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RESOURCE ALLOCATION FOR FOREST FIRE CONTROL

by
P. H. Kourtz

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ABSTRACT

Ideally, the limited resources of a forest protection agency should be allocated to the various activities of the agency in a manner that will achieve the greatest return. However, up to now, such decisions have been based largely on intuition. Now, operations research techniques offer an improved aid to decision makers, techniques developed for other disciplines -- notably defence and water resources -- but surprisingly well adaptable to forestry problems.

EXTRAIT

En théorie, si les ressources financières d'une agence de protection des forêts contre les incendies sont plutôt limitées, elles doivent être utiles au maximum. Jusqu'à ce jour, cependant, on a plutôt fait appel à son intuition. Maintenant, les techniques de recherches sur les opérations, récemment mises au point à propos de la défense nationale et des ressources d'eaux - très facilement adaptables aux problèmes forestiers - sont à la disposition des planificateurs.

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P.H. Kourtz[1]

INTRODUCTION

No forest protection agency has all the money it would like to have; its present and future actions are guided by present and future budget levels. Each agency, therefore, faces a problem of distributing or allocating its limited resource (money) among its many competing fire control activities. Ideally, the resource should be allocated to the various activities in a manner that will achieve the greatest return. But which activities make the best use of the resource? Should the last dollar be spent on detection, suppression or presuppression, and how should the effectiveness of the resource used by each activity be measured?

New ways of formulating and solving allocation problems similar to those encountered by fire control agencies have been presented in recent literature. In this paper an attempt will be made to summarize some of these ideals and to describe how they might be applied.

THE NEED FOR IMPROVED DECISION MAKING

Resource allocation has been carried out up to now by experienced decision makers. With decisions based on intuition, however, it is rarely known whether the best possible allocation has been achieved or even approached (Hitch, 1955). This is particularly true for a forest protection agency, which must deal with an unpredictable opponent -- fire.

Many decisions regarding activity levels have been made by the "requirements approach" (Hitch and McKean, 1965). That is, the problem is defined, a seemingly feasible solution is proposed, and the necessary requirements for its application are drawn up. These requirements are checked to determine whether they can be afforded and whether they will produce the desired results. If this feasibility test is passed, the solution approach is adopted; if not, the requirements are further modified.

[1]Research Officer, Forest Fire Research Institute, Department of Forestry and Rural Development, Ottawa.

There are several faults in this approach. In fire control, for example, necessary requirements are frequently drawn up with no idea of the benefits that will be derived and with no consideration of alternate ways of allocating the money.

The cost of poor decisions regarding the allocation of the resource to fire control activities is frequently borne by the nation as a whole and not by the decision maker. It is no wonder, therefore, that steadily increasing pressure is being put on decision makers to increase efficiency. The relatively recent introduction of program-budgeting in the United States Department of Defence and Department of Agriculture, Forest Service, is an example of pressure of this kind (Novick, 1965).

OPERATIONS RESEARCH AND SYSTEMS ANALYSIS

These times are marked by rapid changes, and the approach to decision making is no exception. Specifically, two terms are appearing with increasing frequency in the literature, namely, "operations research" and "systems analysis". Unfortunately, even the experts have difficulty in clearly expressing the intended differences between these terms. Many authors do not separate the two and prefer "operations research".

By general agreement, "operations research" is the name given to the type of scientific research that deals with the resource-allocation problems of existing operating systems. Operations researchers, applying the scientific method to operational problems, identify alternative courses of action for the purpose of discovering more efficient methods of operation. Over the past 20 years this research has resulted in general problem classifications and corresponding problem formulations and solution algorithms. The best known of these problem-solving techniques are linear and dynamic programming and queueing and game theory.

The operational problems dealt with by systems analysis are supposedly much wider in scope and are usually problems of future resource allocation. Thus, the systems analyst has more freedom to examine a wide variety of possible alternatives (Novick, 1965).

Some common features of the solution approaches used in operations research and systems analysis follow (McKean, 1958):

(a) Desired goals or objectives are stated.

(b) Limited resources are specified.

(c) Mathematical models of the system under study are developed.

(d) Alternative courses of action are examined.

(e) Common measures of effectiveness of resource use (criteria) are used to assess the worth of each alternative.

In fire control, problems of both the operations research and the systems analysis type can be recognized. Operations research can be used to improve the allocation of men or equipment or to improve operational procedures. Systems analysis can be used to plan new and more effective detection and suppression systems.

The important elements of most fire control problems can be classified as qualitative or quantitative. The elements in the quantitative classes can be evaluated by means of the techniques of operations research or systems analysis. It is the job of the decision maker to combine the results produced by these techniques with the qualitative information, to find the best solution. It should be re-emphasized that solutions found through the use of operations research or systems analysis are not intended to replace decision makers. These techniques merely provide the decision maker with more and better information, which forms a basis for better decisions (Enthoven, 1964).

THE COST-EFFECTIVENESS FRAMEWORK

The cost-effectiveness approach evaluates the cost and the effectiveness of each alternative and compares these with other alternatives so that the alternative that is most effective for a given cost or achieves a given level of effectiveness for the least cost may be found. Every resource allocation problem can be formulated within the cost effectiveness framework, provided it is possible to find a suitable measure of the effectiveness of each alternative.

Two main classes of alternatives are of interest in the cost effectiveness approach. A feasible alternative is one that satisfies budgetary and effectiveness constraints. An efficient alternative is the one feasible alternative that will attain either the most benefits for a given expenditure or a prescribed goal for the least cost. Thus, for any fixed budget or effectiveness level there is only one efficient alternative. For example, a feasible fire detection alternative might be a specific lookout system that could be afforded and could detect fires. An efficient detection alternative might be a specific combined lookout aircraft detection system that would give the best level of detection for a given expenditure or budget level. A third type, the optimal alternative, results in the greatest excess of benefits over costs - for example, in fire control, the alternative that results in least cost plus loss. An optimal detection system might be a specific combination of lookouts and air patrols that would result in the greatest <u>net</u> detection benefits.

There are several reasons why optimal solutions to fire control problems are rarely found. First, the measure of effectiveness or benefits attained from most expenditures cannot be expressed in monetary terms; hence, the net benefits cannot be shown. Secondly, the money might not be available for an optimal solution, or there might be better uses for the additional money required for an optimal solution (Baumol, 1965).

Consequently, most cost effectiveness analyses in fire control deal with efficient rather than optimal solutions. The goal of these analyses will be to find either the most effective alternative for a given budget or the least expensive alternative for a specified level of effectiveness. It is interesting to note that both approaches will result in the same answer (McKean, 1958). The alternative that maximizes effectiveness for a given budget is the alternative that minimizes the cost of attaining the particular level of effectiveness.

THE MEASUREMENT OF EFFECTIVENESS

The alternative selected as a solution to a particular fire control problem should be ideally the one that contributes most to the nation's well-being. At this time, however, it is impossible to evaluate the worth of fire control alternatives in these terms. It is necessary to be satisfied with a quantifiable criterion that reflects the contribution of each alternative to the ultimate goal but is only distantly related to it (Hitch and McKean, 1965).

The use of such a "proximate" criterion (McKean, 1958) immediately introduces sources for error. In the acceptance of a lower-level criterion, boundaries must be placed to limit the scope of the solution. Thus many factors that are distantly related to the effectiveness of the alternatives and the achievement of the ultimate goal must be ignored. The operations research term for this is "suboptimization" (Hitch, 1953) -- a necessary evil.

An example of a proximate criterion for the evaluation of several detection alternatives might be the familiar sum of costs and losses resulting from each alternative. This criterion does not directly measure the preferability of each alternative in terms of contributions to the nation's well-being. In using this criterion, the assumption is made that such well-being will be advanced if the sum of suppression costs and losses is reduced. The proximate criterion presents no measure to compare the effectiveness of the most efficient detection alternative with that of all other alternative uses of the money that may influence the nation's well-being. Perhaps it would be best to spend this money in some other area - for example, on education or welfare.

CRITERIA ERRORS

Probably the most critical and difficult task in a cost effectiveness analysis is that of determining a suitable criterion. If the wrong criterion is selected, a problem will eventually be solved; but it will not be the problem in which there is interest. Some of the more common criterion errors are referred to in the following (McKean, 1958):

(a) The criterion should be consistent with the higher level criterion or ultimate goal. For example, a criterion to assess the worth of several detection alternatives might be the number of fires detected by each. This criterion is poor, because even the least efficient detection system will detect large fires. It is against the national interest to have a detection system that will result in very large damage and suppression costs.

(b) There must be a positive correlation between expenditures and benefits. Benefits must not decrease with increased expenditures. For example, a criterion such as the reciprocal of the detection cost per protected acre is poor. If this were used, the best alternative would be not to operate a detection system (the less spent on detection, the greater the benefits).

(c) The criterion that maximizes benefits and at the same time minimizes costs is irreconcilable. It is impossible to find the detection alternative that obtains the most protection for the least cost. But is is possible to obtain efficient alternatives by fixing a series of either costs or effectiveness levels.

(d) The use of cost effectiveness ratios as criteria should be avoided (Hitch and McKean, 1965). A policy of selecting the alternative that results in the highest cost effectiveness ratio disguises the true costs and benefits of the alternative.

(e) A source of error is encountered in specifying the budget or the level of effectiveness. For example, the effectiveness criterion for evaluating two detection alternatives might be the average area burned per fire up to the time of detection. If a large burned area is specified as an effectiveness level, perhaps a visual detection system will do the job for the least cost. If, however, a small area is specified, an infrared detection system may be the least costly. Which level of effectiveness is justifiable?

Fortunately, for most fire control activities, the problem of setting an appropriate effectiveness level can be avoided. It is more realistic to set a budget level and find the most effective alternative for the amount of money budgeted. It would be impractical to set a goal and then find the least expensive alternative to attain that goal if there already is a limit on the amount of money available for that activity. Planning and budgeting cannot be separated. The cost effectiveness technique with the fixed budget approach ensures that planning and budgeting are both considered at the same time. To provide decision makers with more information concerning not only current but future allocations in the event of increased or decreased budgets, a range of budget levels may be examined.

THE MODEL

Now that the decision making framework has been outlined, the next step is to discuss the procedure for using it. The ideal would be to set a few attractive budget levels and conduct a set of field experiments for each level. Each experiment would determine the effectiveness of a feasible alternative. This approach, if properly planned and executed, may give the correct answers, but it is obviously too expensive and time-consuming. To overcome this, the experiments could be carried out on paper instead of in real life. Treating the problem in this fashion condenses time and, hopefully, is less expensive.

To experiment on paper, a model is required. A model consists of a set of statements that express the relations among objectives, the relevant alternatives available for attaining the objectives, and the estimated cost and effectiveness of each alternative (Novick, 1965). The model will be used to predict outputs when specific inputs and various constraining conditions are given. A particular set of inputs and constraints constitutes an alternative. With the fixed budget approach, the input will be the amount of money available and the output will be the effectiveness of the particular alternative under study. The most efficient alternative can be found after examining all the feasible alternatives.

A model is an abstraction of a real world situation. Consequently the answers produced from a model are only as good as the abstraction itself (Hawthorne, 1964). The neglect of important variables removes the model further from reality. A model that takes into account many relatively unimportant variables becomes hopelessly complex.

There is a group of general models that have been developed to solve specific classes of problems. These models and their uses are described in operations research textbooks. The most popular of these models is that of linear programming. It has been widely used in industry and is beginning to be applied to natural resource allocation problems (Maass *et al.* 1962).

The linear programming model deals with sets of activity levels. The number of hours spent each day patrolling with infrared and with visual detection aircraft might be two activity levels considered in a detection system analysis. Each set of activity levels corresponds to a feasible alternative. The model itself consists of an objective function and a set of restrictions or constraints. The objective function relates the effectiveness of each activity level to a common criterion. In the detection example, the objective function might appear as follows:

$$E = C_1 X_1 + C_2 X_2$$

where E is the measure of effectiveness, C_1 and C_2 are coefficients relating the hours spent on infrared and visual detection each day to the common effectiveness criterion, and X_1 and X_2 are the hours spent on infrared and visual patrolling respectively. Several constraints for the model might be:

1) $180 X_1 \leqq 1{,}000$

2) $AX_1 + BX_2 \leqq 900$

3) $X_1 \leqq 7$

4) $X_2 \leqq 12$

Constraint 1 indicates that the number of hours spent patrolling with an infrared detector for a 180-day period must be less than 1,000. In constraint 2, A and B represent the hourly cost of each type of patrol. Thus this constraint limits the daily expenditure on detection. Constraints 3 and 4 limit the daily number of hours for each type of patrol. The linear programming solution algorithm will find the alternative or particular activity levels that maximize the criterion and yet stay within the bounds of the set of restrictions placed on the solution. The term "linear" refers to the necessity of having the objective and constraint functions linear. That is, the effectiveness and resource use must be proportional to the level of each activity conducted individually (Hillier and Lieberman, 1967). The term "programming" is synonymous with planning. Linear programming is in no way related to computer programming, although computers are used as a tool to help solve large linear programming problems.

Queueing models are another set of operations research models that are of interest to fire control planners. These models deal with waiting lines of people or equipment. Queues form when the demand for service exceeds the current capacity to supply the service. A fire control organization's communications system may occasionally become so congested that each user must wait a long time before being able to send a message. Queueing models will provide information such as: the average number of people waiting to use the system; the average waiting time of each person; and the probability that people will be waiting to use the system. The models will also show the effect of adding a second or third communications channel to help relieve the congestion. Thus the cost effectiveness framework may be applied, by using a criterion such as the average waiting time in the queue, to provide decision makers with more and better information on which to base decisions.

USE OF THE MODELS

A solution procedure involving a series of simple calculations and manipulations has been developed to solve a linear programming problem (Hillier and Lieberman, 1967). Queueing models combine probabilistic data concerning servicing times and the times of arrivals of customers with service mechanism data to provide information on queue characteristics. Most fire control models involve the combining of probabilistic data with systems design data. Unfortunately, no general models of this type have been developed -- as has been done for queues. There is, however, a technique that is very useful in dealing with such problems.

In a visual-infrared fire detection model two types of variables would be recognized. Design variables would be those that could be controlled by man (Maass *et al.* 1962). Each set would make up a detection alternative. Some design variables might be the number of infrared and visual flights carried out each day and the time and altitude of each flight.

Environmental variables are those that are not under man's control and that will influence the effectiveness of each alternative (Kourtz, 1966).

Some environmental variables might be the daily visibility, the fire occurrence pattern, the rate of fire spread, and cloud height and density. The manipulation of design and environmental variables in a model that relates the final criterion to these variables is known as simulation.

The most desirable airborne visual infrared detection system might be found by using simulation through the following steps:

(a) Decide upon a suitable measure of effectiveness that can be used to assess the worth of each alternative.

(b) Set a range of feasible budget levels.

(c) Select the environmental variables that may influence the criterion.

(d) Decide upon the design variables that should be considered in the model.

(e) Develop a model that will relate environment and design variables to the criterion.

(f) Obtain environmental data covering many years.

(g) List all or many of the feasible combinations of design variables for each budget level. That is, list the detection alternatives that can be bought for each budget level.

(h) Simulate the operation of each detection alternative over the span of the environmental data and note the effectiveness of each.

(i) Select the efficient alternatives.

A graph may be used to show the effectiveness that can be purchased at each budget level (Figure 1). In the process of finding the information to construct this graph, the proportion of money to be spent on each detection method and the most desirable alternative for each budget level would be described.

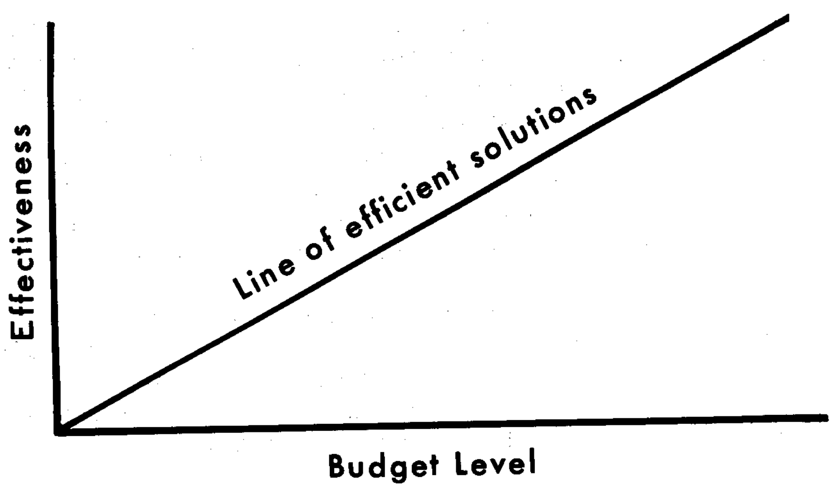

Figure 1. Relation between budget level and effectiveness.

It is now up to the decision maker to combine this information with all other relevant information not considered in the model. Some of these considerations might be the use of visual patrol aircraft for supplementary transportation and the use of infrared equipment for fire-mapping or nighttime navigation.

CONCLUSIONS

For every fire control model, simplifying assumptions will have to be made. An important part of a proposed solution will be a description of these assumptions and discussion of their implications. Considering these, the cost effectiveness approach will probably provide much better answers than subjective reasoning for the quantitative section of the problem.

The approaches to decision making presented in this paper are not new. Many of the ideas were first developed and put to use in disciplines other than forestry -- notably in the defence and water resource fields, where there are even greater pressures to improve resource allocations. Foresters would do well to study the resource allocation techniques used in these two disciplines, both of which have problems surprisingly similar to those encountered in forestry.

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