z^k from Section C2) is necessary. The decision maker selects trade-offs that are acceptable to him. How much reduction of Z^1 will I accept in order to increase Z^2 by some amount? This process is repeated until an acceptable solution is found.

1. Discussion

The interactive programming model seems to have considerable potential for treating the problem of diminishing marginal utility of goals within the solution procedure itself. However, there is some doubt by Roy (1970) as to whether the decision maker can make the trade-offs with any degree of accuracy. Specifying these local marginal rates of substitution (as they are sometimes called) among criteria at various points along the iterative procedure requires information concerning one's preference function which is often not available.

A study by Dyer (1973) indicates one approach to solving the trade-off determination problem. The decision maker is asked questions by the computer program with the hope that his responses will "reveal" his trade-offs without requiring that he be aware of their meaning or significance. This is accomplished via a series of ordinal comparisons, where the decision maker is asked to indicate how much he would give up from one criterion in order to obtain a specified increment in another.

The study by Dyer (1973) partially solves the trade-off problem, however, it is this writer's contention that the successful operation of Dyer's (1973) approach requires a continuous availability of experts to interface between the decision maker and the computer. Therefore, success of the Dyer technique, and hence the interactive programming procedure, would depend on having one's own analytical capability within the organization. In most cases, this is simply not realistic. Many organizations, at present, do not have the analytical capability to make decisions via interactive programming techniques. The Forest Service, although possessing the capability at the Washington office, does not have this capability on each of the National Forests. In fact, it is only recently that the National Forests in Missouri (the study area for this thesis) acquired a "computer terminal".

VIII. APPENDIX B: CLASSICAL ECONOMIC THEORY - PROBLEMS IN APPLICATION TO MULTIPLE USE MANAGEMENT

In the past two decades, there has been an increasing concern over the applicability of the classical economic theory to contemporary management decision problems. Some of these problems, according to Lane (1972) can be grouped into two main categories:

1. Motivational Criticisms - There is a concern over the assumptions which are made with respect to the consumer's utility function and the firm's objective function. One assumes the certain attributes concerning the utility function such as:
   a. convexity - implying dimenishing marginal utility for each added unit;
   b. transitivity - implying one can always group bundles of goods;
   c. non-satiety - implying more is always preferred to less.

One says nothing of the shape of the function other than it exhibits these attributes.

The major assumption made of the firm is that it seeks profit maximization. But profit maximization is only one of many related goals sought by the entrepreneur as stated by many authors (Charnes and Stedry, 1964; Hayes, 1950; Cooper, 1951; Simon, 1959). There is need for a more general preference function to replace the unidimensional, profit function so prevalent in classical theory.

2. Cognitive Criticisms - These are criticisms which relate to the knowledge assumed to be possessed by the decision maker.

   a. It is assumed that the decision maker is aware of nis true preference function and is able to make the necessary mathematical trade-offs between alternatives. One assumes the decision maker goes through the "marginal condition" calculations before making decisions.

   b. One assumes he is omniscient; i.e. is fully aware of the conditions under which he is acting. One assumes the decision maker is aware of:

      (1) the set of alternatives open to him;

      (2) the relationship that determines the pay off as a function of the alternative he has chosen;

      (3) the preference ordering among pay-offs.

More specifically, Lloyd (1969) deals with the problems of applying production economics to multiple use management of the forest. He states that production economics provides a basis for determining an economic optimum mix of inputs and outputs when:

1. The forest is managed and used by a single firm;
2. The firm's primary objective is net revenue maximization;
3. The price system is reasonably operative, through the market, in establishing prices and values for the goods and services produced;
4. The biological and technical relationships of the production process are known.

None of these conditions are met in public forest management and few are met in private forest management. Net revenue maximization is not always the primary goal of management as already mentioned.

In trying to apply production economics to multiple use management of the forest one is immediately faced with the very difficult problem of determining production functions for the various forest products. There is a very conspicuous lack of data in a form useful for estimating production functions. Some people, such as Muhlenberg (1964) argue that the derivation of continuous production functions is impossible in forestry.

Lloyd (1969, p. 51) has also mentioned that "administrative and institutional structures involved do not provide for open market adjustment among different uses. There is no way to balance the trade-offs that might be required. The problem becomes one of welfare economics rather than production economics."

The above quote suggests that one must also ask the question: Who should receive the goods and services produced? Thus, the planner is faced with a distribution problem in addition to the production problem. Multiple use decision making must somehow consider the best distribution of goods and services in addition to determining the proper mix of goods and services. Classical theory assumes distribution is optimal; in fact the classical theory says very little about the optimum distribution of goods and services.

IX. APPENDIX C: INFORMATION USED IN CALCULATING MANAGEMENT COSTS

The various types of information used in calculating management costs for this study are presented in the following tables. They include: contract costs for silvicultural operations (Table 14); overhead cost information by management strategy (Table 15); annual maintenance costs for savannahs, open glades and open fields (Table 16); and annual equivalent costs (total) by management strategy (Table 17).

Table 14. Contract costs[a] for silvicultural operations (per acre basis)

Operation	Hardwood types		Pine type
	Even age	All-age	
Pre-commercial thinning	$40	$40	$56
Intermediate thinning	$35	$35	$49
Harvest cutting	$60	$90	$84

[a]Estimates made by the author from data on recent contract work in the Missouri Ozarks.

Table 15. Overhead cost information (percentage[a] of contract costs) by management strategy

Management strategy	% of contract cost
EAM11	100
EAM12	60
EAM13	40
EAM14 (and EAM15)	0
EAM16	40
AAM11	100
AAM12	60
AAM13	40
AAM14 (and AAM15)	0
AAM16	40
PTM11	100
PTM12	60
PTM13	40
PTM14 (and PTM15)	0
PTM16	40
CCH11	100
CCH12	60
CCH13	40
CCH14 (and CCH15)	0
CCH16	40

[a]Percentages estimated by author.

Table 16. Annual maintenance costs[a] for savannahs, open glades and open fields

Management strategy	Annual costs
Savannahs	$1.00
Open glades	$1.00
Open fields	$2.00

[a]Provided by Mark Twain planning team.

Table 17. Annual equivalent[a] costs (total[b]) by management strategy

Management strategy	Annual costs
EAM11	$3.04
EAM12	1.71
EAM13	.43
EAM14	1.63
EAM15	.35
EAM16	0
AAM11	$3.14
AAM12	1.80
AAM13	.48
AAM14	1.63
AAM15	.35
AAM16	0
PTM11	$4.46
PTM12	1.80
PTM13	1.12
PTM14	2.52
PTM15	.35
PTM16	0
SVM11	$1.00
SVM12	0
CCH11	$3.14
CCH12	2.20
CCH13	.79
CCH14	1.80
CCH15	.35
CCH16	0
OGM	
OGLM11	$1.00
OGLM12	0
OFM11	$2.00
OFM12	0

[a]Annual equivalent costs were calculated using a 4% discount rate and standard discounting procedures.

[b]The costs include contract costs, overhead costs and, where applicable, pond construction costs, and maintenance costs for savannahs, open fields and open glades.

X. APPENDIX D: CALCULATING PRODUCTION COEFFICIENTS

The general method used in calculating the production coefficient was discussed in the text of the thesis. This appendix will provide a more detailed description of the process with the idea that potential users of the goal programming approach can benefit from this information.

As noted in the text, the procedure was essentially a two step process.

A. Develop Coefficients for the Eight Major Management Activities (AAM11,EAM11,PTM11,SVM11,CCH11,OGM,OGL11,OFM11)

The first step in this stage was to correlate the various cover types (Table 18) existing on the Unit, with the management activities (CCH11,AAM11,EAM11, etc.) which were determined to be highly suitable for these cover types. It was the desire of the study to use the Pearson's (1943) concept of multiple use in developing the management strategies and the coefficients (areas highly suitable for recreation would utilize management practices emphasizing recreation; the same would hold true for the other forest products).

The production coefficients were then developed for a particular cover type assuming the most appropriate activity would be practiced on that type. Open field management would always be practiced on the O-types; cedar and cedar

Table 18. Acreages of various land cover types deemed highly suitable for listed management activities

Activity	Suitable cover type[a]	Acreage
EAM11 - EAM16	K & Y types	1600
AAM11 - AAM16	K & Y types	900
PTM11 - PTM16	P types	136
SVM11 - SVM12	K & Y types	800
CCH11 - CCH16	C & X types	3558
OGM	Size class 7 & 8 stands in K&Y, C&X and P types	1052
OGL11 - OGL12	Z types	1701
OFM11 - OFM12	O types	776

[a]The cover types are described in Appendix E.

hardwood management would always be practiced on the C&X-type, etc.

The following assumptions were made in developing the coefficients for particular goods and services for the eight major management strategies.

(1) Timber products - The coefficient represents the allowable cut on a particular cover type assuming a particular management strategy. These coefficients will understandedly vary from one management practice to another. There is no timber cut on savannah types, old growth, open glades, and

open fields.

The allowable cut was converted to an annual average, per acre basis using Table 43, Average Annual Allowable Cut of Growing Stock for 1972-1981 from Harvest Cuttings and Thinnings on Commercial Forest Land, by Species, and Forest Type, SW Ozarks, Missouri; Table 51, Area of Allowable Cut for 1972-1981, by Harvest Cuttings on Commercial Forest Land, by Forest Type, and Stand Age Class, SW Ozarks, Missouri; and Table 52, Area of Allowable Cut by Thinnings on Commercial Forest Land for 1972-1981, by Forest Type and Stand Age Class, SW Ozarks, Missouri. These tables were compiled by the Forest Service and can be found in Ostrom and Hahn (1974).

Once the average annual per acre allowable cut was calculated, this figure was adjusted to reflect the specific conditions on the Swan Creek unit. The stands on the unit were found to be in extremely poor condition in addition to being very young. Consequently, their allowable cut is approximately 10% of the average stand in the Missouri Ozarks.

(2) Dispersed Recreation - It was assumed that the best habitat for dispersed recreation is an area where no timber harvesting is going on; areas such as SVM11, OGM, OGL11, OFM11. It was also assumed the maximum use would be four V.D./acre/year. This was strictly an assumption by Mark Twain personnel based on their experience on the Mark Twain. Beyond four

V.D./acre/year, it was felt the ecology of the area would suffer and the area would not be able to maintain quality dispersed recreation capability. The dispersed recreation coefficients for other management strategies such as EAM11, AAM11, CCH11 were assumed to be ½ what they are on the Old growth areas (OGM). It was also assumed that the appropriate coefficient is zero dispersed recreation on the pine type.

(3) Wildlife Forest Species - The coefficients for hunting refer primarily to the "carrying capacity" of the cover type under a particular management strategy. The carrying capacity will determine how many animals can be supported on a particular cover type. It was assumed the number of V.D. of hunting which an area can provide will vary directly with the number of animals existing on an area.

The carrying capacities were determined via consultation with the staff biologist on the Mark Twain National Forest.

Another assumption made was that forest species will be hunted only on forested land (EAM series; AAM series; PTM series; CCH series; and the OGM type). Of course the coefficients for each management strategy will vary due to the different habitats which result from the various management strategies. The best habitat for forest species, according to wildlife biologists, is created via the all-age management system, hence, the AAM11 - AAM16 strategy will have the highest coefficient, which was set at 4.0. The other management strategies were adjusted downward to reflect the changed quality of the habitat.

(4) Wildlife Open Species - These coefficients were calculated in a similar manner to the ones for forest species. The major assumption here is that open species hunting will only occur on open areas such as open fields, and open glades.

The open field was thought to be the best habitat available, due to the plentiful forage produced, and the coefficient was set at 4.0 by the planning team. The coefficients for open glades were assumed to be ½ of the open fields coefficients due to less forage being available.

(5) Grazing - Grazing was assumed to occur only on savannahs, open glades and open fields; the relatively open areas where no timber harvesting takes place. Grazing will not be allowed on commercial timber producing areas due to their basic incompatibility. The actual coefficient refers to the carrying capacity of the cover type under a particular management strategy. The best range habitat available exists on the open fields where there is good quality forage available. These open fields can provide 4.0 AUM/year if properly maintained. Coefficients for the open glades and savannah are poorer due to lower quality forage and habitat.

B. Develop Coefficients for Less Intensive Management Practices[1] (AAM12,AAM13...AAM16; EAM12...EAM16; etc.)

The procedure used here was to adjust the coefficients as calculated in (A) above. Many assumptions were used in this process with the important ones listed in the footnotes to the Tables 19-25 in this Appendix. The assumptions used were based on the professional judgement of the planning team, and the Ozark Highlands Task Force Report[2] (U.S.D.A., Forest Service, 1974), as interpreted by this winter. In addition, the Wildlife Habitat Management Guide for the National Forests in Missouri (Forest Service, 1974) was used by the author to help develop coefficients for the wildlife (hunting) categories.

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[1]The less intensive management practices are described in detail in Table 4 of the text. They are modifications of the major practices. They are an attempt at putting more points on the production function.

[2]Recall that the Task Force Report contained the written findings of the interdisciplinary team, assigned to collect data to be used in developing the Ozark Highlands Area Guide and the individual Forest plans.

Table 19. Converting EAM11 coefficients to less intensive management strategy coefficients (% change from the EAM11 coefficients)

Goal	Units	EAM11	EAM12[a]	EAM13[b]	EAM14[c]	EAM15[d]	EAM16[e]
			Activities				
Hardwood saw.	CU.FT.	6.37	-50%	-50%	-100%	-100%	-100%
Hardwood pulp	"	6.63	NC[f]	-30%	NC	-100%	-100%
Softwood saw	"	0.62	-50%	-50%	-100%	-100%	-100%
Softwood pulp	"	0.10	NC	-30%	NC	-100%	-100%
Dispersed rec.	VIS.DYS.	2.0	NC	NC	NC	+25%	+25%
Hunting FS	"	3.0	-20%	-30%	-35%	-30%	-40%
Hunting OL SP.	"	0	NC	NC	NC	NC	NC
Grazing	AUM	0	NC	NC	NC	NC	NC

[a]The assumption was that absence of a specific strategy of saw timber management reduced the allowable cut by 50% of EAM11, to what it would be on unmanaged land (based on paper by Clawson, 1974); there was no change in pulpwood production nor dispersed recreation; the hunting coefficient was reduced by 20% (from EAM11) because a full complement of silvicultural operations is not carried out on the EAM12 level activity, hence the forage and general cover capability of an area is reduced thus reducing the wildlife population (based on information in the Wildlife Habitat Management Guide for the National Forests in Missouri (U.S.D.A., Forest Service, 1973a)).

[b]The same assumptions were used here as above, except the percentage changes (from EAM11) are different; in addition, pulpwood yield is reduced (from EAM11 level) due to lack of pre-commercial thinning practices.

[c] In the EAM14 practice, we have simply pulpwood management. It was assumed there would be lower quality wildlife habitat, (than the EAM11 strategy) in addition to no saw timber products.

[d] EAM15 includes the establishment of ponds for wildlife as the only activity. It was assumed that the ponds would improve the habitat to the level of the EAM13 practice. No timber harvesting is allowed because timber sale administration and planning is not provided for. Recreation habitat was assumed to be improved due to lack of timber sale activity, hence the +25% improvement over EAM11 level management.

[e] The assumption here is that EAM16 does not allow for timber sale administration, hence no timber can be cut as is Forest Service policy. In addition, it was assumed that lack of timber sale activity resulted in a better habitat (than EAM11) for recreation. Conversely, lack of timber sale activity reduces the capability of the habitat to support wildlife populations, hence wildlife capability was reduced 25% from EAM11 level.

[f] NC indicates no change from the EAM11 level of management.

Table 20. Converting AAM11 coefficients to less intensive management practice coefficients (% change from the AAM11 coefficients)

			Activities				
Goal	Units	AAM11	AAM12[a]	AAM13[b]	AAM14[c]	AAM15[d]	AAM16[e]
Hardwood saw	CU.FT.	5.73	-40%	-40%	-100%	-100%	-100%
Hardwood pulp	"	5.97	NC	-20%	NC	-100%	-100%
Softwood saw	"	0.52	-40%	-40%	-100%	-100%	-100%
Softwood pulp	"	0.08	NC	-20%	NC	-100%	-100%
Dispersed rec.	VIS.DYS.	2.0	NC	NC	NC	+25%	+25%
Hunting FS	"	4.0	-20%	-30%	-25%	-30%	-40%
Hunting OL SP.	"	0.0	NC	NC	NC	NC	NC
Grazing	AUM	0.0	NC	NC	NC	NC	NC

[a]The assumption was that absence of saw timber management reduced the allowable cut by 40% (from AAM11 level) to what it would be on unmanaged land; hunting capability was reduced 20% (from EAM11 level) because the wildlife habitat is less desirable due to fewer silvicultural operations being carried out.

[b]Same assumption as in Table 19 with some changes in the percentage reduction due to a different management strategy.

[c]Same assumptions as in Table 19.

[d]Same assumptions as in Table 19.

[e]Same assumptions as in Table 19.

Table 21. Converting CCH11 coefficients to less intensive management practice coefficients (% change from CCH11 coefficients)[a]

		Activities					
Goals	Units	CCH11	CCH12	CCH13	CCH14	CCH15	CCH16
Hardwood saw	CU.FT.	4.46	-50%	-50%	-100%	-100%	-100%
Hardwood pulp	"	4.62	NC	-25%	NC	-100%	-100%
Softwood saw	"	0.21	-50%	-50%	-100%	-100%	-100%
Softwood pulp	"	0.03	NC	-25%	NC	-100%	-100%
Dispersed rec.	VIS.DYS.	2.0	NC	NC	NC	+25%	+25%
Hunting FS	"	1.0	-20%	-20%	-20%	-20%	-30%
Hunting OL SP.	"	0.0	NC	NC	NC	NC	NC
Grazing	AUM	0.0	NC	NC	NC	NC	NC

[a]Assumptions used in developing the % changes in the table are same as used in Table 19.

Table 22. Converting PTM11 coefficients to less intensive management practice coefficients (% change from PTM11 coefficients)[a]

		Activities					
Goals	Units	PTM11	PTM12	PTM13	PTM14	PTM15	PTM16
Hardwood saw	CU.FT.	0.0	NC	NC	NC	NC	NC
Hardwoof pulp	"	0.0	NC	NC	NC	NC	NC
Softwood saw	"	3.51	-50%	-50%	NC	-100%	-100%
Softwood pulp	"	0.57	NC	-20%	NC	-100%	-100%
Dispersed rec.	VIS.DYS.	0.0	NC	NC	NC	NC	NC
Hunting FS	"	1.0	-20%	-20%	-20%	-20%	-30%
Hunting OL SP.	"	0.0	NC	NC	NC	NC	NC
Grazing	AUM	0.0	NC	NC	NC	NC	NC

[a]Assumptions used in developing the % changes in coefficients are the same as those used in Table 19 except the percentage changes are different.

Table 23. Converting SVM11 coefficients to less intensive management practice coefficients (% change from SVM11 coefficients)

		Activities	
Goals	Units	SVM11	SVM12[a]
Hardwood saw	CU.FT.	0.0	NC
Hardwood pulp	"	0.0	NC
Softwood saw	"	0.0	NC
Softwood pulp	"	0.0	NC
Dispersed rec.	VIS.DYS.	4.0	-25%
Hunting FS	"	4.0	-50%
Hunting OL SP.	"	0.0	NC
Grazing	AUM	0.7	-75%

[a]The assumptions used in this table are: dispersed recreation capability is reduced when the savannah condition is not properly maintained (due to brushy condition); savannah maintenance is necessary for maintaining abundant forage for livestock and wildlife (keeps the carrying capacity at a higher level), lack of maintenance thus reduces the carrying capacity.

Table 24. Converting OFM11 coefficients to less intensive management practice coefficients (% change from OFM11 coefficients)

Goals	Units	Activities OFM11	OFM12[a]
Hardwood saw	CU.FT.	0.0	NC
Hardwood pulp	"	0.0	NC
Softwood saw	"	0.0	NC
Softwood pulp	"	0.0	NC
Dispersed rec.	VIS.DYS.	3.0	-25%
Hunting FS	"	0.0	NC
Hunting OL SP.	"	4.0	-25%
Grazing	AUM	1.8	-75%

[a]The assumptions used here are same as in Table 23 for savannah management, the only differences being in the % changes.

Table 25. Converting OGL11 coefficients to less intensive management coefficients (% change from OGL11 coefficients)

		Activities	
Goals	Units	OGL11	OGL12[a]
Hardwood saw	CU.FT.	0	NC
Hardwood pulp	"	0	NC
Softwood saw	"	0	NC
Softwood pulp	"	0	NC
Dispersed rec.	VIS.DYS.	4	-25%
Hunting FS	"	0	NC
Hunting OL SP.	"	2	-25%
Grazing	AUM	0.8	-75%

[a]The assumptions used here are the same as in Table 23 for savannah management, except the % changes are different.

XI. APPENDIX E: COVER TYPE DESCRIPTIONS[1]

The following is a list of the various cover types, composing the 10,000 acre Swan Creek unit:

1. K - Type (Oak/Hickory);

   A stand in which upland oak or hickory, singly or in combination comprise a plurality of the stocking except where shortleaf pine comprises 25-50% in which case, the stand is classified oak-pine. (Common associates include gum, maple, yellow poplar, and black walnut.)

2. Y - Type (Oak/Pine);

   A stand in which hardwoods (usually upland oaks) comprise a plurality of the stocking, but in which shortleaf pines comprise 25-50% of the stocking. (Common associates are gum, hickory, and yellow poplar.)

3. P - Type (Shortleaf Pine);

   A stand in which shortleaf pine comprises a plurality of the stocking. (Common associates include gum, oak, and hickory.)

4. C - Type (Eastern Red Cedar);

   A stand in which red cedar predominates and may occur in pure stands or in association with various oaks.

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[1]Taken from USFS Handbook; Appendix 100--1 (U.S.D.A., Forest Service, 1971); "Timber Resources of Missouri's SW Ozarks" (Ostrom & Hahn, 1974); and the Swan Creek Unit Plan.

5. X - Type (Blackjack Oak-Post Oak);

A stand in which blackjack and post oak predominate.

6. Z - Type (Open Glades);

The open glades are noncommercial forest land areas with less than 20% woody cover. They are landscapes characterized by thin soils and limestone outcroppings with native grasses and cedar being the vegetative cover.

7. O - Type (Open Fields);

The open field is similar to the glade except the soil is deeper on the open fields and the vegetation consists entirely of broom sedge and various other grasses. Many of the fields are improved pastures.

8. Size Class 7 & 8 Stands (Old Growth Type);

These are stands which consist primarily of saw timber size trees.

XII. APPENDIX F: COMPUTER RUN RESULTS FOR THE MODELS RUN FOR THIS STUDY

Appendix F includes the computer run results to the various models developed for this study. Individual model descriptions can be found in Table 6 of the results section (III B2) of the text. Each table in the appendix includes results for a particular model (R1-74, R11-74, R3-74, etc.) under three or four budget levels. There are two parts to each table:

1. Top half of table - lists the computer calculated, acreage allocations for a particular model under a particular budget level.

2. Bottom half of table - lists the goal underachievement resulting from the acreage allocation generated under a particular model and budget level.

Table 26. Basic model (R1-74) results. This model includes 1974 goal levels; an old growth constraint, but no hardwood overcut constraint

Management strategy	Budget	$6000	$8000	$10000	$ Unlimited
EAM11		659[a]	1397	1600	1600
EAM12					
EAM13					
EAM14					
EAM15		940	202		
EAM16					
AAM11		900	900	900	900
AAM12					
AAM13					
AAM14					
AAM15					
AAM16					
PTM11					136
PTM12					
PTM13		136	136	136	
PTM14					
PTM15					
PTM16					
SVM11		800	800	800	800
SVM12					
CCH11				77	3558
CCH12					
CCH13					
CCH14					
CCH15				3481	
CCH16		3558	3588		
OGM		1052	1052	1052	1052
OGL11					
OGL12		1701	1701	1701	1701
OFM11					550
OFM12		776	776	776	226
Goal under-achievement	**Units**				
Disp. rec.	V.D.	5661[b]	5661[b]	2891[b]	6729[b]
Hunt. FS	V.D.	14556	13892	13339	12602
Hunt OL Sp.	V.D.	2879[b]	2879[b]	2879[b]	3429[b]
Hard. saw	CU.FT.	446	4476[b]	6171[b]	21217[b]
Hard. pulp	CU.FT.	10256	5363	3664	12418[b]
Soft. saw	CU.FT.	756[b]	1213[b]	1355[b]	2324[b]
Soft pulp	CU.FT.	20[b]	94[b]	116[b]	236[b]
Grazing	AUM	750	750	750	0
Total	---	26008	20005	17753	12602

[a]Acres.

[b]Goal overachievement.

Table 27. Model (R11-74) results. This is the no ranking of goals model, which includes the old growth constraint, but excludes the hardwood overcut constraint

Management activity	Budget	$6000	$8000	$10000	$ Unlimited
EAM11			111[a]	1418	1600
EAM12			1488	181	
EAM13		1600			
EAM14					
EAM15					
EAM16					
AAM11		507	900	900	900
AAM12					
AAM13		392			
AAM14					
AAM15					
AAM16					
PTM11					133
PTM12					
PTM13					02
PTM14					
PTM15					
PTM16		136	136	136	
SVM11		800	800	800	800
SVM12					
CCH11					3558
CCH12					
CCH13		2216	1161	1161	
CCH14					
CCH15					
CCH16		1341	2396	2396	
OGM		1052	1052	1052	1052
OGL11					
OGL12		1701	1701	1701	1701
OFM11		556	556	556	556
OFM12		220	220	220	220
Goal under-achievement	Units				
Disp. rec.	V.D.	4734[b]	4839[b]	4839[b]	6735[b]
Hunt. F.S.	V.D.	15635	14616	13832	12602
Hunt. OL. Sp	V.D.	3455[b]	3435[b]	3435[b]	3435[b]
Hard. saw	CU.FT.	4305[b]	3206[b]	7363[b]	21217[b]
Hard. pulp		0	0	0	0
Soft. saw	CU.FT.	743[b]	754[b]	1160[b]	2319[b]
Soft. pulp	CU.FT.	1048[b]	75[b]	75[b]	235[b]
Grazing	AUM	0	0	0	0
Total	---	15635	14616	13832	12602

[a]Acres.

[b]Goal overachievement.

Table 28. Model (R3-85) results. This model maximizes wildlife production for 1985 goals. The model includes the old growth constraint, but does not include the hardwood overcut constraint

Management strategy	Budget	$6000	$8000	$10000
EAM11		215[a]	805	1394
EAM12				
EAM13				
EAM14				
EAM15		1384	794	205
EAM16				
AAM11		900	900	900
AAM12				
AAM13				
AAM14				
AAM15				
AAM16				
PTM11				
PTM12				
PTM13		136	136	136
PTM14				
PTM15				
PTM16				
SVM11		800	800	800
SVM12				
CCH11				
CCH12				
CCH13				
CCH14				
CCH15				
CCH16		3558	3558	3558
OGM		1052	1052	1052
OGL11				
OGL12		1701	1701	1701
OFM11				
OFM12		776	776	776
Goal underachievement	**Units**			
Disp. rec.	V.D.	2600	2600	2600
Hunt. FS	V.D.	24956	24452	23894
Hunt. OL Sp.	V.D.	879[b]	879[b]	879[b]
Hard. saw	CU.FT.	18408	14473	10538
Hard. pulp	CU.FT.	43201	39289	35378
Soft. saw	CU.FT.	480[b]	856[b]	1212[b]
Soft. pulp	CU.FT.	30	35[b]	94[b]
Grazing	AUM	750	750	750
Total	---	89939	81564	73160

[a]Acres.

[b]Goal overachievement.

Table 29. Model (R3-74) results. This model maximizes wildlife production for 1974 goals. The model includes the old growth constraint, but does not include the hardwood overcut constraint

Management strategy	Budget	$6000	$8000	$10000
EAM11		689[a]	1427	1600
EAM12				
EAM13				
EAM14				
EAM15		910	172	
EAM16				
AAM11		900	900	900
AAM12				
AAM13				
AAM14				
AAM15				
AAM16				
PTM11				
PTM12				
PTM13				136
PTM14				
PTM15				
PTM16		136	136	
SVM11		800	800	800
SVM12				
CCH11				76
CCH12				
CCH13				
CCH14				
CCH15				3481
CCH16		3558	3558	
OGM		1052	1052	1052
OGL11				
OGL12		1701	1701	1701
OFM11				
OFM12		776	776	776
Goal underachievement	**Units**			
Disp. rec.	V.D.	4400[b]	4400[b]	6179[b]
Hunt. FS	V.D.	14543	13879	13339
Hunt. OL Sp.	V.D.	2879[b]	2879[b]	2879[b]
Hard. saw	CU.FT.	452	4248[b]	5691[b]
Hard. pulp	CU.FT.	10056	5163	3664
Soft. saw	CU.FT.	535[b]	992[b]	1355[b]
Soft. pulp	CU.FT.	39	34[b]	116[b]
Grazing	AUM	750	750	750
Total	---	25806	[illegible]9792	17753

[a]Acres.

[b]Goal overachievement.

Table 30. Model (R1-85) results. This basic model uses 1985 goal levels; including the old growth constraint; but not including the hardwood overcut constraint

	Budget	$6000	$8000	$10000	$ Unlimited
Management strategy					
EAM11				660[a]	1600
EAM12					
EAM13					
EAM14					
EAM15		1600	1600	939	
EAM16					
AAM11			392	900	900
AAM12					
AAM13					
AAM14					
AAM15		900	507		
AAM16					
PTM11					
PTM12					
PTM13					136
PTM14					
PTM15					
PTM16		136	136		
SVM11		800	800	800	800
SVM12					
CCH11					3507
CCH12					
CCH13					
CCH14			246		
CCH15				3558	51
CCH16		3558	3312		
OGM		1052	1052	1052	1052
OGL11		1701	1701	821	821
OGL12				880	880
OFM11		709	776		
OFM12		66		776	
Goal under-achievement	Units				
Disp. rec.	V.D.	189	0	0	0
Hunt. FS	V.D.	26325	25734	24213	22653
Hunt. OL Sp.	V.D.	2534[b]	2506[b]	1290[b]	1290[b]
Hard. saw	CU.FT.	25000	22751	15437	6480[b]
Hard pulp	CU.FT.	50000	46520	40247	17816
Soft. saw	CU.FT.	360	83[b]	517[b]	2075[b]
Soft. pulp	CU.FT.	180	78	42	219[b]
Grazing	AUM	772	682	258	258
Total	---	102826	95765	80197	40727

[a]Acres.

[b]Goal overachievement.

Table 31. Model (P1-74) results. This model maximizes revenue. The model includes the old growth constraint, but does not include the hardwood overcut constraint

Management strategy	Budget	$6000	$8000	$10000
EAM11				32
EAM12				
EAM13		269[a]	1600	1567
EAM14				
EAM15				
EAM16		1330		
AAM11			484	900
AAM12				
AAM13		900		
AAM14				
AAM15				
AAM16				
PTM11				
PTM12				
PTM13				
PTM14				
PTM15				
PTM16		136	136	136
SVM11		800	800	800
SVM12				
CCH11				
CCH12				
CCH13				3558
CCH14				
CCH15		3558	3558	
CCH16				
OGM		1052	1052	1052
OGL11		1701	1701	1701
OGL12				
OFM11		776	776	776
OFM12				
Goal underachievement	**Units**			
Disp. rec.	V.D.	9319[b]	10433[b]	8654[b]
Hunt. FS	V.D.	16262	15297	14755
Hunt. OL Sp.	V.D.	4506[b]	4506[b]	4506[b]
Hard. saw	CU.FT.	3985	696	8293[b]
Hard. pulp	CU.FT.	13379	7703	4834
Soft. saw	CU.FT.	191[b]	516[b]	969[b]
Soft. pulp	CU.FT.	91	5	76[b]
Grazing	AUM	1317[b]	1317[b]	1317[b]
Total	---	33707	23701	19589

[a]Acres.

[b]Goal overachievement.

Table 32. Model (R2-74) results. This model maximizes timber production. The model includes the old growth constraint, but not the hardwood overcut constraint

Management strategy	Budget	$6000	$8000	$10000
EAM11			785[a]	1600
EAM12		234	814	
EAM13		1365		
EAM14				
EAM15				
EAM16				
AAM11		900	900	900
AAM12				
AAM13				
AAM14				
AAM15				
AAM16				
PTM11				
PTM12				
PTM13		136	136	136
PTM14				
PTM15				
PTM16				
SVM11		800	800	800
SVM12				
CCH11				
CCH12				
CCH13		1946	1161	1161
CCH14				
CCH15				2152
CCH16		1611	2396	243
OGM		1052	1052	1052
OGL11				
OGL12		1701	1701	1701
OFM11				
OFM12		776	776	776
Goal underachievement	**Units**			
Disp. rec.	V.D.	4205[b]	4283[b]	3207[b]
Hunt. FS	V.D.	15079	14199	13494
Hunt. OL Sp.	V.D.	2879[b]	2879[b]	2879[b]
Hard. saw	CU.FT.	4602[b]	5584[b]	8419[b]
Hard. pulp	CU.FT.	0	0	0
Soft. saw	CU.FT.	1038[b]	1202[b]	1455[b]
Soft. pulp	CU.FT.	972[b]	137[b]	137[b]
Grazing	AUM	750	750	750
Total	---	15829	14949	14244

[a] Acres.

[b] Goal overachievement.

Table 33. Model (R10-74) results. This model includes given priority levels for 1974 goals, however it excludes the hardwood overcut constraint. This model, in addition, includes an old growth constraint

Management strategy	Budget	$6000	$8000	$10000
EAM11		474[a]	1212	1873
EAM12				
EAM13				
EAM14				
EAM15		1398	660	
EAM16				
AAM11		1058	1058	1058
AAM12				
AAM13				
AAM14				
AAM15				
AAM16				
PTM11				
PTM12				
PTM13				
PTM14				
PTM15				
PTM16		157	157	157
SVM11		800	800	800
SVM12				
CCH11				
CCH12				
CCH13				
CCH14				
CCH15				599
CCH16		4158	4158	3558
OGM		0	0	0
OGL11				
OGL12		1701	1701	1701
OFM11				
OFM12		776	776	776
Goal underachievement	**Units**			
Disp. rec.	V.D.	1954[b]	1954[b]	2253[b]
Hunt. FS	V.D.	15202	14538	13884
Hunt OL Sp.	V.D.	2879[b]	2879[b]	2879[b]
Hard. saw	CU.FT.	915	3785[b]	7993[b]
Hard. pulp	CU.FT.	10538	5645	1265
Soft. saw	CU.FT.	484[b]	941[b]	1351[b]
Soft. pulp	CU.FT.	48	24[b]	91[b]
Grazing	AUM	750	750	750
Total	---	27453	20933	15899

[a]Acres.

[b]Goal overachievement.

Table 34. Model (R2-85) results. This model maximizes timber production for 1985 goal levels. The model includes the old growth constraint but does not include the hardwood overcut constraint

Management strategy	Budget	$6000	$8000	$10000
EAM11		472[a]	1122	1600
EAM12				
EAM13		1127	477	
EAM14				
EAM15				
EAM16				
AAM11				170
AAM12				
AAM13		900	900	729
AAM14				
AAM15				
AAM16				
PTM11				
PTM12				
PTM13				
PTM14				
PTM15				
PTM16		136	136	136
SVM11				
SVM12		800	800	800
CCH11				
CCH12				
CCH13		3558	3558	3558
CCH14				
CCH15				
CCH16				
OGM		1052	1052	1052
OGL11				
OGL12		1701	1701	1701
OFM11				
OFM12		776	776	776
Goal underachievement	**Units**			
Disp. rec.	V.D.	4558	4558	4558
Hunt. FS	V.D.	27499	26915	26280
Hunt. OL Sp.	V.D.	974[b]	974[b]	974[b]
Hard. saw	CU.FT.	7220	4960	2907
Hard. pulp	CU.FT.	25022	23730	22576
Soft. saw	CU.FT.	917[b]	1118[b]	1302[b]
Soft. pulp	CU.FT.	781[b]	391[b]	108[b]
Grazing	AUM	1174	1174	1174
Total	---	65473	61337	57495

[a]Acres.

[b]Goal overachievement.

Table 35. Model (R10-85) results. This model is the same as (R1-85) except that (R10-85) does not include the old growth constraint

Management strategy	Budget	$6000	$8000	$10000
EAM11				
EAM12				
EAM13				
EAM14				
EAM15		1873[a]	1873	1873
EAM16				
AAM11				
AAM12				
AAM13				
AAM14				
AAM15		1058	1058	525
AAM16				
PTM11				
PTM12				
PTM13				
PTM14				
PTM15				
PTM16		157	157	157
SVM11		800	800	800
SVM12				
CCH11				
CCH12				
CCH13				
CCH14				
CCH15		4158	4158	4158
CCH16				
OGM		0	0	0
OGL11		1504	1701	1701
OGL12		196		
OFM11			702	776
OFM12		776	74	
Goal underachievement	**Units**			
Disp. rec.	V.D.	1462	564	490
Hunt. FS	V.D.	26483[b]	26483[b]	25845[b]
Hunt. OL Sp.	V.D.	1631[b]	2431[b]	2506[b]
Hard. saw	CU.FT.	25000	25000	21950
Hard. pulp	CU.FT.	50000	50000	46823
Soft. saw	CU.FT.	360	360	83
Soft. pulp	CU.FT.	180[b]	180[b]	137[b]
Grazing	AUM	152[b]	1217[b]	1317[b]
Total	---	103485	102587	95328

[a]Acres.

[b]Goal overachievement.

Table 36. Model (R100-74) results. Same as (R1-74) except old growth excluded and hardwood overcut included

Management strategy	Budget	$6000	$8000	$10000
EAM11		439[a]	618	618
EAM12				
EAM13				
EAM14			59	1254
EAM15		1433	1195	
EAM16				
AAM11		1058	1058	1058
AAM12				
AAM13				
AAM13				
AAM14				
AAM15				
AAM16				
PTM11				157
PTM12				
PTM13		157	157	
PTM14				
PTM15				
PTM16				
SVM11		800	800	800
SVM12				
CCH11				
CCH12				
CCH13				
CCH14				75
CCH15			4158	4082
CCH16		4158		
OGM		0	0	0
OGL11				
OGL12		1701	1701	1701
OFM11				
OFM12		776	776	776
Goal underachievement	**Units**			
Disp. rec.	V.D.	1954[b]	4033[b]	4025[b]
Hunt. FS	V.D.	15218.	14630.	14343.
Hunt. OL Sp.	V.D.	2879[b]	2879[b]	2879[b]
Hard. saw	CU.FT.	1136	0	0
Hard. pulp	CU.FT.	10768	9192	918
Soft. saw	CU.FT.	739[b]	849[b]	1124[b]
Soft. pulp	CU.FT.	21[b]	44[b]	183[b]
Grazing	AUM	750	750	750
Total	---	27872	24572	16011

[a]Acres.

[b]Goal overachievement.

Table 37. Model (RR1-74) results. This model is the same as (R1-74) with one exception: RR1-74 includes the hardwood overcut constraint

Management strategy	Budget	$6000	$8000	$10000	$ Unlimited
EAM11		659[a]	760	760	
EAM12					
EAM13					
EAM14			466	839	
EAM15		940	372		1600
EAM16					
AAM11		900	900	900	
AAM12					
AAM13					
AAM14					
AAM15					
AAM16					900
PTM11				136	
PTM12					
PTM13		136	136		
PTM14					
PTM15					
PTM16					
SVM11		800	800	800	800
SVM12					
CCH11					2242
CCH12					
CCH13					
CCH14				870	1155
CCH15			3558	2688	160
CCH16		3558			
OGM		1052	1052	1052	1052
OGL11					
OGL12		1701	1701	1701	1701
OFM11				100	776
OFM12		776	776	676	
Goal under-achievement	Units				
Disp. rec.	V.D.	4400[b]	2154[b]	2665[b]	3165[b]
Hunt. FS	V.D.	14556	14016	13901	13901
Hunt OL Sp.	V.D.	2879[b]	2879[b]	2980[b]	3480[b]
Hard. saw	CU.FT.	446	228[b]	228[b]	228[b]
Hard. pulp	CU.FT.	10256	6491	0	0
Soft. pulp	CU.FT.	756[b]	818[b]	1056[b]	1056[b]
Grazing	AUM	750	750	614	60[b]
Total	---	26000	21257	14515	13901

[a]Acres.

[b]Goal overachievement.

Table 38. Model (RR1-85) results. This model is the same as model (R1-85) with one exception: RR1-85 includes the hardwood overcut constraint

Management strategy	Budget	$6000	$8000	$10000	$ Unlimited
EAM11					623[a]
EAM12					
EAM13					
EAM14					
EAM15					
EAM16		1600	1600	1600	
AAM11			392	900	900
AAM12					
AAM13					
AAM14					
AAM15		900	507		
AAM16					
PTM11					136
PTM12					
PTM13			136	136	
PTM14					
PTM15					
PTM16		136			
SVM11		800	800	800	800
SVM12					
CCH11					3558
CCH12					
CCH13					
CCH14			246	1015	
CCH15					
CCH16		3558	3312	2543	
OGM		1052	1052	1052	1052
OGL11		1701	1701	1701	1701
OGL12					
OFM11		709	776	391	776
OFM12		67		385	
Goal under-achievement	**Units**				
Disp. rec.	V.D.	189	---	---	---
Hunt. FS	V.D.	26325	25734	25048	23285
Hunt. OL Sp.	V.D.	2534[b]	2506[b]	2121[b]	2506[b]
Hard. saw	CU.FT.	25000	22751	19843	187[b]
Hard. pulp	CU.FT.	50000	46521	39937	17581
Soft. saw	CU.FT.	360	83[b]	347[b]	1718[b]
Soft. pulp	CU.FT.	180	78	15	236[b]
Grazing	AUM	772	682	1201	682
Total	---	102826	95765	86044	41548

[a]Acres.

[b]Goal overachievement.

Table 39. Model RR3-74 results. This model is one which maximizes wildlife production. The model includes both the old growth constraint and the hardwood overcut constraint

Management strategy	Budget	$6000	$8000	$10000
EAM11		689[a]	760	760
EAM12				
EAM13				
EAM14			546	839
EAM15		910	293	
EAM16				
AAM11		900	900	900
AAM12				
AAM13				
AAM14				
AAM15				
AAM16				
PTM11				136
PTM12				
PTM13				
PTM14				
PTM15				
PTM16		136	136	
SVM11		800	800	800
SVM12				
CCH11				
CCH12				
CCH13				
CCH14				870
CCH15			3558	2688
CCH16		3558		
OGM		1052	1052	1052
OGL11				
OGL12		1701	1701	1701
OFM11				100
OFM12		776	776	676
Goal underachievement	**Units**			
Disp. rec.	V.D.	4400[b]	6179[b]	6192[b]
Hunt. FS	V.D.	14543	14043	13901
Hunt. OL Sp.	V.D.	2879[b]	2879[b]	2879[b]
Hard. saw	CU.FT.	452	0	0
Hard. pulp	CU.FT.	10056	5966	0
Soft. saw	CU.FT.	535[b]	579[b]	1056[b]
Soft. pulp	CU.FT.	39	22[b]	156[b]
Grazing	AUM	750	750	614
Total	---	25840	20730	14515

[a] Acres.

[b] Goal overachievement.

Table 40. Model (RR2-74) results. This model is one which maximizes timber production. The model includes both the old growth constraint and the hardwood overcut constraint

Management strategy	Budget	$6000	$8000	$10000
EAM11			666[a]	760
EAM12		858		
EAM13				
EAM14		741	933	839
EAM15				
EAM16				
AAM11		597	933	900
AAM12				
AAM13		302		
AAM14				
AAM15				
AAM16				
PTM11				136
PTM12				
PTM13		136	136	
PTM14				
PTM15				
PTM16				
SVM11		800	800	800
SVM12				
CCH11				
CCH12				
CCH13		1265	266	
CCH14			670	869
CCH15				2688
CCH16		2292	2691	
OGM		1052	1052	1052
OGL11				
OGL12		1701	1701	1701
OFM11				100
OFM12		776	776	676
Goal underachievement	**Units**			
Disp. rec.	V.D.	3532[b]	3708[b]	2665[b]
Hunt. FS	V.D.	15107	14296	13901
Hunt. OL Sp.	V.D.	2879[b]	2879[b]	2879[b]
Hard. saw	CU.FT.	25[b]	200[b]	228[b]
Hard. pulp	CU.FT.	0	0	0
Soft. saw	CU.FT.	675[b]	787[b]	1056[b]
Soft. pulp	CU.FT.	136[b]	140[b]	155[b]
Grazing	AUM	750	750	614
Total	---	15857	15046	14515

[a]Acres.

[b]Goal overachievement.

XIII. APPENDIX G: REVENUE VALUES FOR VARIOUS PRODUCTS

This appendix includes the revenue values for the various products dealt within this study. The values are presented in Table 41.

Table 41. Revenue values for the various products used in the study[a]

Product	Unit	Revenue value
Dispersed recreation	Visitor days	$4.50
Wildlife forest species	Visitor days	$6.00
Wildlife open species	Visitor days	$6.00
Hardwood saw timber	CU.FT.	$0.2790
Hardwood pulpwood	CU.FT.	$0.0263
Softwood saw timber	CU.FT.	$0.3465
Softwood pulpwood	CU.FT.	$0.1316
Grazing	AUM	$4.00

[a]These values were provided by the Mark Twain planning team and represent estimates by them as to the value of each listed product.