The Economic Efficiency of the National Fire Management Analysis System and FIREPRO[1]

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Abstract

The economic efficiency of the National Fire Management Analysis System (NFMAS) and FIREPRO is examined. A brief history of the two programs is provided, as well as recent improvements to the contemporary theory of cost plus net value change (C+NVC). The NFMAS process is reviewed relative to the theory of C+NVC with particular focus on its ability to reliably locate the most efficient level (MEL) of preparedness/presuppression. FIREPRO is reviewed with regard to its ability to ensure cost effective resource allocations. Improvements and alternative approaches for both systems are suggested.

Introduction

The National Fire Management Analysis (NFMAS) is used by the USDA Forest Service and the Bureau of Land Management. FIREPRO is used by the National Park Service, and its related program FIREBASE is used by the Fish and Wildlife Service. These three programs provide key guidance in allocating management budgets. For example in 1994 the Forest Service spent nearly 1 billion dollars on fire management (Bell and others 1995). Thus, even small improvements in economic efficiency would have significant effects on the costs of fire management on public lands administered by these three agencies. This paper does not provide a comprehensive review of all parts of the two programs (Fried and Fried 1996). Instead, it examines how these programs conform to the theory of cost plus net value change (C+NVC).

Since the pioneering work of Sparhawk (1925), Hornby (1936) and Headley (1943), there has been a realization that at least in theory there is an optimal level of fire management effort. Implicit in this realization is that not all fires should be fought as aggressively as possible. Despite this ground breaking work, in 1935 the Forest Service adopted the "10:00 a.m. policy" (Gorte and Gorte 1979). This policy was adopted after two severe fire seasons in the Pacific Northwest.

The approved protection policy on the National Forests calls for fast, energetic, and thorough suppression of all fires in all locations, during possible dangerous fire weather.

When immediate control is not thus obtained, the policy then calls for the prompt calculating of the problems of the existing situation and probabilities of spread, and organizing to control every such fire within the first work period. Failing in this effort, the attack each succeeding day will be planned and executed with the aim, without reservation, of obtaining control before 10 o'clock in the next morning.

Interestingly, this policy was viewed by many at the time as not contradictory to the idea of economic efficiency (Hornby 1936). This policy continued into the 1970's. During the 1970's congressional budget requests by the Forest Service for fire fighting increased significantly without a concomitant decrease in suppression costs or damages. This resulted in Congress including a mandate for cost-benefit analysis in the 1979 appropriation (NFMAS Reference Material 1992).

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After this, the Forest Service developed NFMAS in 1979. At the heart of NFMAS is the theory of C+NVC, which was developed by Sparhawk (1925) some 55 years previously.

In the mid-1980's the National Park Service (NPS) developed the first version of its own system called FIREPRO. FIREPRO has gone through several incarnations, with the current version based on performance targets established in 1989 (NPS 1997). FIREPRO is a very different system than NFMAS, which is partly a result of the different philosophies of the two agencies. The NPS is charged with land stewardship and public enjoyment of resources rather than resource utilization. This is reflected in the architecture of FIREPRO, which does not consider resource values lost to fire. However, FIREPRO is designed to find the most cost efficient way of achieving program targets. While resource values are not considered directly in formulating these targets, FIREPRO is charged with finding the least cost to achieve them. Although these two models have differing objectives, they are both philosophically based on economic theory.

This paper examines the economic efficiency of the two most widely used fire management computer programs: NFMAS and FIREPRO. We also examine the mechanics of FIREPRO and NFMAS to illuminate their principles of operation. Data for NFMAS illustrative examples were drawn from the sample administrative unit data set that accompanies NFMAS. Data for FIREPRO examples were drawn from the 1999 budget request process. Although specific data sets are used, the conclusions drawn are generally applicable.

Recent Improvements to the Theory of C+NVC

Recently, it has been shown that the Sparhawk model, and those derived from it, are inappropriate representations of the fire management problem (Donovan and Rideout 1999). We demonstrated that in two-dimensional graphical representations of the model, too many inputs (both presuppression and suppression) are allowed to vary. If the x-axis is labeled presuppression (as is conventionally done) then suppression becomes a function of presuppression and becomes an output of the model rather than an input. It is shown that two conditions must hold in order for the true minimum of the C+NVC bowl to be identified:

1. Allow inputs (presuppression and suppression) to be independent and simultaneously modeled, but related through the production function, unless a formal functional dependence is established.
2. Two-dimensional illustrations including presuppression, suppression, and net value change need to hold one of these variables constant while viewing the relationship between the other two. Such a requirement is fundamental to properly carrying out partial sensitivity analysis, which is central to the way NFMAS identifies the most efficient level (MEL) of presuppression expenditure.

NFMAS

The National Fire Management Analysis System (NFMAS) is a computerized fire management and budgeting system. Interagency Initial Attack Assessment (IIAA) is its key computational component and is used to test different fire organizations and dispatch philosophies against specific wildfire conditions and resource values, which identifies MEL. The analysis is carried out at the smallest organizational level that is responsible for planning, budgeting, and administering its own fire management plan (NFMAS Reference Material 1992). For the Forest Service this is most often the National Forest. Budget data so generated can be aggregated to generate a national budget request.

NFMAS and Sensitivity Analysis

Partial sensitivity analysis is central to the running of IIAA to identify MEL. Central to correctly carrying out partial sensitivity analysis is the method of only varying one input at a time while holding the others constant. According to Boardman and others (1996):

> Partial sensitivity analysis: How do benefits change as we vary a single assumption while holding all others constant? Partial sensitivity analysis is most appropriately applied to what the analyst believes to be the most important and uncertain assumptions.

Violation of this condition can produce an identification problem. When two variables simultaneously change, it may be impossible to track changes in an output to specific changes in an input. In the context of NFMAS there are three types of inputs: presuppression expenditure (preparedness), suppression expenditure, and mix of presuppression activities. Conventionally when considering the C+NVC model the specific mix of the presuppression organization is not considered. This is appropriate when examining the fire management problem in general, but not when trying to apply it at an operational level. Consider the graphical representation of isoquants when examining the theory of the firm. The specific mix of capital goods is not considered, but implicit in this generalization is that the mix of capital goods is at all times technically efficient. In other words, no increases in output can be achieved by reallocating a fixed amount of capital. The importance of optimizing the mix of presuppression resources has been recognized by both Mills (1979) and González-Cabán (1986). The principle of technical efficiency presents particular problems when conducting partial sensitivity analysis. In principle partial sensitivity analysis could be carried out on either presuppression or suppression when the mix of presuppression activities is not optimized, as long as organizations of equal technical inefficiency are examined. In practice it would be problematic to ensure that two organizations were of equal inefficiency, so the only meaningful comparison is between technically efficient organizations.

Presuppression expenditure is decided in NFMAS via the included items list *(fig. 1)*. For the presuppression organization, defined as HIS, the included items list indicates which items from the menu of available resources is funded. The included items list allows presuppression expenditure to be fixed while other variables are changed.

NFMAS treats suppression expenditure differently. For each fire fighting resource, in each geographical location a fire intensity level at which this resource is to be dispatched is established *(fig. 2)*.

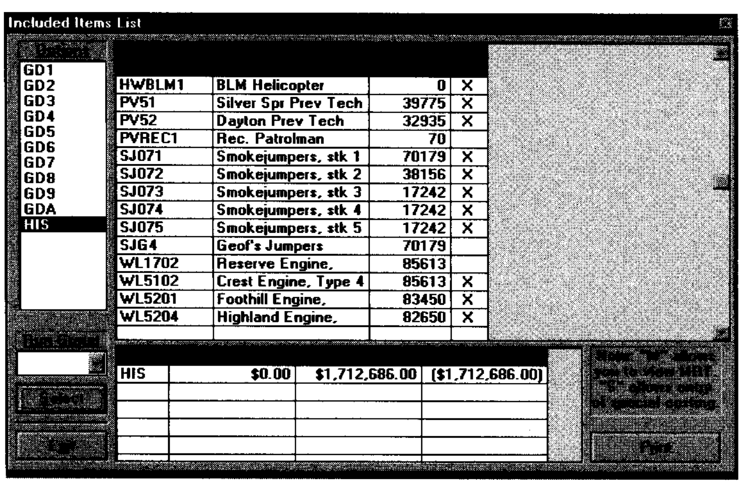

Figure 1

NFMAS included items list.

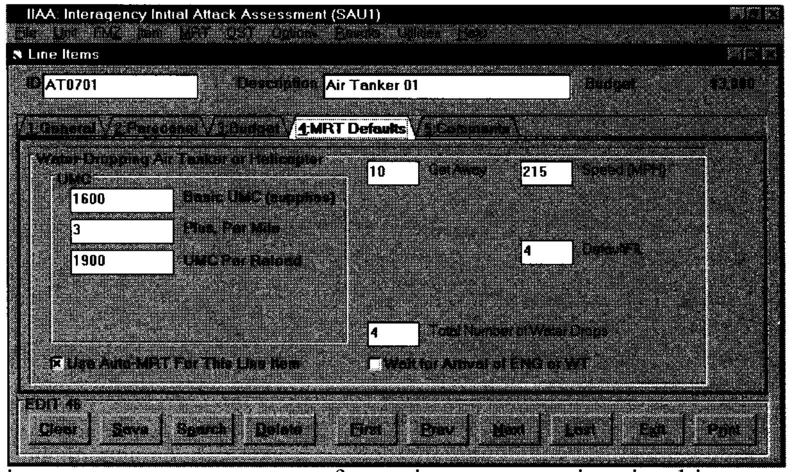

Figure 2
Default FIL dispatch levels.

An important consequence of treating suppression in this way is that suppression expenditure cannot be fixed independent of presuppression expenditure. As the number of resources on the included items list is changed this will have a direct effect on suppression expenditure. This means that partial sensitivity analysis cannot be correctly carried out on presuppression levels, as suppression expenditure cannot be kept constant.

Finally, how is the mix of presuppression resources treated? The importance of optimizing the mix is recognized in NFMAS literature, "[The objective of NFMAS is] identifying the most efficient (lowest C+NVC) program budget, and the mix of program components that goes with that budget" (NFMAS Material 1992). Does the NFMAS architecture allow for the identification of the efficient mix of resources? The problem with suppression not staying constant as presuppression varies also applies to the case of varying the presuppression mix. This leads to an identification problem that will prevent the efficient mix from being found. The inability of NFMAS to assure technical efficiency in presuppression organizations means further identification problems in trying to find optimal levels of presuppression and suppression. For example, if an increase in presuppression expenditure results in a decline in C+NVC, there is no way of knowing whether this is a result of the increment of presuppression expenditure, changes in technical efficiency, or changes in suppression activities.

An extreme example of technical inefficiency is given by the removal of the NVC function from NFMAS runs. Because this often leaves optimal presuppression little changed is offered as evidence of NFMAS's insensitivity to resource values (Bell and others 1995). This observation illustrates both the issue of technical efficiency and misunderstandings about its importance to the NFMAS process. If the NVC function is removed from the analysis because neither presuppression nor suppression expenditure can reduce the damages of wildfire, then the optimal level of both is zero. Any solution that has positive values of presuppression and suppression is technically inefficient, as C+NVC can be reduced (in this case to zero) without increasing expenditure on presuppression or suppression. This misconception seems to indicate that although NFMAS users are told to consider presuppression mix, it is perhaps not being given the weight it should.

Thus, NFMAS is not able to correctly perform a partial sensitivity analysis. Because sensitivity analysis is central to identifying efficient solutions, any C+NVC curve generated will be on, or more likely above, the true C+NVC curve. There is also reason to believe that the levels of MEL generated by NFMAS will be systematically higher than those of the true C+NVC curves.

The reason for this stems from the deterministic nature of NFMAS. Previously, we pointed out that suppression levels depended both on the dispatch philosophy and the presuppression level. While an aggressive dispatch philosophy is not the sole determinant of suppression level, it will tend, all other things being equal, to increase suppression expenditure. Under certain production conditions this will increase the marginal productivity of presuppression resources, thereby increasing the optimal level of presuppression. The required production conditions are that the cross partial of the NVC function with respect to presuppression and suppression is positive:

$$\delta^2 NVC / \delta S \delta P > 0$$

Nicholson (1995) says that while this is the most prevalent case, this is not necessarily always true. Truet (1984) goes further and gives examples of when production functions might not have a positive cross partial. He states that a negative cross partial is nearly always found between two inputs that are very close substitutes. The example of male and female waiters in the production of meals at a restaurant is given. This close substitutability would not seem to be the case in the wildfire problem. Consider the case of an air tanker. If presuppression resources are not used to buy the air tanker, then it can't be used as a suppression resource. The requirement of some expenditure on one of the inputs in order for the other one to contribute to the production process, implies a degree of complementarity, and therefore a positive cross partial, over the range of output examined.

An NFMAS user who uses an aggressive dispatch philosophy will likely generate higher levels of MEL. Therefore, NFMAS generated C+NVC curves will likely be above the true C+NVC curve, and their minimum will occur at higher levels of presuppression expenditure (budget).

Improvements to the NFMAS Process

If the current NFMAS architecture is to be retained, then the most important improvements that could be made are those that would allow partial sensitivity analysis to be correctly carried out. Of these, the most fundamental is that NFMAS has the capacity to vary one input while holding all others constant. The included items list allows presuppression to be held constant, so no changes are required in the way that NFMAS fixes presuppression. The way that the dispatch philosophy is currently used does not allow suppression to be fixed. However, the use of a dispatch philosophy does have some operational realism, so there may be some benefit to retaining elements of it. One solution would be to use the dispatch philosophy to rank resources in order of importance, and use this ranking in conjunction with a suppression budget cap to determine what resources should be used given a particular budget.

Ensuring technical efficiency for each presuppression organization is problematic. For example, each change in presuppression expenditure may result in significant changes to the efficient mix of resources. The fact that the majority of a presuppression organization's budget may consist of a few high cost items (For example air resources.) makes this problem worse. Consider the example of two presuppression organizations with a modest increment in budget between them. The organization with the smaller budget may have been just unable to afford an air tanker, and so would have to rely more heavily on less productive ground resources. The organization with the higher budget would be able to afford the air tanker and would therefore use less ground resources. If changes were made in the way that NFMAS deals with suppression, then the main problem NFMAS has in ensuring technical efficiency is a practical one. The number of runs that would have to be made in order to ensure the technical efficiency of just one presuppression organization are daunting. Considering the numerous runs that are required to identify MEL, the number becomes prohibitive. Thus, even if the flaws in NFMAS's sensitivity analysis are addressed, practical problems remain that would prevent MEL from being reliably identified. If the current NFAMS architecture is inappropriate, then what would be a better approach?

Considering the problems with the current NFMAS process and issues that have risen in importance since its development as well as vastly improved computer and programming technology, an optimization approach should be considered. For example, an optimization approach could address the problems that NFMAS has with sensitivity analysis, and with optimizing the mix, as this would be carried out by the program. Ecosystem considerations are becoming an increasingly important part of the fire management problem. These ecosystem constraints do not fit easily into current C+NVC models. We suggest that the fire management problem will increasingly become a constrained optimization problem. As such the way that any program manages these constraints will be as important as the way in which the objective function is optimized. Optimization is well suited to this sort of process and would provide valuable information on the costs of these constraints.

FIREPRO

FIREPRO is a computerized fire management budget planning and programming system developed and used by the National Park Service (NPS 1997). FIREPRO has very different goals and approaches to the fire management problem. This is partly because of the different objectives of the NPS. The NPS is charged with land stewardship and public enjoyment of lands rather than resource utilization (NPS 1997). Rather than having a goal of optimizing an objective function, such as NFMAS, FIREPRO was designed to implement nine program performance targets. These targets address such issues as initial attack success rate; hazard fuels reduction projects; and fire effects monitoring. FIREPRO was designed to implement these targets at least cost. To thoroughly define a least cost solution these items must be generated: presuppression level, suppression level, and the mix of presuppression activities.

FIREPRO focuses on generating staffing levels, and as such, it does not address all components of a presuppression organization, such as capital equipment. It is impossible to calculate the efficient level of staffing for a fire organization without considering all elements of that organization. This is because the utilization of one resource will have an affect on the productivity of another, and thus its efficient level. Similarly, FIREPRO does not generate a complete suppression budget, which needs to be done even if the user is not directly concerned with suppression levels. Finally an efficient mix of presuppression resources cannot be arrived at for the same reasons.

Unlike NFMAS, FIREPRO does not have a simulation component but applies a rules base approach to analyze a park's workload and program complexity to assign a fire management budget. Ninety-six matrices are used to perform the actual analysis.

Another major difference between the two programs is the role of the user. Unlike NFMAS, FIREPRO is operated centrally with the parks providing data, but not conducting the analysis. The FIREPRO analysis falls into four phases, with the user making changes to the raw output (output generated by the matrices) in the last three phases. These changes are made in response to unique local conditions, or because the user feels that the unmodified output will not help parks reach their performance targets. An advantage of having fixed performance targets is that they provide verifiable grounds for budget changes. However, this is predicated on the performance targets themselves being appropriate.

FIREPRO could generate a complete fire organization, but because it lacks a simulation component, it could not compare alternative organizations. For the sake of illustration, the FIREPRO process can be considered to have two parts. The first part is the attainment of the program performance targets. The success of this part of the FIREPRO is verifiable at the end of a given fire season. The second part of the FIREPRO process is ensuring that these targets are achieved at least cost, which FIREPRO cannot do. The problems with the FIREPRO process stem from the scope of the analysis being too narrow and that alternative organizations cannot be compared. Thus, changes to the current FIREPRO framework should concentrate on expanding the elements of a fire organization considered by FIREPRO and including a capability to compare different organizations.

Discussion

NFMAS and FIREPRO embody different approaches to the fire management problem, reflecting contrasting agency missions. Both programs were developed from the ground up and represent real progress in applying economic principles to the fire management problem. However, if some of the areas for improvement in this paper were addressed, the two processes might be more similar. For example, one of the main problems with the FIREPRO process is that its scope is too narrow. If FIREPRO were to consider all elements of presuppression and suppression, along with a simulation component, then the two processes would be more similar. The optimization approach suggested for NFMAS would be particularly useful to the NPS with its many ecological constraints. It would be a more productive approach to design a program around a generic principle, such as constrained optimization, rather than allow the specific agency requirements to drive the establishment of the core process. With this central principle in place, its application could be agency specific.

Misconceptions about the C+NVC model are likely a result of the shortcomings of NFMAS and FIREPRO. Recognizing and addressing inconsistencies with basic economic theory often takes years to resolve; for example, consider the amount of time the 10:00 a.m. policy was considered to be economically efficient. Misconceptions regarding the original work of Sparhawk (1925) and more contemporary related models have only recently been revealed. Assimilating such change and transferring the change into modern technology and planning models is typically a lengthy path.

C+NVC is a strategic level theoretical model that illustrates the relationships between the fire management inputs and outputs. It does not however address many of the practical problems that arise when trying to operationalize the problem. For example, the issue of technical efficiency (the efficient mix) is not addressed explicitly but is of paramount importance to any operational model. The C+NVC model provides a theoretic framework that any tactical model should adhere to; however, it does not directly address many operational issues, such as ensuring an efficient mix that is necessary for operationally viable implementations. A thorough understanding of the role of the C+NVC model will help in improving current models and developing others.

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