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Contribution of suppression difficulty and lessons learned in forecasting fire suppression operations productivity: A methodological approach

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ABSTRACT

We propose an economic analysis using utility and productivity, and efficiency theories to provide fire managers a decision support tool to determine the most efficient fire management programs levels. By incorporating managers' accumulated fire suppression experiences (capitalized experience) in the analysis we help fire managers determine fire suppression productivity and efficient budget allocation. Furthermore, monitoring of the management index (MI) helps identify operational deficiencies in the different districts where the analysis is applied. This is so because internally the area contraction factor (ACF) provides information regarding the effectiveness of fire suppression operations by including a comparison ratio between the area affected and the potential fire area without suppression actions. We used the Almonaster fire that occurred in 2008 in the Huelva Province, Spain as a case study to test the applicability of the methodology. Our evaluation showed that the combinations of firefighting resources assigned to the Almonaster fire resulted in a fire suppression efficiency of only 33%, measured as the ratio between damages avoided and suppression costs involved.

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Introduction

Wildland fires continue to be an important and ever growing problem worldwide, thus the economic relevance of fire management and protection programs; particularly when considering the increase in wildfire costs and losses globally; in addition to justifications for budget allocation for management and protection of forest ecosystems (González-Cabán (2013)). For example, from 2000 to 2013 the U.S. Department of Agriculture, Forest Service and other Department of Interior agencies with fire protection responsibilities have spent over \$US21.7 billion in suppression costs on fires affecting more than 37.3 million ha of forest and brush lands (National Interagency Fire Center Wildland Fire Statistics 2014). Recent estimates of the bushfires cost to Australia are as high as \$US6.625 billion (Ashe et al., 2006). According to the Global Fire Monitoring Center (GFMC) in Freiburg, Germany, 998 fatalities were reported worldwide from 2008 to 2010 (GFMC, 2012a); furthermore, in 2011 over 85,000 evacuations and more than 7,500 homes lost globally (GFMC, 2012b) indicate the magnitude of the socioeconomic significance of wildfires. These impacts have resulted in more public and government oversight demanding greater accountability for fire management actions and expenditures. A myriad of wildland uses has effects ranging from recreation to wildlife interests and from ecosystems sustainability to traditional commodity outputs. The demands are multiple and the financial resources are limited. Therefore, to distribute budget funds according to priorities (Rodríguez y Silva et al., 2014) established in strategic and economic planning processes we need appropriate analytical tools that allow us to measure the direct suppression expenditures and the financial and economic impacts of wildfires.

These analytical tools are varied and used to address various dimensions of the wildland fire management problem. As discussed by Thompson and Calkin (2011) uncertainty is a major component to consider in developing decision support methodologies "... to facilitate cost-effective, risk-based wildfire planning efforts (p. 1895)." While they agree there has been significant advances in the treatment of risk and uncertainty in wildfire management analytical models improvements are needed in fire behavior and ignition occurrence models. However, the area in most need of further development is the characterization of nonmarket resources at risk. Furthermore, they propose a measurement of risk in terms of net value change (NVC), which considers the interaction of fire with a resource and the intensity of the fire. They also highlight the need to bring together the fields of decision science and environmental economics in developing new analytical models

Using the microeconomic production theory, Mendes (2010) proposes framing the wildfire problem as a production problem in which fire managers choose the most appropriate combination of firefighting resources that is simultaneously the most cost effective and technologically efficient in suppressing wildfires. Further, Mendes (2010) applies a marginal rate of technical substitution (MRTS) analysis to help determine effectiveness of different combinations of firefighting resources. This information would help fire managers find that combination of resources that produces the highest productivity (suppression effort) at the lowest cost. Of course, fire managers must have a system in place to acquire not only suppression cost information but also the economic impacts of the fire, for the sum of both represent the total economic cost of the production function.

Hesseln et al. (2010) tries to explain the contribution of highly specialized costly geospatial technologies on wildfire suppression costs by estimating random parameters regression models of total fire expenditures, agency fire suppression costs, fire duration and area burned. Authors find that suppression costs does not appear to increase significantly with the use of geospatial technologies; however, they think that the cost of using these technologies may be offset by allowing a more efficient use of firefighting resources by fire managers trying to minimize fire suppression costs in controlling large fires.

An important parameter in fire suppression efforts is the productivity or efficiency of firefighting resources during extended attack. However, Holmes and Calkin (2013) point out that little is known about these resources productivity or efficiency. Without this knowledge is not possible to determine if changes in firefighting strategies could result in suppression costs reductions within safety and resource protection goals. They use operational data from large fires to estimate the parameters of economic production functions relating fireline construction to the level of fire suppression inputs; then use the parameter estimates to evaluate whether these are different from standard fireline

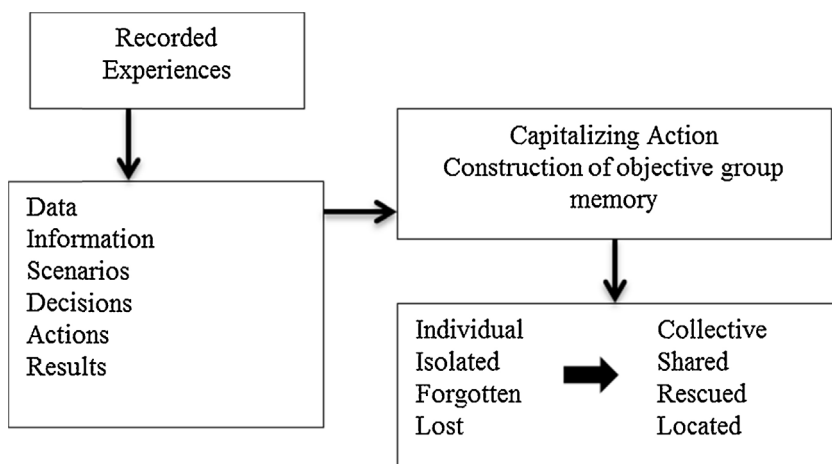


Fig. 1. Experience capitalization procedure.

production rates values used by the FS. Their results show their estimates are between 14 and 93% of the standard production rates. Because the productivity of all resources together increase proportionally more as their use is increased they posit this as existence of economies of scale or that managers learn how to deploy the resources more productively as the fire progress.

As noted recently there has been an increase in the use of economic theory models for analyzing fire suppression productivity efforts during wildland fire management. Along those lines we propose an econometric model to provide fire managers a decision support tool to determine the most efficient fire management programs levels. Different than previous work we propose the incorporation of accumulated managers' fire suppression experiences in an econometric model for determining fire suppression efficiency.

The section following this introduction explains the concept of knowledge capitalization and how is incorporated in the model as well as the Fire Management Index concept. We then use a case study (section 'Estimation of the efficiency of suppression methods with nonparametric methods') of fires in the Province of Cadiz to present the estimation of the efficiency of suppression methods. In the final section we present our conclusions.

Knowledge capitalization and the Management Index

Capitalizing on the experience of documented operations/attack plans allows information exchanges among fire managers. It provides validation of lived events and helps improve operational decisions and human behavior in suppression work. Capitalization converts experiences from being individual to collective, isolated to shared, and forgotten to reused; in this way, the experience becomes available, locatable, and accessible (Fig. 1) (Rodríguez y Silva et al., 2007).

The primary reason for knowledge capitalization is to share the data extracted from the experience and obtained through the fire events (Rodríguez y Silva et al., 2007; MacGregor and González-Cabán, 2008). Sharing events and knowledge acquired from real-life situations facilitates exchanges of experience regarding the behaviors during development of operations/attack plans. The benefit is access to knowledge among various officials and firefighters regardless of whether they had been eyewitnesses to the event or not.

When managing suppression work, the requested resources are managed by the Incident Commander and its Staff at all different levels. These managers gather all possible information on the current fire situation to evaluate and analyze it to make appropriate decisions regarding the most appropriate operations/attack plan; thus implementing the most efficient and safe distribution of available suppression resources.

Knowing and understanding how and why firefighting resources and operational plans were implemented in similar situations (i.e., objective group memory information) allows managers to use previous lessons learned information to develop an operation/attack plan for the current incident. This is important because as MacGregor and González-Cabán (2008) inform us, many fire managers anchor their decisions on previous salient features of fire suppression experiences.

The databases described below provide the necessary information for selection of the variables and parameters that enables studying, analyzing and evaluating the productivity and efficiency of the suppression operations based on the accumulated prior experiences. Basically the following variables should be considered:

- Fireline production rate (fireline produced by unit of time; measured as m/min)
- Area contraction factor, or ACF (difference between the unit and the ratio between the actual area affected by the fire and the potential area affected by a free-burning fire, i.e., without suppression operations; considering the time elapsed from detection until the fire is controlled) (Rodríguez y Silva et al., 2007; Rodríguez y Silva and González-Cabán, 2010).
- Average area affected per recorded forest fire (ha/fire)
- Average suppression costs per affected area (\$/ha; €/ha);
- Ratio between suppression cost and natural resources net value change.

As pointed before, the capitalization of prior wildland fire suppression experiences results in the availability of databases with information on the different wildfire scenarios in which fire suppression actions took place. Also the effectiveness of suppression actions measured in terms of reduction of affected area per fire controlled (see area contraction factor above); and in efficiency measured in terms of reduction in fire suppression costs and reduction in the economic losses in the value of natural resources protected. Therefore, allowing fire planners being able to establish a hierarchy of importance or preference of firefighting resources to use based on the prior experiences, and enhanced with information on the utility theory and econometric model presented here. This knowledge capitalization is made operational through a Management Index explained below.

Assessing management efficiency is always necessary for responding to inquiries about investments made and the results obtained. Applying econometric tools to the evaluation of investments in forest fire protection is always difficult due to the lack of variables that define suppression costs and effectiveness in suppression operations in an integrated way. To help clear this problem, an integrative variable called *Management Index* (MI) (Carmona and Rodríguez y Silva, 2009) was defined that enables including information on costs and effectiveness in fire suppression operations, and the capitalization of the experiences. MI is defined as the ratio between the area contraction factor (ACF) and the suppression cost per hectare (C_a), as represented for one fire in Eq. (1):

$$MI = \frac{100ACF}{C_a} = \frac{100(A_v - A_q/A_v)}{C_t/A_q} \quad (1)$$

where A_q is the area affected, and A_v is the area affected in a simulated free-burning fire (without suppression operations) for the time between detection and control.

Conducting a differential analysis to determine changes in MI relative to the behavior of each of the three variables (A_q, A_v, C_{tot}), permits us to obtain the conditions that maximizes the function explaining the variations in MI (Eq. (2)).

$$\begin{aligned} dMI &= \frac{\partial MI}{\partial A_q} + \frac{\partial MI}{\partial A_v} + \frac{\partial MI}{\partial C_{tot}} = \frac{100A_q}{C_{tot}^2} + \frac{100A_q^2}{A_v C_{tot}^2} + \frac{100}{C_{tot}} + \frac{100A_q^2}{A_v^2 C_{tot}} - \frac{A_q}{A_v C_{tot}} \\ d^2MI &= \frac{-200}{A_v C_{tot}} - \frac{200A_q^2}{A_v^3 C_{tot}} + \frac{200A_q}{C_{tot}^3} + \frac{200A_q^2}{A_v^2 C_{tot}} + \frac{400A_q}{A_v^2 C_{tot}} - \frac{200A_q^2}{A_v^2 C_{tot}^2} - \frac{200}{C_{tot}^2} + \frac{400A_q}{A_v C_{tot}^2} \end{aligned} \quad (2)$$

Solving for the first derivative to be zero then the values that make the second derivative of the determining function of MI negative will provide the sufficient condition for MI to reach its highest value under those conditions; though not necessarily a single global maximum. That is, when MI is at its maximum, the AFC is also at its maximum, and the suppression cost per ha is at its minimum.

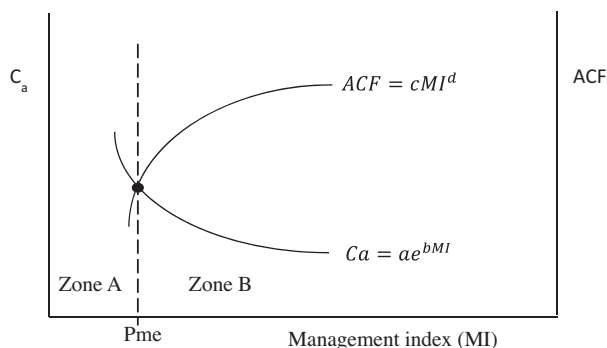


Fig. 2. Graph showing the most efficient management program. Zone A represents an inefficient management and Zone B an efficient management.

Using this procedure, one can study each fire individually or analyze a given district or province for a particular time period. The comparison between periods allows tracking MI determination of a point at which MI is most efficient. As seen in Fig. 2, the joint graphic representation of the regressions between MI versus C_a and ACF shows that there is a corresponding cutoff point (P_{me}) below which C_a exceeds the efficiency of the resources represented by ACF; that is, to left of this point the difference between the actual area burned with the assigned fire suppression resources is closer to the simulated area of the free burning fire. That means, that although the fire suppression costs are increasing the management of the fire does not result in a corresponding reduction on total area affected. The further to the right of the Point of *Minimum Efficient Management* (P_{me}), the greater the efficiency (zone B). Therefore, the more positive the assessment of fire management is. On the contrary, MI values located to the left of P_{me} (zone A) are poorly managed fires, in which the ACF is less than C_a . That is, the suppression costs of all firefighting suppression resources used is greater than the reduction in area affected when compared to a free burning fire.

The mathematical representation of the minimum efficient management point takes the following general form (Eqs. (3) and (4)):

$$C_a = ae^{bxMI} \quad (3)$$

$$ACF = cMI^d \quad (4)$$

where C_a is fire suppression costs per ha; and the values for the coefficients (a) and (c), as well as for the powers (b) and (d), are obtained through regression analysis from historical records of fire occurrence for a period of time and district or region in which the analysis is performed.

The MI utility range is broad within the analytical framework that integrates fire suppression operations results and associated costs. Regular monitoring of MI helps identify operational deficiencies in the different districts where the analysis is applied. Internally the ACF provides information regarding the effectiveness of fire suppression operations by including a comparison ratio between the area affected and the potential fire area without suppression actions. This comparison is done for the period of time between the start of the fire and the time fire is declared controlled. Applying the model to different provinces provides numerical information for the coefficients and powers of Eqs. (3) and (4). The example that follows is for a study of the province of Cádiz, Spain, for the fire years 2001 to 2011.¹

The values for equations 5 and 6 were obtained from the analysis of 78 wildfires. We obtained information for actual area burned (Aq) and final perimeter using GPS to georeferenced points around the area burned, and simulated or virtual area burned (Av). In addition we determined the total fire suppression cost for each one of the 78 wildfires and divided it by its actual area burned to determine suppression cost per hectare for each wildfire. We then ran two regressions. The first on suppression

¹ This study has not been published but results and data are available from authors.

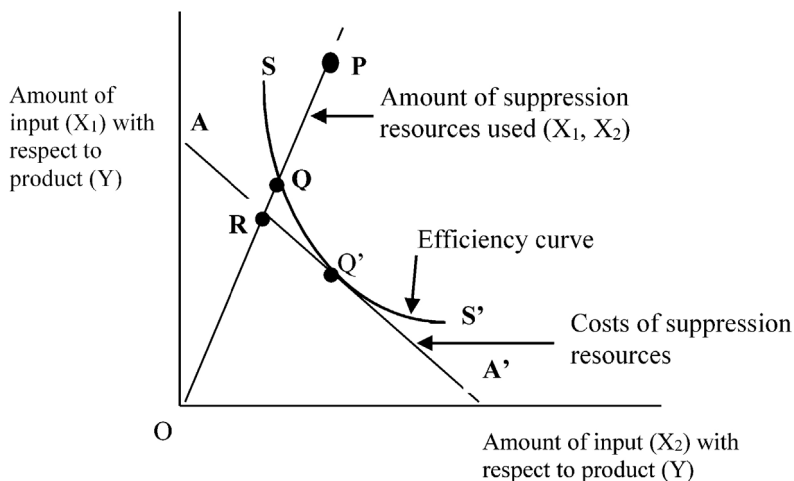


Fig. 3. Graphic representation of efficiency analysis relating the amount of inputs to their prices and the amount thereof used in suppression.

costs per hectare (C_a) as function of the management index (MI) using information for all 78 wildfires (Eq. (5)); $R^2 = 0.89$. The second equation is of the ACF as function of the MI for the 78 wildfires (Eq. (6)); $R^2 = 0.80$.

The estimated value for C_a is greater than the value for ACF; this means that MI is in the zone of efficient management. Therefore, the combination of firefighting suppression resources assigned to the fire was most efficient resulting in a smaller area affected and lower suppression costs.

$$C_a = 3754.2e^{-13.99MI} \quad (5)$$

$$ACF = 297.16MI^{0.508} \quad (6)$$

Estimation of the efficiency of suppression methods with nonparametric methods

The study and determination of efficiency can be approached either through parametric methods by determining the stochastic production possibility frontier², which is a deterministic procedure, or by nonparametric methods using linear programming techniques (Parra Rodríguez et al., 2009).

For simplicity, consider the case of two types of suppression resources whose costs or prices derived from their use are (X_1) and (X_2), respectively. Moreover, Y can be defined as the final product obtained by their marginal utility or as the final result after fire is declared controlled measured for example, as area controlled per unit of time or ACF reached. A graphical representation of the efficiency analysis permits us to define two important concepts: *technical efficiency* (TE) and *allocative efficiency* (AE). TE is defined as the maximum output with a given set of inputs and AE as the reduction in production costs if the unit produced used its production inputs most efficiently (Fig. 3, adapted from Farrell, 1957).

The curve SS' represents the production isoquant for the combination of firefighting suppression resources X_1 and X_2 . The segment QP determines both the **technical inefficiency** (TIE) and the reduction in the amounts of firefighting suppression resources X_1 and X_2 , without affecting the output target (or initially agreed final suppression variable). The value of TIE is determined by the ratio between the distances defined by the segments QP and OP (Eq. (7)).

$$TIE = \frac{QP}{OP} < 1; \text{ in percentage is } TIE\% = \frac{QP}{OP} \times 100 \quad (7)$$

² This refers to the maximum possible production of a product given a set amount of resources. See chapter 2 in Kumbhakar and Knox Lowell (2000).

Based on the above expression, the general *technical efficiency* (TE) is determined as one minus the value of *TIE*.

$$TE = 1 - TIE = \frac{OP - QP}{OP} = \frac{OQ}{OP} \quad (8)$$

Knowing the price variation between firefighting suppression resources with the same classification or type (e.g., transport and attack helicopters), one can determine AE (reduction in production costs, if the firefighting suppression resource assigned was efficient). AE is represented by the segment RQ and determines the cost reduction by switching the efficiency point Q to position Q' (Fig. 3). Finally, *economic efficiency* (EEI) can be obtained by the product of TE and AE (Eq. (9))

$$EEI = \frac{OQ}{OP} \frac{OR}{OQ} = \frac{OR}{OP} \quad (9)$$

Using the analysis method presented here for determining efficiency requires the prior definition of the following econometric model applied to forest fire suppression operations. *Benefits* refer to the economic value of the area that has been successfully protected based on fire suppression activities defined when planning the suppression operations (Eq. (10)).

$$B = V_r - V_r(F_d) = V_r(1 - F_d) \quad (10)$$

where *B* represents the total economic value saved from the impact of the fire within the fire perimeter, *V_r* is the economic value of each of the resources protected in the area where the wildfire has evolved (area bounded by the final fire perimeter), expressed in monetary units (€, \$), and *F_d* is the depreciation factor of the economic value due to the effect or impact of the fire (Molina et al., 2009; Rodríguez y Silva and González-Cabán, 2010; Rodríguez y Silva et al., 2012).

The total economic value for all existing resources saved is given by Eq. (11). All variables as previously defined.

$$\sum I = \sum V_{r_i} - \sum V_{r_i}(F_{d_i}) = \sum V_{r_i}(1 - F_{d_i}) \quad (11)$$

On the other hand, suppression costs (*C_{e_j}*) are the sum of the costs of all individual firefighting suppression resources (*j*) dispatched to the fire. In terms of efficiency analysis, the resulting solution comes from the combination of firefighting suppression resources with a production rate level assigned to the protection of natural resources at risk saved from the fire impact, i.e., economic value of the resources at risk saved. This is the suppression costs of the operational suppression system. Accordingly, the technical efficiency expression (from equation 8 above) can be rewritten as follows to put it in terms of the fire suppression capabilities, where TE is the technical efficiency estimator, *i* represent the different natural resources protected, and all other variables as previously defined:

$$TE = 1 - \left[\frac{\sum_{j=1}^{j-m} C_{e_j}}{\sum_{i=1}^{i-n} V_{r_i}(1 - F_{d_i})} \right] \quad (12)$$

From Eq. (12), TE values result from the ratio between revenues (outputs) and suppression costs (inputs); therefore, it can be generalized that:

If $TE < 1$, then the efficiency is low to very high

If $TE = 1$, then the efficiency is achieved

To establish measurement consistency, adjustments are necessary to the TE equation (Eq. (12)). To do this, weights are introduced that normalize the measurement heterogeneity among the variables in the equation. The weights help put all variables in terms of the ratio of its value to the total overall value for that variable. Thus, for the case of the different firefighting suppression resources used, the weights (β_j) represent the time each resource was used in relation to the total elapsed time from the start of suppression actions until the fire is declared controlled. For the economic value of each natural resource, the weights (α_i) represents the ratio of the economic value of each resource to the

Table 1
Qualitative classification to establish an efficiency ranking.

Efficiency value interval (ET)	Qualitative classification
$ET < 0.25$	LOW
$0.26 \leq ET < 0.5$	MODERATE
$0.6 \leq ET < 0.7$	HIGH
$0.8 \leq ET < 1$	VERY HIGH

Table 2
Economic valuation of the natural resources and losses due to the impact of the Almonaster fire.

Resource	Value			Weight (α_i) ^d
	Existing ^a	Lost ^b	Saved ^c	
	Vr_i	$Vr_i * Fd_i$	$Vr_i - Vr_i * Fd_i$	
	Euros (€)			
Timber	246,658	145,322	101,337	0.4485
Firewood	65,426	31,734	33,693	0.1491
Fruit	38,195	12,727	25,469	0.1127
Biodiversity	75,436	45,387	30,049	0.1323
Recreation	35,124	25,761	9,363	0.0414
Hunting	87,356	61,324	26,032	0.1152
TOTAL	548,195	322,255	225,943	

^a This is the total economic value of each resource present in the area where a fire occurs. It is estimated using the methodology of Rodríguez y Silva and González-Cabán (2010) and Rodríguez y Silva et al. (2012).

^b Applying a depreciation factor (percent) to the total resources value provides estimates of the loss caused by the Almonaster fire in the evaluated are.

^c Residual value or value saved as result of suppression actions in area.

^d Represents the ratio of the economic value of each resource to the total economic value of all natural resources in the area affected by the fire. For example, the weight for timber was computed as 101,337/225,943 (total value of natural resources affected by the fire).

total economic value of all natural resources in the area affected by the fire. Applying the weighting criteria to ET, we obtain the following equation:

$$TE = 1 - \left[\sum_{j=1}^{j-m} \frac{\beta_j C_{e_j}}{\sum_{i=1}^{i-n} \alpha_i V_{r_i} (1 - Fd_i)} \right] \tag{13}$$

For simplicity, we suggest a somewhat arbitrary qualitative classification of the results to establish an efficiency ranking (Table 1) by associating the TE estimates to four categorical levels: Low, Moderate, High, and Very High.

Empirical example of the model

We used the Almonaster fire that occurred in 2008 in the Huelva Province, Spain as a case study to test the applicability of the methodology. This fire is typical of the fires occurring in the area with slopes greater than 55%, high temperatures (38%), low relative humidity (17%), and winds of about 17 km/h. Furthermore, fuels are characterized by Mediterranean chaparral, presenting a medium to high suppression difficulty. Determining the economic valuation of the natural resources and their economic depreciation as a result of a fire enables obtaining their residual economic value and therefore, the equivalent volume that forms the numerator of Eq. (18) that provides the economic efficiency value EEI (Table 2).

Table 3 shows each firefighting suppression resource cost (C_{e_j}), intervention time and weight value (β_j).

Table 3

Costs of firefighting suppression resources dispatched to Almonaster fire.

Quantity	Suppression resource	Total Suppression cost (C_{ej}) (€)	Duration time (min)	Weight (β_j) ^a
2	CL-215T Aircraft	62,940	826	0.043
3	Bell 412 Helicopter	38,430	1261	0.066
1	KAMOV K32 Helicopter	25,423	726	0.038
2	Air Tractor 802 Aircraft	15,247	1401	0.074
10	Crew (15 members)	73,990	8057	0.420
1	Bulldozer	1156	946	0.050
8	Fire Engine	8782	5605	0.290

^a Represent the time each resource was used in relation to the total elapsed time from the start of suppression actions until the fire is declared controlled. For example the weight for the CL-215T Aircraft was computed as 826/18,822 (total time all firefighting resources were assigned to the fire).

The resulting Efficiency Factor (ET) for the 2008 Almonaster fire achieved with the combination of firefighting suppression resources listed in Table 3 as shown in Eq. (14), was 0.33 or 33%.

$$TE = 1 - \left[\frac{\sum_{j=1}^{j-m} \beta_j C_{ej}}{\sum_{i=1}^{i-n} \alpha_i V_{ri} (1 - Fd_i)} \right] = 1 - \frac{41017}{60728} = 0.33 \quad (14)$$

As shown in Table 2 this efficiency ratio enabled saving 41%³ of the economic value of the natural resources in the area affected by the fire. In our qualitative ranking (Table 1) 33% efficiency corresponds to a classification of moderate efficiency.

Efficiency analysis can be directed beyond the individualized study of forest fires. Indeed, it enables comparative evaluations between fires and even determines the efficiency of a given forest fire protection program in a forest district as shown here. For example, we can assume that each of the (N) fires has (K) firefighting suppression resources and (M) revenues or benefits obtained by protecting the economic values of natural resources. The matrix (KxN) of inputs X (firefighting suppression resources used) and the matrix (MxN) of outputs (value of acres saved from fire), and Y represent the data of the (N) fires considered in the analysis. The purpose of applying data envelopment analysis is to build through a nonparametric method a production possibility frontier on the reference points, such that all observed points are either on or inside the frontier.

The efficiency for each fire is obtained from the ratio of all the outputs over all the inputs ($U'y_i/V'x_j$), where (U') is the vector of output weights (dimension Mx1) and (V') is the vector of input weights (dimension Kx1). The selection of the optimum weights is obtained from Eq. (15).

$$\max_{u,v} (U'y_i/v'x_j) \text{ s.t. } U'y_i/v'x_j \leq 1, U, V \geq 0, \text{ and } j = 1, 2, 3, \dots, N \quad (15)$$

This implies determining the values of U (weight associated with the generic i th output) and V (weight associated with the i th generic input), such that the efficiency of the i th forest fire of the total fires (N) under study is maximized, subject to the efficiency measures being less than or equal to one; considering the following restriction:

$$V_{x_j} = 1, \quad \max_{u,v} (U'y_j) \text{ s.t. } U'y_j - V'x_j \leq 0 \quad (16)$$

Applying linear programming, the above expressions are as follows,

$$-y_j + Y\lambda \geq 0 \quad (17)$$

$$\Theta_{x_i} - X\lambda \geq 0 \quad (18)$$

$$\lambda \geq 0 \quad (19)$$

where λ is the efficiency of the i th fire. A linear programming solution is necessary for each of the N fire records being analyzed, at the spatial-geographic or temporal scale.

³ Computed as Value saved/Existing value or 225,943/548,195.

Conclusions

There has been an increase in the use of economic theory models for analyzing fire suppression productivity efforts and optimize fire budget allocation in wildland fire management operations. In continuing with these efforts in this work we propose an econometric model using utility and production function theories to provide fire managers a decision support tool to determine the most efficient fire management programs levels. We further incorporate managers' accumulated fire suppression experiences (capitalized experience) in the model together with utility and production theory for determining fire suppression productivity and optimal budget allocation.

In the process of analyzing a potential operation/attack plan for a current incident knowing and understanding how and why firefighting resources and operational plans were implemented in similar situations (i.e., objective group memory information) allows managers to use previous lessons learned information to develop an operation/attack plan for the current incident. Moreover, these prior experiences provide information on the effectiveness of fire suppression actions in terms of reduction in fire suppression costs and economic losses to natural resources protected. This is similar to findings by MacGregor and González-Cabán (2008) when they say that fire managers many times anchor their current decisions on previous experiences. A catalogue of lessons learned would provide a structured approach to using prior experiences.

The model proposed here helps managers to determine the optimization of the combination of firefighting suppression resources available given the resources price, their suppression capability, available budget and the utility function defined. Thus, the fire manager obtains the best combination of firefighting suppression resources given their production capabilities, utilities and budget restriction. Furthermore, regular monitoring of the management index (MI) helps identify operational deficiencies in the different districts where the analysis is applied. This is so because internally the area contraction factor (ACF) provides information regarding the effectiveness of fire suppression operations by including a comparison ratio between the area affected and the potential fire area without suppression actions.

Finally, the methodological approach presented here provides options for the combined study of fire suppression costs and residual economic valuation of natural resources after the impact of a forest fire. For example, the information produced permit managers not only to analyze and classify the results of agreed upon and applied fire suppression options, but also to make adjustments in the combination of firefighting suppression resources assigned if necessary. The information also allows forecasting fire suppression operations productivity based on suppression difficulty and cost, as well as on records from documented fire suppression operation plans from prior fires.

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