A Subjective Measure of Forest Fire Management Effectiveness

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Abstract

The effectiveness of forest fire management systems is usually expressed in terms of loss; namely money spent, area burned and property destroyed. The author describes a method of estimating a lower bound for the monetary benefits of fire management efforts. A measure of effectiveness based on dollars spent, together with subjective estimates concerning the dollar value of timber and property saved, is proposed as a supplement to traditional measures of fire management effectiveness.

Introduction

Severe forest fire problems arise from time to time in many parts of Canada. Although weather conditions are obviously important, the strength of the fire management organization certainly influences the impact of fires that occur. Historical records provide vivid accounts of the enormous loss of lives, property and timber that was common before the advent of organized fire management systems. Although society will not tolerate the consequences of spending no money on forest fire management, fire management agencies do not possess sufficient resources to eliminate the destructive impact of all fires.

After rejecting these two extreme alternatives, forest managers must resolve the difficult problem of deciding how much money to spend on fire management activities. Many people have addressed this fire economics problem. Sparhawk (1925) was one of the first to advocate use of the familiar least-cost-plus-damage or LCD model. Very briefly, fire damage is assumed to be a decreasing function of expenditures. The optimal allocation of funds is an amount which minimizes the sum of fire damage and expenditures. Arnold (1949), Miller (1968) and Simard (1976) present overviews of this subject and there is no need to duplicate their efforts with a comprehensive literature survey.

The result of fire management efforts is a reduction in area burned. Davis (1964) showed that the fire management budget problem can be formulated from a profit maximizing standpoint to yield the same solution as the loss minimizing LCD approach. Miller (1968) used a similar approach as did Gamache (1969) and Maloney (1972) who extended the model to include more than one type of fire management resource. Williams (1969) stated, "Perhaps what is really needed is a measure of what was saved not what was lost. After

all, the whole fire control effort is designed to save forests."

Many practical and theoretical obstacles hinder or preclude the successful implementation of LCD methods. Given the complexity of the highly uncertain decision-making environment forest fire managers must deal with, it is not surprising that few if any have been able to use LCD models. The true optimal level of fire management funding could only be specified if one were able to accomplish the impossible task of formulating and solving a comprehensive model that incorporates all of society's desires and resources. The basic principles of fire economics must be re-examined and practical methods developed to deal with the economic aspects of fire management. The purpose of this paper is to describe a technique that can be used to quantify some of the monetary benefits of fire management and relate them to the amount of money spent.

The Economic Impact of Forest Fire Management

The implicit objective of most forest fire management agencies is to minimize the net destructive impact of fires subject to constraints on resource availability and utilization. Funds are allocated to fire management on the assumption that the subsequent benefits will exceed the value of the money spent.

Fire management costs are readily expressed in monetary terms. Salaries and equipment costs are easily assessed as is the cost of supporting fire management personnel in the field. The annual cost of fixed assets is less easily identified but standard accounting practices should yield reasonably accurate estimates.

The benefits of fire management activities include the reduced losses that result from limiting the number and size of destructive wildfires, the increased effectiveness that results from the proper use of prescribed fire and the enhanced environment that would result from successfully monitoring and modifying the suppression of beneficial wildfires. Although fire managers are certain the net benefit of their efforts is positive, they find it difficult if not impossible, to quantify the monetary consequences of their actions. In the following paragraphs the benefits of fire management are discussed and those that can be expressed in monetary terms indicated.

Public safety is perhaps the most important benefit of forest fire management. Modern fire management agencies are sufficiently effective that 'non-fire' personnel are seldom injured or killed by forest fires. However, it would be virtually impossible to determine how many lives are saved as a consequence of fire management activities.

The reduction of property damage is an obvious benefit of fire management programs. In order to evaluate this benefit in monetary terms, one must first identify the property that was saved as a consequence of fire management efforts. How this might be accomplished is discussed in the next section of the paper. Once the saved items have been identified, replacement cost could be used to estimate the monetary value of this benefit.

A third major benefit of fire management activities is the protection of timber. Evaluation of this benefit entails a two step process. The fire manager must first identify the stands of timber that were not burned as a consequence of fire management efforts. Once the saved areas have been delineated, it is necessary to assign a monetary value to the timber damage that was averted. Although Mactavish (1966) and others have studied this problem in considerable detail, there is currently no widely accepted method of appraising the monetary value of fire damage to timber. Nevertheless, most Canadian fire management agencies use what they believe are suitable damage rates to estimate annual fire losses. These values could be used to estimate the monetary value of timber damage reduction.

The fourth and possibly the most complex benefit of fire management efforts, is protection of the aesthetic benefits that accrue to people who use the forest or derive satisfaction from the knowledge that certain ecosystems exist. In order to assess the aesthetic benefits of fire management one must predict the long-term consequences of a fire and place a monetary value on the resulting environment. Aesthetic benefits simply cannot be expressed in monetary terms at the present time.

There are of course, many indirect benefits that result from fire management. Forest fires often affect wildlife populations, diminish air, soil and water quality and disrupt human activities. Although indirect fire management benefits are obviously important, they cannot presently be expressed in monetary terms.

A Subjective Measure of Fire Management Effectiveness

Given the complexity of fire damage, it is unreasonable to expect fire managers to quantify all the benefits that result from their efforts. It is suggested that initially fire managers attempt to estimate the consequences of their actions in terms of the dollar value of timber and property damage averted.

Let T denote an estimate of the dollar value of the timber saved as a consequence of fire management efforts during the fire season being assessed. It is given by

$$T = \sum_{i=1}^F t_i \dots \dots \dots (1)$$

where t_i = estimated value of the timber saved from fire i

F = number of fires that were subjected to management efforts

Most fire managers would find it difficult to assign a precise value to t_i . The first requirement is a prediction of the final size and shape of the fire had it not been managed. Let A_0 represent the final size and shape of a free-burning fire. An estimate of A_0 could be provided by experienced fire managers and fire behavior specialists who would consider what fuel, weather and topography the fire would have experienced had it not been managed. The difference between a fire manager's estimate of A_0 and the actual final size and shape of the fire thus represents an estimate of the area saved. When fires occur close together, care must be taken to ensure that saved areas are not counted as having been saved more than once.

The next step would be to assign a dollar value to the timber saved. Existing fire damage values could be used to estimate t_i as follows.

$$t_i = \sum_{j=1}^M V_j A_{ij} \dots \dots \dots (2)$$

where A_{ij} = area of the j th sector saved from fire i

M = number of sectors saved from damage by fire i

and V_i = estimated dollar value of the damage that would have resulted had a unit area of sector j been burned by fire i

Since fire intensity is strongly influenced by weather, the damage factor V_j would depend upon the weather conditions that would have prevailed at the time section j was burned by fire i , had it been allowed to burn freely. Using equations (1) and (2), one could estimate the value of the timber saved as a consequence of the action taken on all fires that occurred during the fire season.

Let P denote an estimate of the dollar value of property damage that was averted as a consequence of fire management efforts. It is given by

$$P = \sum_{i=1}^F p_i \dots \dots \dots (3)$$

where p_i = the estimated dollar value of the property saved from fire i

Using the projected non-suppression size and shape of fire i , the fire manager could identify property that would have been damaged had fire i not been managed. The value p_i is then given by

$$p_i = \sum_{j=1}^N R_{ij} \dots \dots \dots (4)$$

where R_{ij} = replacement value of the fire damage that would have been inflicted on property j had fire i not been managed

N = number of unburned property units that would have been damaged had fire i not been managed

R_{ij} would of course depend upon the weather con-

ditions that would have prevailed when the free-burning fire burned close to property j.

The quantity B given by

$$B = T + P \dots \dots \dots (5)$$

represents an estimated lower bound for the true benefits of the fire management program. Let C denote the amount of money spent. If the estimated benefits B exceed C, the true benefits probably exceed C since the true benefits are almost certainly greater than the estimated lower bound B. The ratio B/C thus serves as a useful partial measure of the effectiveness of a fire management system. When B/C exceeds 1 the organization clearly saved more money than it spent. Values of B/C consistently less than 1 signal a need to re-examine budget levels and management practices.

Throughout the preceding discussion it has been assumed that fire managers would be both willing and able to provide point estimates of the final size and shape of free burning fires. Because of the high degree of uncertainty inherent in the situation, it may prove more desirable to have fire managers express their assessments in probabilistic terms. For example, a fire manager may choose to delineate a number of alternative fire configurations and state his subjective assessment of the probability that each of them would have resulted had the fire been allowed to burn freely. If this were done, equations (1) through (5) could be expressed in probabilistic terms to yield an expected value for the ratio B/C.

Discussion

Some people may question the validity of using what is certainly a highly subjective method to estimate the effectiveness of fire management systems. Unscrupulous fire managers could of course inflate effectiveness estimates, by reporting excessively large non-suppression fire size estimates. Although some bias can be expected, this would not be a major problem. Others may feel that it is unreasonable to expect fire managers to accomplish the difficult task of subjectively predicting non-suppression fire behavior, but both research findings and current practices engender optimism.

Schultz (1964) studied the decision-making behavior of fire managers who participated in a simulation game. The participants were presented with hypothetical fire situations that had to be managed. Before the game began a group of fire behavior experts subjectively predicted the consequences of letting the fires burn freely. The decision-makers then selected strategies which were presented to a separate group of referees who subjectively predicted the consequences of the chosen actions. The refereed burned area was then compared with the non-suppression burned area prediction to yield a subjective measure of fire management effectiveness. Although projection of the non-suppression fire behavior did pose a difficult task, most of the game participants felt that the exercise was a good representation of real fire management

situations. Schultz (1964) actually suggested that subjective non-suppression fire predictions be used to estimate fire management effectiveness.

Fire managers already make subjective fire behavior predictions. One of the first tasks of an initial attack fire boss is to assess current fire behavior. He then makes a subjective short term prediction based on fuel, topography and anticipated weather. If the initial attack operation is not successful, the fire moves to an extended attack status and a more long term subjective fire behavior prediction is prepared.

Because of the relatively short time interval considered, suppression fire behavior predictions pose an easier task than long term non-suppression predictions. On the other hand, suppression predictions are based on forecasted weather while non-suppression predictions could be made at a later date, when the true weather conditions are known. The fact that fire managers can produce good suppression fire behavior predictions is evidence which suggests that they can probably provide good non-suppression predictions. Their demonstrated ability to subjectively predict the behavior of prescribed fires also lends support to this belief.

The policies of some Canadian forest fire management agencies make it necessary for fire managers to make crude long term non-suppression fire behavior predictions. In the province of Ontario for example, some fires that occur in remote northern areas and do not threaten either lives or property, are not suppressed. Such fires are classed as Being Observed or BOB. Before a fire manager classifies a fire as BOB he must determine that the potential damage is indeed minimal. This entails subjectively predicting whether or not the fire will eventually spread into designated high value areas. Although it is more difficult to predict the actual final size and shape of a free-burning fire, the fact that fire managers can deal with BOB decision-making suggests that they can probably accomplish the more difficult task.

Fire managers in the state of Alaska have recently implemented a fire attack policy which explicitly recognizes the fact that not all forest fires should be aggressively suppressed (Anonymous, 1976). Aggressive initial attack is initiated on all wildfires that are reported. If initial attack is not successful and the fire can only be controlled with a massive commitment of suppression resources, the need for full attack is reviewed. The fire manager can decide to modify full attack on such fires if he believes that potential damage is low. Alternative strategies are developed and the fire manager must subjectively predict the consequences of implementing the different courses of action. Several Canadian fire management agencies deal with selected fires in a similar manner. The fact that such practices have been implemented lends credence to the belief that fire managers can make good subjective non-suppression fire behavior predictions.

Recent developments in fire behavior modelling may soon make it possible to produce reasonably

good objective fire behavior predictions. Kourtz and O'Regan (1971) have developed a fire spread model that predicts fire growth depending upon fuel, weather and topography. Because of the large amount of data required to describe the fire environment, the current version of the model cannot readily be used on an operational basis. Improved data acquisition systems will eventually make it possible for fire managers to use this powerful tool to enhance their ability to predict non-suppression fire behavior.

Despite believing that fire managers can subjectively make reasonably accurate non-suppression fire behavior predictions, the proposed method should not be immediately applied to all wildfires. Fire managers have seldom explicitly made the detailed type of predictions required. Consequently, they require training and experience plus an opportunity to demonstrate to themselves and others, the degree of accuracy they can attain.

Fire managers should begin by subjectively predicting the non-suppression behavior of BOB fires. The growth of these fires should be closely monitored and recorded on detailed fuel type maps. Detailed weather observations should be compiled for the duration of such fires. These case histories could then be used to train fire managers to predict non-suppression fire behavior and determine the accuracy of their predictions.

Some fire management agencies convene boards of enquiry to examine the management of particularly costly wildfires. These investigations should include a subjective prediction of what would have happened had the fire not been managed. It would then be possible to estimate whether or not the benefits achieved exceeded the cost incurred.

Some obvious steps could be taken to minimize bias when estimating non-suppression fire size. The subjective assessments should be provided by a group of individuals rather than a single person. Collective expertise and peer group attitudes would tend to discourage the submission of intentionally biased estimates. An audit process whereby outside assessors randomly select fires for an in depth re-assessment could also serve to deter the submission of biased estimates. This would also enable novice assessors to benefit from the advice of more experienced fire managers.

Conclusions

A method that can be used to estimate a lower bound for the benefit of fire management efforts has been described. Although prevention efforts would not be considered, the consequences of other activities such as fuel management, pre-suppression planning, detection and suppression efforts would be included. The psychological benefits of expressing effectiveness in terms of values saved as opposed to those destroyed should not be underestimated. At the conclusion of particularly severe fire seasons some people tend to view the widespread destruction as a failure on the part of the fire management system. The ability to estimate the success of their efforts would pro-

bably enhance the morale of fire management personnel.

Forest fire management results in many different costs and benefits to society. Since it is presently not possible, and in some circumstances perhaps not necessary, to express all of these consequences in monetary terms, it would be unreasonable to demand that fire managers base their budgetary decisions solely on economic factors. On the other hand, the economic aspects of fire management should not be ignored. The proposed measure of effectiveness constitutes a partial measure of the economic consequences of past efforts. It should therefore be of use to people who just decide how much money to allocate to forest fire management.

Perhaps the most important consequence of implementing the proposed methodology would be an improvement in the ability of fire managers to predict fire behavior and to resolve resource allocation decision-making problems. The improved fire behavior prediction ability would result from an increased emphasis on that aspect of a fire manager's job and the experience gained when attempting to project the growth of free-burning wildfires. Improved fire behavior predictions would of course give dispatchers better information and thereby enable them to improve their resource allocation decision-making.

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