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The state of development of fire management decision support systems in America and Europe ☆

Robert Mavsar [a,*], Armando González Cabán [b], Elsa Varela [a]

[a] European Forest Institute Mediterranean Regional Office (EFIMED), St. Antoni Maria Claret 167, 08025 Barcelona, Spain
[b] USDA Forest Service, Pacific Southwest Research Station, Riverside (CA), USA

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ABSTRACT

Forest fires affect millions of people worldwide, and cause major ecosystem and economic impacts at different scales. The management policies implemented to minimize the negative impacts of forest fires require substantial investment of financial, human and organizational resources, which must be justifiable and efficient. Decision support systems based on economic models can help to optimize the allocation of limited resources. This paper exposes the development of the economic theory for the efficiency analysis of fire management measures. Then, it provides a review of four fire management decision support systems applied in America and Europe, investigating their degree of performance according to the theoretical foundations of the efficiency analysis.

1. Introduction

Forest fires are a societal problem that threatens the environment and affects millions of people worldwide, causing major ecosystem and economic impacts at different scales. These impacts are reflected in many ways: not only damages and losses of ecosystem goods and services but also health problems or even losses of human life and negative effects on economic activities.

Although the number of forest fires and the affected area vary considerable from year to year (e.g., JRC, 2009; NIFC, 2010), the frequency of disastrous fire years in the last decade seems to be increasing. The driving factors for such development are manifold, like changing climate conditions (Piñol et al., 1998), abandonment of rural areas, expansion of fast growing flammable species, or increment of wildland–urban interface areas (Xanthopolus et al., 2006). The increased incidence of fires attracts more attention, reflecting the increasing public concern for this issue.

The raised public concern for this issue (IESA/CSIC, 2007) spurs the authorities to implement improved policies and management measures, to minimize the negative environmental, economic and social impacts of forest fires (EU, 2005). However, implementation of such measures requires substantial investment of financial, human and organizational resources.

In the past, most fire-prone countries focused their efforts and resources primarily on fire suppression, which contributed to a substantial short-term reduction of burned areas, as was the case in Spain in the 80s and 90s (Vélez Muñoz, 2007). Paradoxically, this approach somehow contributed to the accumulation of flammable fuels, which increased the risk of high-severity wildfires (Reinhardt et al., 2008). Experience suggests that once a certain level of fire suppression is reached, obtaining significant changes in fire losses would require huge expenditures if relying exclusively on suppression activities (Lázaro, 2010; Montiel and San-Miguel, 2009; Rigolot et al., 2009). For example, although the fire management investments in Spain and the United States increased or stayed stable, it seems that this did not affect the extent of the burned areas (see Tables 1 and 2)

In this sense, several authors have analyzed the cost-effectiveness of the expenditures in suppression and prevention activities, frequently finding an over-allocation of fire management funds to suppression activities relative to prevention measures (Lakoande, 2005; Snider et al., 2006).

Decision support systems (DSS) can provide guidance to fire managers how to allocate resources more efficiently (Donovan et al., 2008). When these DSS incorporate economic models, they also enable the assessment of the economic efficiency of fire related investments. Nevertheless, these systems are not broadly implemented as they require reliable knowledge and data on the performance of fire management activities as well as on the physical and economic impacts (negative and positive) of fires which are not always available. However, the understanding and assessment of socio-economic impacts of forest fires, is essential for the development of forest fire related policies and implementation of management practices (Morton et al., 2003).

This paper presents the current stage of development and implementation of four fire management DSS. Section 2 introduces the

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* Corresponding author. Tel.: +34 671480990; fax: +34 930024049.
E-mail address: robert.mavsar@efi.int (R. Mavsar).

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Table 1
Area affected, losses and expenditures (prevention and suppression) of the Spanish government: 2003–2009.

Year	Area affected (in ha)	Losses (in million €)	Investments (in million €)
2003	148,172	405.57	51.09
2004	134,193	359.64	55.29
2005	188,672	505.70	61.96
2006	155,363	752.67	68.31
2007	86,113	227.59	87.40
2008	50,321	–	94.66
2009	150,311	–	111.01

(Source: MARM, 2009).

theory of fire management efficiency evaluation, which is the basis for all the modern fire management DSS. Next, Section 3 presents some of the existing systems and discusses their degree of performance in relation to the economic theory. Finally, in Section 4 the main conclusions are given.

2. Review of theory development

Economics is often defined as the science of allocating limited or scarce resources in a way that attempts to satisfy our unlimited wants and/or provide the greatest wellbeing of society. Thus, fire economics attempts to determine the most efficient allocation of limited resources for fire management (Gorte and Gorte, 1979).

Most of the research in the field of fire economics has been conducted in United States. As early as 1916 Lovejoy (1916) and Headley (1916) formulated the search for economic efficiency of fire management as a minimization problem. The objective was to minimize the sum of management costs and net damages. This means, that the most efficient level of fire protection is found where the cost of management (prevention, presuppression, suppression) and resulting damages are minimized. It was assumed that increasing fire suppression efforts and expenditures would decrease the fire induced damages. Further, it was supposed that increased presuppression investments lead to decreased suppression expenditures. The result of this analysis would be a U-shape function, with a minimum point representing the optimal presuppression level.

2.1. Least-cost-plus-loss model

Sparhawk (1925) further developed Headley's cost plus damage concept into the least-cost-plus-loss model. His model minimizes the sum of the “total liability” costs (suppression costs plus resource losses) and primary protection costs (presuppression), selecting the optimal level of primary protection. Presuppression costs are an independent variable that determines suppression costs and damages (see Fig. 1). Namely, the model assumes that total liability costs depend on fire risk, which in turn may be influenced by presuppression

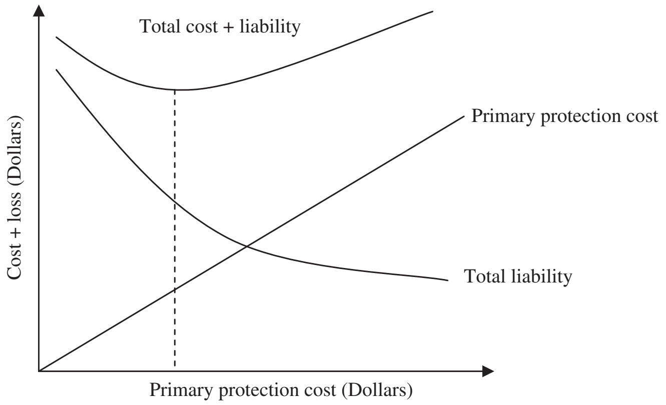

Fig. 1. Sparhawk's least cost-plus-loss model.

efforts (e.g., changes in availability of suppression resources, accessibility, or suppression efficiency). Therefore, in the least-cost-plus-loss model the total liability costs are inversely related to the primary protection efforts (Sparhawk, 1925).

For almost five decades the least cost-plus-loss model was the standard approach to estimate the most efficient level of fire suppression expenditures. Different authors proposed minor changes to the model, but the basic assumptions remained unchanged (González-Cabán, 2007; Gorte and Gorte, 1979).

However, Simard (1976) pointed out that there were two main faults in the definition of the least-cost-plus-loss model. Firstly, he claimed that there was little consistency in the definition of the independent variable in the least-cost-plus-loss model. More importantly, he underlined that the relationship between the cost and damage function were not explicitly examined. He addressed these concerns by developing a marginal analysis model (see Fig. 2) where damages and the costs of fire management efforts were related. Further, this model includes also eventual beneficial effects of forest fires (e.g. maintaining of fire dependent ecosystems).

2.2. Cost plus net value change model

Mills and Bratten (1982) argued that the adequate way to estimate the economic efficiency of forest fire management activities is to estimate all costs and benefits related to them. This approach is also known as the cost plus net value change model (C + NVC). Compared with Sparhawk's least cost-plus-loss model, the C + NVC model had two important improvements. First, the total liability function was separated into the suppression function, and the detrimental and beneficial value change functions (Fig. 3). Second, the model also included the estimation of damages to non-market goods and services.

The C + NVC model is derived by summing presuppression and suppression costs, and the value of the change in resources outputs

Table 2
Area affected and suppression expenditures of the USDA Forest Service: 2003–2009. Source: National Interagency Coordination Center 2010.

Year	Area affected (million ha)	Investments (million US$)
2003	1604	1.326
2004	3278	0.890
2005	3518	0.876
2006	3997	1.900
2007	3777	1.800
2008	2143	1.900
2009	2397	1.230

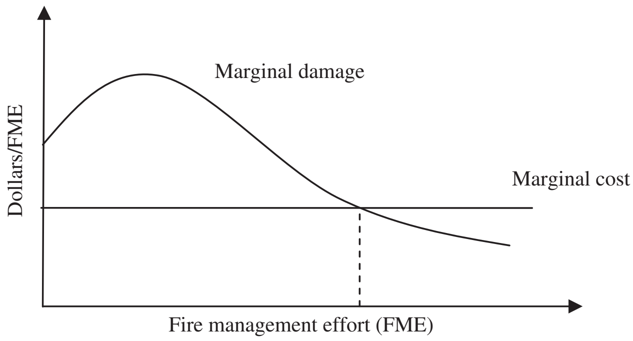

Fig. 2. Simard's marginal analysis model.

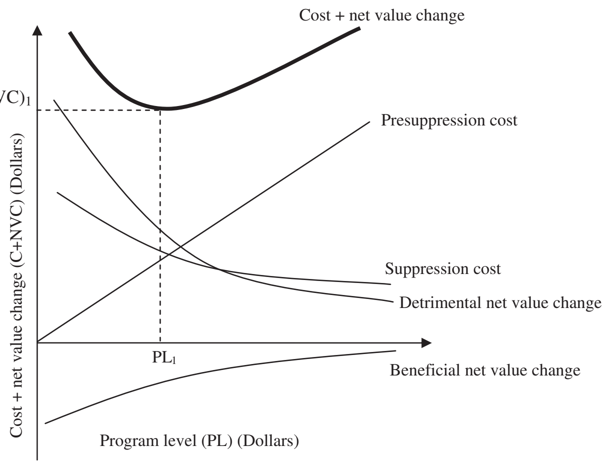

Fig. 3. Graphical representation of the cost plus net value change as specified by Mills and Bratten (1982).

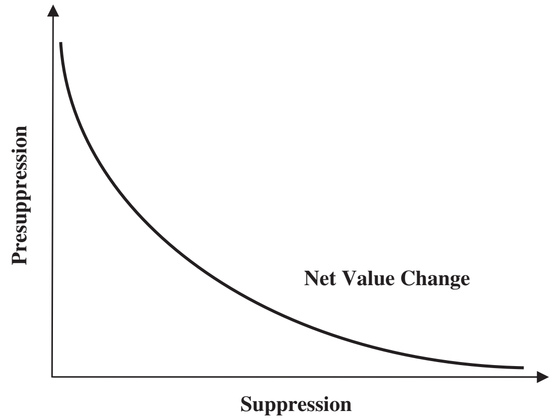

Fig. 4. Net value change level curve.

induced by the fire. The presuppression costs are the expenditures on wildfire management prior to the wildfire season (e.g., purchasing equipment for fire fighting crews); while, suppression costs are fire fighting expenditures during a fire season (e.g., wages for fire fighting crews). The most efficient fire protection program is that in which the combination of presuppression and suppression expenditures results in the lowest total C + NVC. The result of this analysis is a U-shape function (see Figs. 3 and 5), with a minimum point that represents the most efficient presuppression level. This analysis provides a formal and objective process to evaluate the economic efficiency of wildfire protection programs and represents a decision support tool for fire managers.

Rideout and Omi (1990) reformulated the C + NVC model, to make it consistent with the economic theory of the firm. They define the fire management efficiency evaluation as a profit maximization instead of cost minimization problem. This reformulation would also better account for the potential benefits of forest fires.

Donovan and Rideout (2003) also revised the C + NVC model and pointed out that in the original C + NVC model (Mills and Bratten, 1982) suppression is incorrectly represented as an output, and that presuppression and suppression are considered as correlated variables. For example, the purchase of some fire fighting equipment before the fire season, does not define how frequently this equipment will be used during the season. Therefore, they proposed that suppression and presuppression expenditures should be considered as independent inputs, related through the Net Value Change (NVC) function (Fig. 4) (Donovan and Rideout, 2003).

They further argue that these errors "… have serious implications for the model's capacity to correctly identify the most efficient level of fire management expenditures (Donovan and Rideout, 2003: 318)." Therefore, the analysis may result in a C + NVC function without a global minimum, and even if a minimum is obtained, it may not coincide with the minimum of the unrestricted C + NVC function. To overcome this problem, they propose an integer programming[1] model to optimize resource allocation for wildfire containment (Donovan and Rideout, 2003). The reformulated C + NVC model is presented in Fig. 5.

To present graphically the relation of suppression, presuppression and NVC in two dimensions, one of the variables should be held constant (Donovan and Rideout, 2003). For example, given that presuppression expenditures are held constant at its optimal level, the most efficient program is achieved where the summation of costs and the net value change is minimized (i.e., PL* in Fig. 5).

The C + NVC model is a strategic model that helps to identify the optimal levels of presuppression, suppression and NVC, but it does not provide information on how these optimal budgets should be allocated (González-Cabán et al., 1986).

3. Review of fire management decision support systems

Fire management decision support systems are tools aimed at improving the efficiency of the allocation of resources for fire protection programs.

This section describes four models that address, in one way or another, the above mentioned requirements. The models considered are the Canadian LEOPARDS model, the Chilean KITRAL model, the SINAMI model that was developed for Spain and the US FPA model.

Other models in existence in the late 1990s and early 2000s like those of the US Department of Interior National Park Service, FIREPRO; US Department of Agriculture, Forest Service, NFMAS and ADFF, were not included because they are no longer used by the agencies. Nowadays, all federal agencies in the US with fire protection responsibilities are mandated to use FPA to plan their fire management programs needs. The Spanish model ARCAR41 being developed in the late 1990s was abandoned in favor of the SINAMI model discussed here. The Russian Federal Forest Service, St. Petersburg Forestry Research Institute developed their forest Fire Management Decision Support System back in 1995. However, this is not included in the discussion here because very little documentation is available on this system. A more recent system developed by Keramitsoglou et al. (2004) for forest fire crisis management for

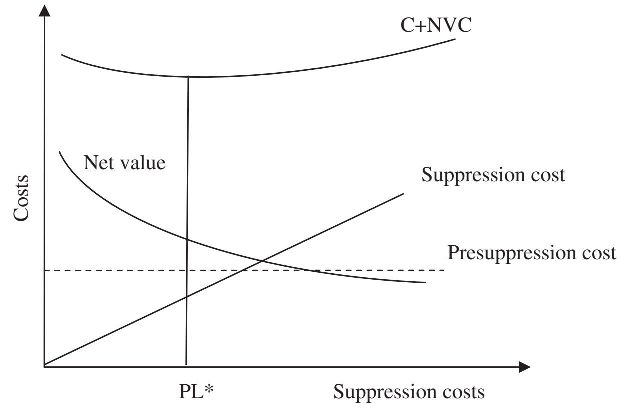

Fig. 5. Illustration of the improved C + NVC model as specified by Donovan and Rideout (2003).

[1] The Forest Service has pursued this possibility further in developing a new generation of fire management program economic analysis but has encountered serious problems in the process and abandoned this pursuit altogether choosing instead a goal programming approach devoid of any economic analysis as presented in the discussion of the FPA model.

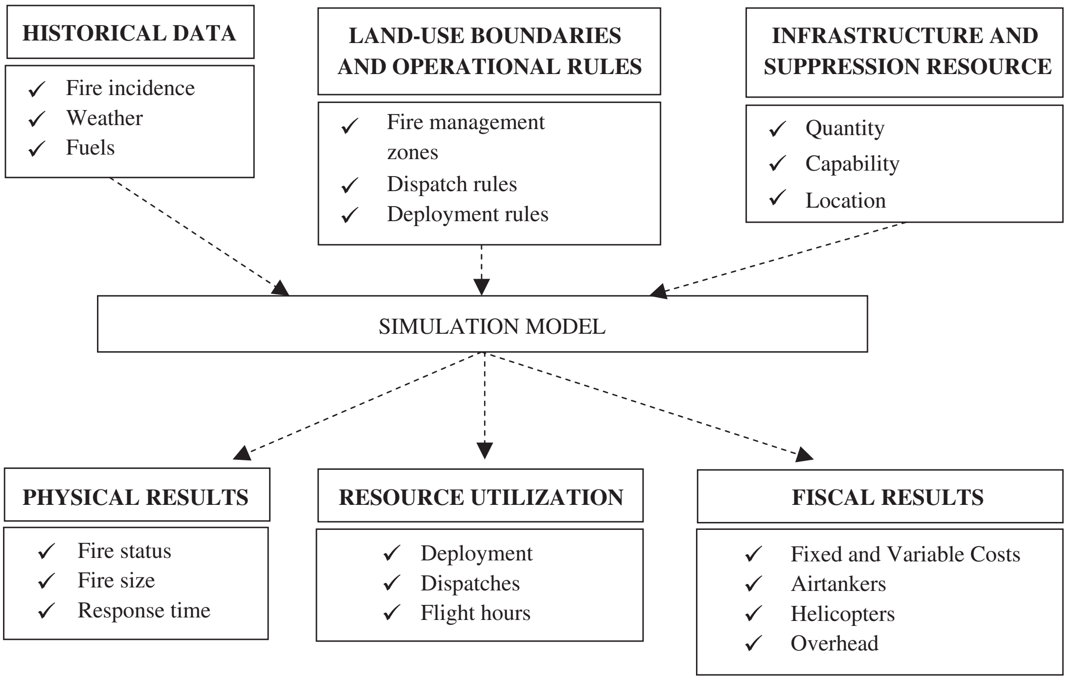

Fig. 6. The structure of the LEOPARDS model.
Adapted from (Mc Alpine and Hirsch, 1999).

Greece is not included either because it is not used for any economic analysis of potential fire management programs; and does not have any economic analysis capabilities. Finally, the state of California Department of Forestry and Fire Protection system FPPS/CFES is not presented because it operates under the same principles of the Spanish SINAMI model; and the latter is a more advance updated version.

3.1. The LEOPARDS model

3.1.1. Model description

The Level of Protection Analysis System (LEOPARDS) was developed for the province of Ontario (Canada) by the Ontario Forest Service in 1999. The aim of LEOPARDS is to support the strategic development of presuppression and suppression activities in the frame of the regional fire management planning. Information of a previous version of LEOPARDS can be found in (Martell et al., 1984).

The model addresses two main types of issues (Mc Alpine and Hirsch, 1999). First, it deals with evaluation of policy changes and resource allocation alternatives; like, costs and impacts of changes both on the protection levels and on the number and distribution of firefighting resources. Second, evaluation of alternative suppression resource uses to meet the defined policy and budgetary objectives.

Thus, LEOPARDS provides information about the use of firefighting resources among different fire management alternatives, and allows evaluation of their effectiveness (e.g., response time, area burned) and economic efficiency (i.e., presuppression and suppression costs).

The core of LEOPARDS is a deterministic initial attack simulation model (see Fig. 6) that emulates the daily fire suppression activities of a fire management agency.

As shown in Fig. 6, before a simulation run the model requires historical data related to fire occurrence, fire weather, and fuels. A second set of data requirements relates to fire management zones in the planning area, and dispatch and deployment rules to be used. Finally, the system requires information on the infrastructure and firefighting resources available, including quantity, capability, and location.

The historical database provides information on the locations of past fire events, the associated fire weather conditions and fuel type of the area.

Further, dispatch and deployment rules for firefighting resources allocation (dispatch) are selected for different fire behavior conditions. These predefined rules, were derived through focus groups with experienced dispatchers. The rules are based on four criteria: rate of fire spread, fire size, flame length, and fuel type.

Finally, to conduct a simulation the user has to specify the suppression policy and the setup of the suppression organization in terms of quantity, distribution and capacity of the firefighting resources (e.g., number of firefighters allocated to each base, their mode of transportation to the fire and type of airtankers employed).

3.1.2. Structure and simulation process

Based on the specified constraints, the model simulates daily resource deployments and initial attack activities for a region (province) over a selected period of years. For the simulation process past fire events are used, which are assumed to be representative of future forest fire situations.

Once all the historical information and dispatch and deployment rules are in place the simulation model is ready. The simulation process (see Fig. 7) starts at the beginning of a day with the generation of a firefighting resources deployment plan for a province. The plan includes ground crews and air resources deployment. A dynamic deployment database and an aircraft attributes file are used for this purpose.

After a fire is detected, the model begins tracking the fire propagation, based on the historical fire database. This event triggers the start of the initial attack simulation. The model dispatches resources according to the predefined dispatch rules and simulates the fire line construction and the fire growth. The initial attack simulation continues until the user defined conditions for fire containment are met (e.g., 80% of the fire perimeter is contained). If in the simulation process a fire is not contained by 10 a.m. of the following day, it is classified as escaped and the extended attack simulation begins. The model does not simulate suppression activities beyond the initial attack phase; however, it considers competing resource needs (e.g., multiple fire ignitions). For example, for 3 consecutive days after a fire is classified as escaped, the model enables the assignment of fire fighting resources to the fire event. These assigned resources are temporally subtracted from the total number of available firefighting resources.

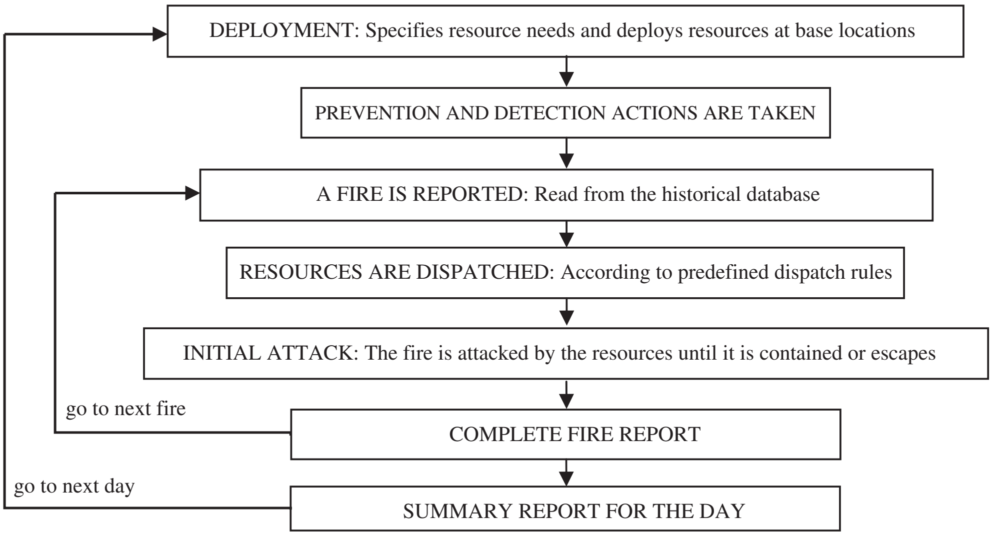

Fig. 7. The simulation procedure of the LEOPARDS model. Adapted from (Mc Alpine and Hirsch, 1999).

The simulation process is repeated for each day of a fire season and for all the fire seasons in the historical database (see Fig. 7).When the simulation process is completed summary reports, including total cost-plus-loss, and physical indicators are generated.

The total costs are the sum of costs for ground crews and air resources (helicopters and airtankers). In the case of air resources, the costs include both presuppression and suppression costs.

Physical indicators are, among others, fire severity, burned area, percentage of fires contained, average response time, and resource utilization (e.g., quantity of ground and air resources used, amount of flight hours).

These outputs are provided for each fire and day included in the historical database. Furthermore, additional software calculates the total costs and the average physical indicators for the planning period considered in the simulation process.

Because escaped fires are not simulated, statistical techniques are used to estimate their characteristics (e.g., area burned, severity).

The sensitivity of specific model variables can be tested by repeating the simulation process for alternative fire management scenarios. Fire management alternatives can be specified according to the number of available firefighting resources, number and distribution of fire fighting bases, and number of fires prevented. This allows the user to determine an optimum fire management setup in terms of dispatch policy and allocation of resources.

At present an improved version of LEOPARDS (Version 2) is being developed. The main improvements are related to the fire behavior simulator and the suppression deployment modeling.

3.1.3. Economic valuation

The economic efficiency analysis of fire management in LEOPARDS focuses exclusively on the estimation of presuppression and suppression costs. The model calculates the costs for each of the modeled management alternatives. For each alternative the fire management budget and resources allocated for presuppression activities can be defined. Rerunning the model, allows the user examine the impacts of change in budget and firefighting resource allocation on the total costs and area burned. By comparing these alternatives, the optimum amount and distribution of suppression resources in an area can be defined.

However, the model does not consider prevention costs and/or damage to goods and services (e.g., net value change) caused by the fire.

3.2. The KITRAL model

3.2.1. Model description

KITRAL is a Chilean model developed to improve of the efficiency of forest fire management countrywide. It was developed in 1996 by the University of Chile and the Chilean Forest Service.

The model enables two types of fire management analysis(Pedernera and Julio, 1999a), daily (real time) allocation of presuppression and suppression resources, and strategic planning of presuppression and suppression activities by evaluating different fire management alternatives.

Based on fuel models KITRAL simulates the fire behavior and determines the distribution and arrival times of the available resources. Based on the simulation process the model designs an optimal presuppression and suppression deployment of ground and air resources. In addition, KITRAL supports the strategic deployment of suppression resources by simulating future fires and evaluating how different suppression resources achieve the established fire management objectives.

3.2.2. Structure and simulation process

KITRAL consists of a number of independent modules (Fig. 8) that allow predicting fire behavior and allocating presuppression and suppression resources (Julio, 1998; Pedernera and Julio, 1999b).

The model is based on a geographical information system (GIS), which provides basic spatial information on topography, vegetation, accessibility, fuel models and distribution of suppression resources for a planning area.

The operational module supports the decision-making process for the allocation of firefighting resources to presuppression and suppression activities. The module is divided into a daily operational subsystem and a dispatch subsystem.

The Daily Subsystem optimizes the daily resource assignment for presuppression activities (ground and air resources), which is based on the calculation of the daily fire risk index, the coverage area and the arrival times of the available resources.

The dispatch subsystem optimizes the assignment of available suppression resources depending on the protection priorities in the area. Further, it provides an index of the number of fire-fighters per hour that should be allocated for suppression, which translate easily into the ground and air resources needed. Finally, the associated costs for the suppression activities are also estimated. This module, together with the fire simulator, is usually employed for tracking real time fires.

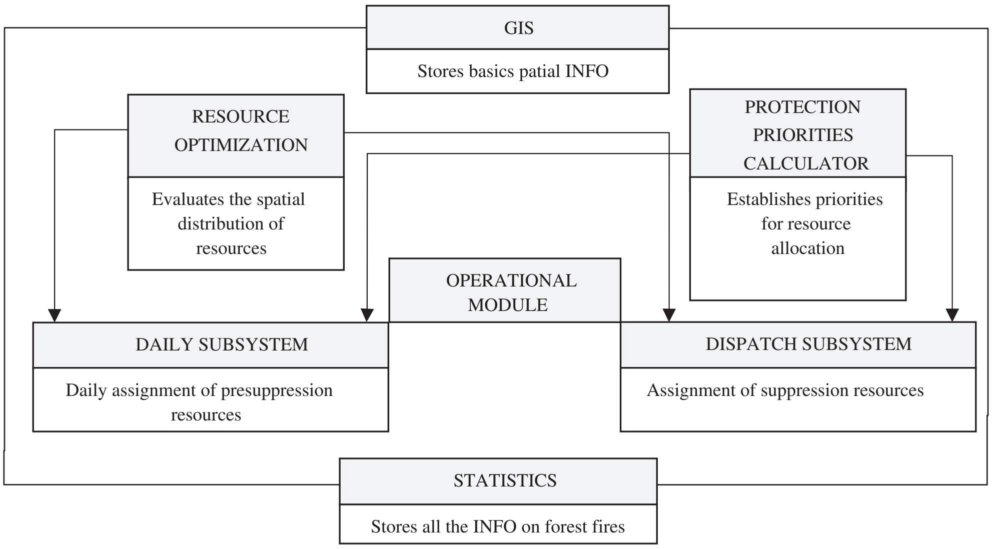

Fig. 8. The structure of the KITRAL model (own elaboration).

The risk index calculator estimates the daily fire risk index for the planning area considering five weather variables: temperature, relative humidity, wind speed, and drought and season indices. As explained above, this calculator is used to define priorities in the allocation of presuppression and suppression resources.

The protection priorities calculator establishes the priorities for presuppression and suppression activities by combining three indexes: fire risk, fire danger, and potential damage estimation. The planning area is divided into three protection priority categories for resource deployment: low, medium and high.

The fire spread simulator tracks fire propagation by providing information about its perimeter, area burned, expected fire behavior, estimated work load for fire containment, and evaluation of probable losses. The simulator is based on GIS fuel model database. This module enables simulation of real-time and hypothetical fires.

The resource optimization module supports the daily and the dispatch subsystems. This module evaluates the spatial distribution of the available firefighting resources and optimizes their assignment for presuppression, detection and suppression activities. The evaluation is based on the protection priority levels, and the efficiency standards and coverage provided by the available resources.

Finally, the statistics module stores all forest fires information of the fire season and provides the information for other modules.

KITRAL also allows the simulation of simultaneous fire events. Fire severity is used as the criterion for allocating fire fighting resources for competing needs. As discussed earlier, fire severity for each fire is determined according to the risk index, its location, the potential damage assessment and the protection priorities defined by the user.

In summary, the KITRAL model provides the following outputs:

- physical, fire-related information: risk index, burned area, fire perimeter, characteristics of the burned pixels, fire severity and a protection priorities map;
- optimal allocation of presuppression resources based on the user provided alternatives; and
- optimal allocation of the available suppression resources: work load expressed in amount of fire-fighters/hour and associated costs.

3.2.3. Economic valuation

KITRAL was developed as a decision support system with the goal of reducing presuppression and suppression expenses. Thus, the model calculates the total costs of employed presuppression and suppression resources, based on standard cost rates for each fire management input. However, it does not account for changes to the natural resources, the flow of goods and services, derived from them, or their economic values.

3.3. The SINAMI model

3.3.1. Model description

The fire economics evaluation system SINAMI is the first attempt by Spain to help agencies, with fire responsibilities, to perform an economic analysis of their budget requests for fire management and protection. Its main objective is evaluating the economic efficiency of forest fire protection programs for strategic fire planning purposes. SINAMI analyzes agencies' budget requests for fire management and protection, and determines the most efficient program and budget level for fire protection for a simulated fire season.

The SINAMI model was developed as a strategic decision support tool for fire managers. It should help them to identify both the potential benefits and economic consequences of alternative management options.

The model is based on the structure of the USDA National Fire Management System (NFMAS), expanded and adapted to Mediterranean conditions. The model uses a marginal analysis and the cost-plus-net-value-change (C+NVC) criterion to assess the most efficient program and budget level for fire protection.

The SINAMI model was designed to assess three key aspects of forest fire management(Molina et al., 2009):

i. The comparison of the efficiency and effectiveness of a fire management program and its possible alternatives.
ii. The estimation of the area burned and the number of fires by size and intensity for a fire season.
iii. The evaluation of the dispatch and protection response options for specific fire types.

The modular format of the model permits updating individual modules without affecting other modules (see Fig. 9). The system requires data for at least 10 years.

There are three input sources for the simulation model (see Fig. 10). First, the fire characterization module includes information on historic fire occurrence. The operational rules module provides with behavior data characteristics (e.g., fire line productivity) and organization of suppression resources, fire suppression procedures, information about existing fire progression barriers. Further, it incorporates information about procedures used in actual suppression activities, including real

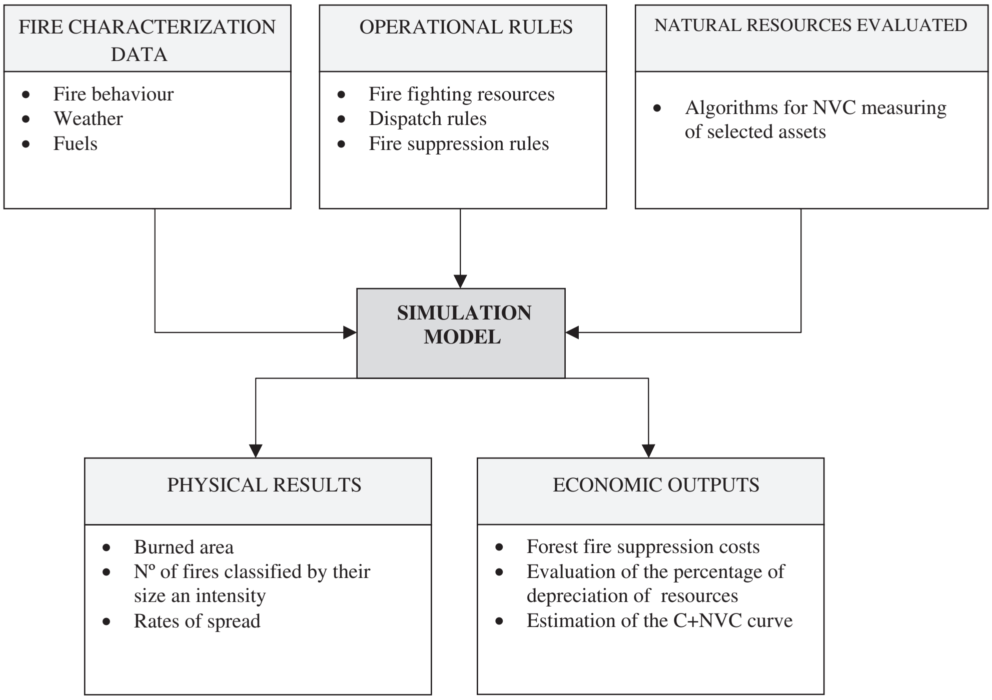

Fig. 9. The structure of the SINAMI model.

time effectiveness and fire suppression costs for the 2002 and 2003 fire seasons. Finally, to evaluate the net value change due to forest fires in the selected natural assets, a third module provides with the information about natural resources to be evaluated.

3.3.2. Structure and simulation process

Before applying the system this needs to be calibrated. The calibration process consists of running the model and making the necessary adjustments until the model results correctly represents the average historical information (fire management program, area burned, number of fires by intensity level, etc.) used for the model development for the proposed planning area.

After the model is calibrated, the simulation process starts with a random selection of a fire. Based on the fire characteristics, its location and the initial attack dispatch philosophy, the system automatically assigns suppression resources to the fire. Given the number of fire suppression resources assigned, the system calculates their combined fireline production capacity.

After the first initial attack dispatch, the system compares the combined fireline produced by all dispatched resources to the growth in fire perimeter of the simulated fire. If the growth rate in the fire perimeter is larger than the combined fireline construction rate of all resources, additional suppression resources are allocated. This comparison continues until one of three things happens: a) the fireline construction rate of all assigned suppression resources is larger than the growth in fire perimeter; at this point the fire is declared controlled, no more resources are assigned, and simulation for that fire stops; b) the simulated fire perimeter reaches the maximum size established in the model for a fire to be contained; or c) the fire simulation time is larger than that established in the model to simulate a fire. If the simulated fire reaches either condition b or c, the fire is declared an *escaped fire* and is kicked out of the system. For all escaped fires the system uses the historical escape fires table to assign their characteristics (size, suppression costs, behavior, etc.). For all contained or escaped fires the system calculates area burned, suppression costs, and net value change of the affected goods and services incorporated in the system.

The SINAMI model provides information on the fire occurrence and fire characterization (e.g., number of fires classified by intensity levels, their spread rate and area burned), data on dispatched resources and economic indicators (e.g., suppression costs, annual budget, economic damages). It also determines the most efficient program through the estimation of the C + NVC curve (see Figs. 3 and 5).

These outputs also allow conducting tradeoff analysis, for example, between increases or decreases in budget levels and potential impacts on suppression costs and net value change, as well as in the number of fires and total area burned; or potential losses.

3.3.3. Economic valuation

The SINAMI model incorporates the economic theory of marginal analysis, and the criterion for economic efficiency is the “cost + net value change” (C + NVC) of the resources affected (Mills and Bratten, 1982).

At this point the model considers the impact of wildfires only on the following natural resources: timber, forage, underbrush, fruits, water, fishing, fauna, recreation, hunting and landscape. The impacts are evaluated for each fire management analysis zone in the planning area. To evaluate those impacts five types of information are needed: a) identification and listing of the effects of fires on the resource; b) spatial identification of the effects; c) quantification of the effects and development of the appropriate economic measurement; d) determination of the resources' annual production without fires; and e) total production for the planning area without fires. A subprogram called ECONOSINAMI is used to calculate all the economic impacts.

Concerning the issue of lack of a global minimum, addressed in C + NVC model description section, it should be considered that the SINAMI model uses a marginal analysis to evaluate the effectiveness of different options, and not finding a global minimum does not invalidate the economic analysis. The arguments from Donovan and Rideout (2003) are concerned with the theoretical representation of the C + NVC function components, not with application of the C + NVC theory; we see no problems in the practical application of the model. They themselves still propose the use of the C + NVC economic theory to perform fire management programs efficiency analysis. While acknowledging the concerns in the graphical representation of the C + NVC components, SINAMI developers consider that application of their model is an improvement because it applies economic analysis to

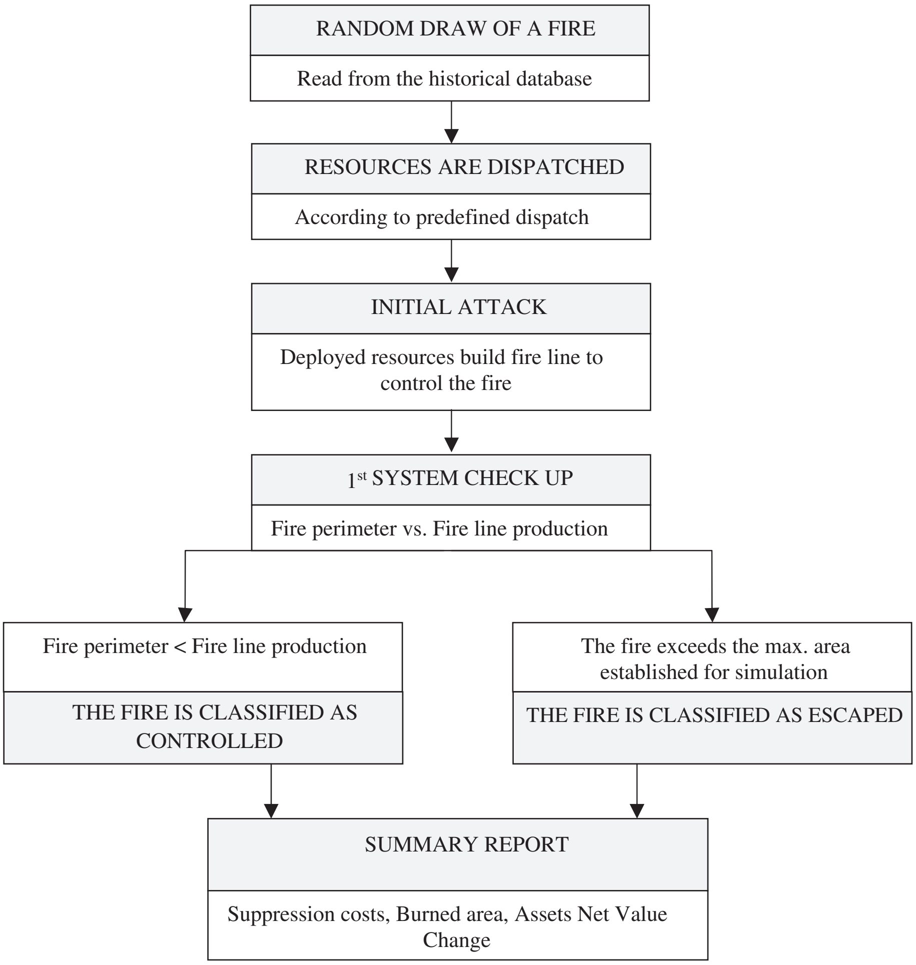

Fig. 10. The simulation procedure of the SINAMI model.

fire management and protection programs in the Mediterranean basin countries, where none is applied today. As a decision support tool for fire managers, the model would help them identify potential benefits of different fire management options and potential economic consequences, even if a global minimum could not be guaranteed.

3.4. Fire Program Analysis (FPA)

3.4.1. Model description

Prior to 1980, the five federal agencies responsible for wildland management separately developed fire management programs using different fire planning systems (Hubbard, 2001). To create a common interagency decision support tool the Fire Program Analysis (FPA) was developed by the USDA Forest Service and the four Department of Interior agencies with wildland fire management responsibility. Additional top-level goals include (FPA, 2010d):

- Support fire planning, informing both Fire Planning Unit (FPU) and National Level Management priorities.
- Support budget development and implementation.
- Identify the most efficient fire program according to effectiveness, efficiency and performance (EEP) measures.

FPA evaluates the effectiveness of alternative fire management strategies defined by local agencies for the area covered by each Fire Program Unit (FPU). The generated cost-efficient scenarios recognize the interactions among fire program components, such as the synergistic interactions of fuel treatments, wildland fire use, and suppression of wildland fires. The model's first stage purpose is to explore a wide range of management options at various budget levels.

The outputs from these calculations are evaluated under a national goal programming system and employed to assess national budget decisions on fire management.

3.4.2. Structure and simulation process

The FPA (FPA, 2010a, 2010b) is built on a simulation system that generates basic information on fire related topics and calculates performance measures for proposed investment alternatives. Investment alternatives describe varying strategies for achieving land management goals in a Fire Planning Unit (FPU). These investment alternatives are generated and described in terms of their:

- Preparedness options, comprising:
  - o Description of initial response organizations and fire resources (personnel, crews, helicopters). These are used to model their effect on initial response success.
  - o Fire prevention programs. These are used to model how increasing or decreasing prevention activities affect the number of human caused fires.
- Fuel treatment options. These describe on-the-ground fuel treatment projects and the changes in fuel conditions resulting from the treatments. These options are used to model their influence on initial response and large fire growth.

The FPU investment alternatives are modeled and tested for their ability to meet the performance measures and the associated costs. The modeled performance measures and costs for each alternative can be compared enabling the FPU planner to select combinations of investment alternatives that are likely to be the most cost efficient.

The selected alternatives are then analyzed at the national level in terms of effectiveness, efficiency and performance (EEP) indicators with specific decision support tools. The results of this analysis provide data to support fire planning, budget development and implementation at the national and FPU level (Fig. 11).

The FPA is a modular simulation system (Fig. 11) (FPA, 2010b, 2010c). After the user defines the investment alternatives, the simulator evaluates them. Detailed modeled simulations focus on the consequences of different resource distribution strategies within the FPU.

The Initial Response Simulator (IRS) is a strategic model that simulates a FPU's initial response to fires. The module tests how different combinations of the FPU's preparedness and fuel treatment options affect initial attack success. The simulation is based on fire behavior data. Initial attack resources under user-defined conditions are employed to simulate fire containment. This module enables fire planners to compare efficiency and probable cost of alternative initial attack organizations, prevention programs, and fuel treatments.

The Large Fire Module analyzes the impact of fuel treatments and preparedness resources on large fire behavior. Large fires are those fires that exceed the initial attack simulation limits. This module combines statistical analysis with fire simulations to calculate the probability of large fires for all the pixels in a FPU. The large fire probability calculation is based on repeated simulations of different possible fire seasons. The fire seasons differ with respect to fuels, weather, suppression, and applied treatments. The Large Fire Module enables fire planners to calculate performance measures for the investment alternatives.

The Initial Response Simulator (IRS) and Large Fire Module provide data on effects of treatment and suppression for each investment alternative. This data is used to evaluate the performance measures for the alternatives.

The Performance Measure Calculator processes output from the Initial Response Simulator and Large Fire Module to quantify how well the different investment alternatives meet the FPA performance measures. Following are the five FPA performance measures:

- Reducing the probability of occurrence of costly fires
- Reducing the probability of occurrence of costly fires within the Wildland Urban Interface (WUI)
- Increasing the proportion of area treated with fire risks reduction measures
- Protecting high value areas
- Maintaining a high initial attack success rate.

Further, based on modeled fire size a fire cost estimator provides probable costs. Alternatives that obtain the highest EEP scores at the local level are then submitted to the national level planners for trade-off analysis.

The National Trade-Off Analysis Module is used to analyze the effectiveness of proposed investment alternatives submitted by each Fire Planning Unit (FPU), to obtain a combination of alternatives that performs best at the national level. The National trade-off analysis module uses as input the five EEP measures and the modeled costs for each investment alternative from each FPU. Goal programming techniques are applied to obtain the following outputs:

- set of five national EEP measures
- total national cost for initial response organizations, prevention programs and fuels treatments.

The national analysis is used for the annual budget formulation process, and for the evaluation of the longer-term strategic decisions about fire program allocations.

Unlike the previous presented models, the approach taken by the FPA developers is to use a goal programming as a means of deciding the effectiveness of selected programs. At the beginning of the analysis process they set a goal or benchmark on a set of measures they would like to achieve and then design alternatives that would allow them to reach their goals. As best as we can tell the FPA model does not include any theoretical economic foundation in their system.

3.5. Comparison of the economic components of the presented models

The four presented models assess, to some extent, the economic performance of different management alternatives. The review shows that regardless the improvements of the theoretical economic model, these advances are still not fully implemented in practice. In particular, the net value change component of the C + NVC model is rarely incorporated. Such approach is somehow understandable considering that a consistent estimation of the loss of goods and services is still a major challenge.

The KITRAL and LEOPARDS models consider presuppression and suppression costs, while they do not account for potential damages to goods and services caused by the fire.

The FPA model, departs from the C + NVC theoretical framework and sets as fixed the economic variables (pre-suppression and suppression costs) and applies a goal programming procedure instead.

The SINAMI model represents the most complete attempt in incorporating the components of the C + NVC model. It considers presuppression and suppression costs as well as the net value change of an array of affected goods. It should be considered that even if the model includes only a limited number of goods and services, its development was a very demanding and time consuming process, which required years of estimation and calibration procedures (Rodriguez y Silva and González-Caban, 2010).

To sum up, launching more complete decision support systems is a complex and time consuming process, because of the scarcity of empirical evidence about:

- the impacts of forest fires on the spatial and temporal provision of goods and services (e.g., how the quality and quantity of a good or service is affected and for how long);
- the potential effect of the changes caused by forest fires on society's wellbeing (e.g., what is the value of the losses);

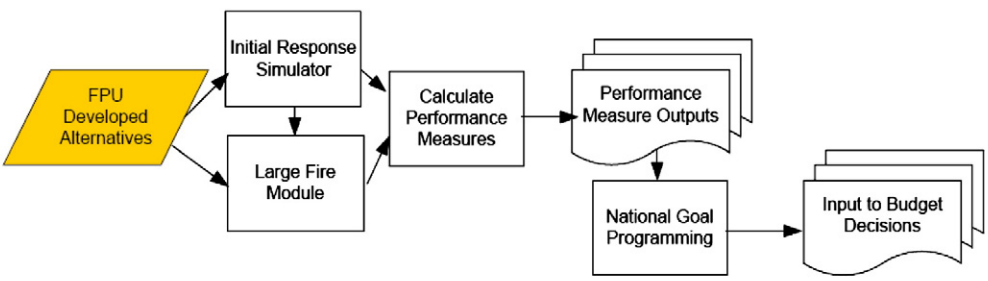

Fig. 11. The structure of the FPA model.
(Adapted from FPA briefing paper, 2008).

- the impact of fire management measures on risk, extent and severity of forest fires (e.g., quantify the effects of different management measures).

4. Conclusions

All decision support models reviewed here use information on fuel behavior, weather conditions and suppression resource deployment as fundamental components of their analysis. However, few of the models evaluated provide an economic theoretical approach to perform an economic analysis of fire management programs investment. Of those presented here only the SINAMI model, based on the C + NVC economic theory, can be considered as capable of helping managers perform an economic analysis of their investments in fire management programs. This is partly because of its ability to include the economic impacts of fires in the stream of goods and services derived from forest lands.

Nevertheless, lack of an economic analysis capability does not negate the usefulness of decision support models in helping managers improve their decision making abilities. The model's utility will depend and be measured against the objective for which the model was developed. As discussed here the objectives and rationale for each of the models drive their applicability to different situations.

Because of their simplifying assumptions most of the models, mainly limit their applicability to the optimization of management efforts within a given framework (e.g., established ratio between prevention and suppression expenditures or established budged restrictions), but in general they do not serve to set-up such a framework or to help make decisions about the adequate allocation between competing management measures. This is mainly because of lacking knowledge about the impacts of different fire management measures on fire behavior and the resulting damages, and economic impacts, including market and nonmarket goods and services. Despite the increasing number of studies being conducted on the potential impact of fuel treatments on reducing the area burned or wildfire risk, no conclusive evidence has been found (Ager et al., 2010; Finney, 2005; Martinson and Omi, 2006; Raymond and Peterson, 2005).

Finally, it is important to recognize that no DSS is a substitute for a decision maker. A DSS only quantifies some of the factors, which are relevant to fire management program planning and helps trace the interaction of relationships that are too complex and numerous for a person to easily follow. However, a decision maker must still weigh and assimilate a large number of relevant factors, many of which cannot be measured in common units or even be measured quantitatively at all, and must place fire programs within the context of other management programs and institutional constraints.

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