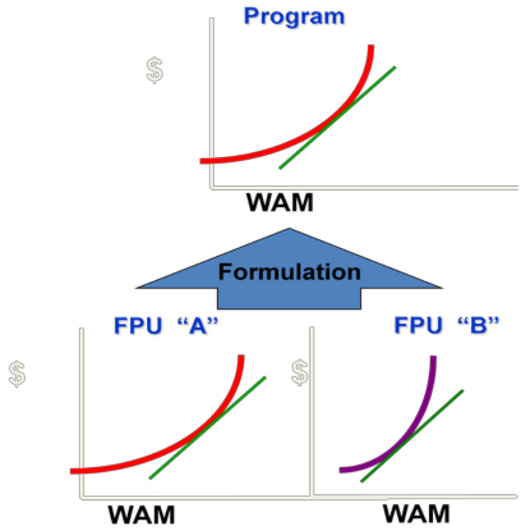
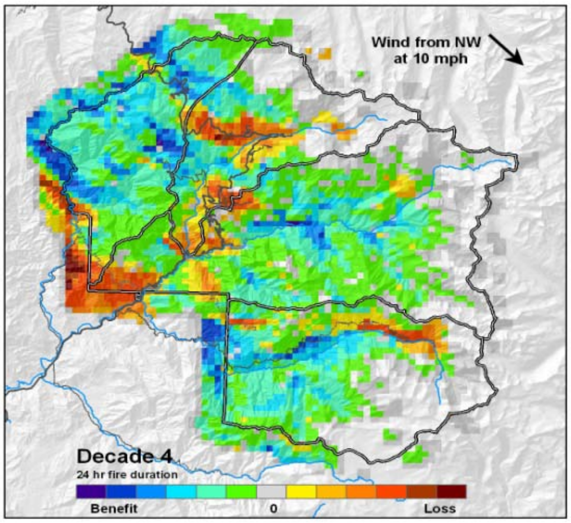
Final Report

NPS Contract number:

H1200040002 CSU-107 CSU-98





Fire Economics & Management Laboratory
Department of Forest, Range and Watershed Stewardship
Colorado State University, Fort Collins, CO 80523

December 30, 2008

Jeff Manley
Deputy, Fire Program Planning
National Park Service
U.S. Department of the Interior
U.S. National Interagency Fire Center
Boise, Idaho 83705

Jeff:

This is intended to serve as a final report for NPS Contract number: H1200040002 CSU-107 CSU-98.

This contract covered a time of major transition in the Fire Program Analysis (FPA) system as reflected by the materials in this report. These materials begin with the documentation of key developments related to Phase One and end with documentation of contributions to the Science Team efforts, including a set of concerns regarding the approach suggested by the Science Team.

Documents 2 through 5 contain publications or manuscripts documenting key advances designed for FPA including a theoretic foundation intended for Phase Two.

> **Doc. 2** is a description and reference for a manuscript outlining the probabilistic approach to fire program planning. As a consequence of recognizing the inherent limitations and expenses of simulating individual fire events (that would never occur) for strategic planning purposes, we set out to develop a better and more cost-effective approach to fire management planning. This approach, known as a probabilistic model, or as the "Unified" model, uses fire probability surfaces to express the impact of fire on the landscape. The strength of the unified model is that it integrates all of the fire program components into a single expression of impact without relying on event-based simulations. Importantly, this model is scaleable from the sub-planning unit, to the planning unit and to the national level. The referenced document has been peer reviewed and published in a recent book on disturbance economics. This theory provided the foundation for the fuels optimization work under tab four and for the development of the AMR management model known as STARFire.
>
> **Doc. 3** contains the abstract and reference for the valuation manuscript that was published in the Journal of Forest Policy and Economics. The manuscript has three key parts: the

foundation in economic theory, the theory of the new valuation system and its relationship to net value change, and the relationships to other valuation systems in environmental economics.

Doc. 4 contains the abstract and reference for the manuscript of the fuels optimization model developed for FPA Phase Two. This was requested by Steve Botti. This model of fuels treatment allocation across a landscape is a particular application of the unified model (document 2, above). It is the first fuels allocation model that does not rely on the assumption of a known fire event and an adaptation of it has become part of the STARFire model.

Doc. 5 documents the current status of the academic version of the FPA-PM model with particular attention to multiple fire events and to the issue of initial attack success rate. As a consequence of the "Science Review" of FPA-PM, we tested alternative objective functions to assess the role of the objective function in initial attack success rate. This manuscript is still in progress.

Doc. 6 contains a paper that directly responds to the findings of the science review (section four) regarding the objective function used in FPA-PM and initial attack success rate. This paper is closely related to the paper under tab five. This paper tests the objective function used in FPA-PM relative to the criticisms, statements and implications regarding the objective function and initial attack success rate. The paper concludes that the findings and the statements of the science review on this topic were largely inappropriate or incorrect.

Doc. 7 contains a PowerPoint file presented at the FPA symposium on the emerging new paradigm of land management as a context for fire management and policy.

Doc. 8 contains an abstract and reference for a manuscript on fire use workload estimation that will be published in the Western Journal of Applied Forestry in 2009.

Documents 9 through 12 address the Science Team approach to FPA Phase Two.

Doc. 9 contains the national tradeoff analysis paper submitted to the science team for its paper on Phase Two. This paper includes the goal programming approach to budgeting the set of annual fire plans that would be forwarded by all of the planning units. It also shows in a tabular form some basics of goal programming.

Doc. 10 contains the paper on the probabilistic approach to fire program analysis consistent with the unified theory addressed above in tab three. This paper is a more pragmatic depiction of the probabilistic approach than the book chapter under tab three. This approach was dismissed by Tom Quigley in our meetings because he incorrectly associated it with optimization.

Doc. 11 contains the material on cost considerations prepared by myself and John Sessions for the Science Team paper. This paper addresses cost issues such as joint costs, prototype modeling and the costs of large fires.

> **Doc. 12** contains a short paper on costs, values and cost effectiveness analysis that would be associated with the Science Team proposal for development of FPA Phase II. This paper was forwarded to the leadership of the DOI to inform and warn them of serious issues emerging with the direction FPA.

Doc. 13 contains a paper produced by the Society of Environmental Toxicology and Chemistry North America in cooperation with the US EPA on an approach to FPA Phase Two. The paper is contained here because I was an active participant in the paper and in the deliberations that played a role in guiding the construction of this paper. The paper contains relevant findings and the outline of a conceptual approach to FPA Phase Two that is distinguished from those of the Science Team. This paper was produced by a science team addressing the same problem as the FPA science team. Their findings and approach to the problem differ in important ways. Two teams of scientists have addressed the FPA Phase Two problem and arrived at different conclusions.

The Fire Program Analysis project has charted a different direction than envisioned by its founders. Nevertheless, key advances in fire program management were produced and many are reflected in this report.

Sincerely yours,

Douglas B. Rideout
Professor

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(Final Report to FPA Phase II)

Document 2

Unified Theory

Book Chapter

Title: Toward a Unified Economic Theory of Fire Program Analysis with Strategies for Empirical Modeling (Chapter 18)
Authors: Douglas B. Rideout, Yu Wei, Andrew G. Kirsch, and Stephen J. Botti
Book: The Economics of Forest Disturbance, 2008

Description

This document is a description and reference for a book chapter outlining the probabilistic approach to fire program planning. As a consequence of recognizing the inherent limitations and expenses of simulating individual fire events (that would never occur) for strategic planning purposes, we set out to develop a better and more cost-effective approach to fire management planning. This approach, known as a probabilistic model, or as the "Unified" model, uses fire probability surfaces to express the impact of fire on the landscape. The strength of the unified model is that it integrates all of the fire program components into a single expression of impact without relying on event-based simulations. Importantly, this model is scaleable from the sub-planning unit, to the planning unit and to the national level. The referenced document has been peer reviewed and published in a recent book on disturbance economics. This theory provided the foundation for the fuels optimization work under tab four and for the development of the AMR management model known as STARFire.

Reference

Rideout, D.B., Y. Wei, A.G. Kirsch, and S.J. Botti. 2008. Toward a Unified Economic Theory of Fire Program Analysis with Strategies for Empirical Modeling. P. 361-380 in The Economics of Forest Disturbance - Wildfires, Storms, and Invasive Species, Holmes, T.P., J.P. Prestemon, and K.L. Abt (eds.). Springer Science.

Document 3

Valuation Manuscript (MARS)

Journal Article

Title: Estimating rates of substitution for protecting values at risk for initial attack planning and budgeting
Authors: Douglas Rideout, Pamela Ziesler, Robert Kling, John Loomis, and Stephen Botti
Journal: Forest Policy and Economics, Volume 10, 2008

Description

This page contains the abstract and reference for the valuation manuscript that was published in the Journal of Forest Policy and Economics. The manuscript has three key parts: the foundation in economic theory, the theory of the new valuation system and its relationship to net value change, and the relationships to other valuation systems in environmental economics.

Abstract

With changes in land management planning and a new federal fire policy, increased emphasis has been placed on protecting a broader set of resource values such as those associated with sensitive species habitat or cultural resources. Fire managers have long needed a system for assessing values at risk across the landscape that can be implemented in accordance with the budgeting and appropriation process and that can be updated annually or every several years. A viable system has to be operational at a reasonable cost and it must support strategic planning and budgeting. Currently available valuation methods, in their entirety, can be costly and time consuming making them problematic for these purposes. Consequently, managers have become accustomed to assessing values at risk without the direct support of structured economic analysis. This paper discusses an approach (Marginal Attribute Rate of Substitution) to assessing values at risk for initial attack planning and budgeting. MARS is an attribute based method for estimating rates of substitution among fire protection attributes in a spatial context. It consists of and builds upon specific elements from well known and peer-reviewed valuation methods for resource valuation. As such, MARS relies upon stated preference, expert opinion, the hedonic price equation and other familiar procedures. The paper concludes with an empirical example of the application of MARS to a forested area in California. As the first construction of this approach it has the potential for further modification and refinement for those that may find it of interest.

Reference

Rideout, D.B., P.S. Ziesler, R. Kling, J.B. Loomis, and S.J. Botti. 2008. Estimating rates of substitution for protecting values at risk for initial attack planning and budgeting. Forest Policy and Economics 10:205-219.

Document 4

Optimizing Fuels Treatment

Journal Article

Title: An optimization model for locating fuel treatments across a landscape to reduce expected fire losses
Authors: Yu Wei, Douglas Rideout, and Andrew Kirsch
Journal: Canadian Journal of Forest Research, Volume 38, 2008

Description

This section contains an abstract and reference for the manuscript of the fuels optimization model developed for FPA Phase Two. This was requested by Steve Botti. This model of fuels treatment allocation across a landscape is a particular application of the unified model (document 2, above). It is the first fuels allocation model that does not rely on the assumption of a known fire event and an adaptation of it has become part of the STARFire model.

Abstract

Locating fuel treatments with scarce resources is an important consideration in landscape-level fuel management. This paper developed a mixed integer programming (MIP) model for allocating fuel treatments across a landscape based on spatial information for fire ignition risk, conditional probabilities of fire spread between raster cells, fire intensity levels, and values at risk. The fire ignition risk in each raster cell is defined as the probability of fire burning in a cell because of the ignition within that cell. The conditional probability that fire would spread between adjacent cells A and B is defined as the probability of a fire spreading into cell B after burning in cell A. This model locates fuel treatments by using a fire risk distribution map calculated through fire simulation models. Fire risk is assumed to accumulate across a landscape following major wind directions and the MIP model locates fuel treatments to efficiently break this pattern of fire risk accumulation. Fuel treatment resources are scarce and such scarcity is introduced through a budget constraint. A test case is designed based on a portion of the landscape (15,552 ha) within the Southern Sierra fire planning unit to demonstrate the data requirements, solution process, and model results. Fuel treatment schedules, based upon single and dual wind directions, are compared.

Reference

Wei, Y., D. Rideout, and A. Kirsch. 2008. An optimization model for locating fuel treatments across a landscape to reduce expected fire losses. Canadian Journal of Forest Research 38:868-877.

Document 5

Initial Attack Optimization

Report

Title: Allocating the Initial Attack Resources to Multiple Wildfire Events with the Consideration of Fire Escapes
Authors: Douglas B. Rideout, Yu Wei, Andrew G. Kirsch
Date: November 13, 2006

Description

This report documents the current status of the academic version of the FPA-PM model with particular attention to multiple fire events and to the issue of initial attack success rate. As a consequence of the "Science Review" of FPA-PM, we tested alternative objective functions to assess the role of the objective function in initial attack success rate. This manuscript is still in progress.

Abstract

Increased scrutiny of federally funded programs combined with changes in fire management has created a demand for new fire program analysis tools. We formulated an integer linear programming (ILP) based initial suppression resources allocation model that operates in a performance based, cost-effectiveness analysis (CEA) environment. The model optimizes the initial suppression resources deployment for a user-defined set of fires that a manager would like to be prepared for across alternative budget levels. The model incorporated potential simultaneous ignitions in a landscape. Based on this model, we analyzed alternative objective functions that incorporate a proxy for the cost of fires that escape initial attack. This type of model can provide the basis for a wider scale formulation with the potential to measure an organization's performance and promote a higher level of accountability and efficiency in fire programs.

Title: Allocating the Initial Attack Resources to Multiple Wildfires Events with the Consideration of Fire Escapes

Authors: Douglas B. Rideout [1], Yu Wei [2], Andrew G. Kirsch [3]

November 13, 2006

Version 1.5

[1] and [2]: Professor and Assistant Professor in the Department of FRWS, Colorado State University, Fort Collins, CO 80526

[3]: Program Analyst, Fire Program Analysis (FPA) system, NIFC -Boise, ID and

Acknowledgements: The authors thank Steve Botti of the National Park Service for supporting this work and for helpful comments.

ABSTRACT

Increased scrutiny of federally funded programs combined with changes in fire management has created a demand for new fire program analysis tools. We formulated an integer linear programming (ILP) based initial suppression resources allocation model that operates in a performance based, cost-effectiveness analysis (CEA) environment. The model optimizes the initial suppression resources deployment for a user-defined set of fires that a manager would like to be prepared for across alternative budget levels. The model incorporated potential simultaneous ignitions in a landscape. Based on this model, we analyzed alternative objective functions that incorporate a proxy for the cost of fires that escape initial attack. This type of models can provide the basis for a wider scale formulation with the potential to measure an organization's performance and promote a higher level of accountability and efficiency in fire programs.

Keywords: mixed integer programming, initial attack, suppression, performance,, fire escape, wildland fire.

Introduction

In the United States, all five[1] major federal land management agencies conduct extensive planning and budgeting analysis to prepare for the upcoming fire season(s). Historically, these agencies have used an array of analytical models and approaches to prepare the annual budget and its allocation to the planning units responsible for wildland fire protection. In 2002, these agencies embarked on the development of a new fire planning system known as Fire Planning

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[1] These include the USDA Forest Service, and in the U.S. Department of Interior, the National Park Service, the Bureau of Land Management, the Fish and Wildlife Service and the Bureau of Indian Affairs.

Analysis (FPA). This included the direction to replace current preparedness[2] models with a new single interagency system based on the tenants of performance based planning and budgeting (Rideout and Botti 2002). The central part of preparedness is the preparation for initial attack activities and initial attack planning models.

Wildland fire organizations customarily divide the fire suppression problem into stages of management. US federal land managers organize the suppression of unwanted fires into the three stages of initial attack (IA), extended attack (EA) and large fire management. Compartmentalizing the problem allows organizations to focus on the functioning and funding of different levels of fire management. While there are many potential approaches to addressing the planning issues for initial attack preparedness, we illustrate a performance-based optimization formulation that includes three important features: 1. use of an integer linear program (ILP) to include a functional relationship between cost and performance as illustrated in Figure 1, 2. multiple fires are included with the potential of simultaneous ignitions, and 3, the cost of escaped fires is approximated. The prototype ILP presented here was used as a basis for the commercial development of the first phase of the FPA interagency preparedness program (Parija and Booher 2004).

The wildland fire management literature includes several methods focused on optimization and simulation to address various parts of the wildland fire preparedness programs. For example, Parks (1964) designed a deterministic model to minimize the cost of suppression plus damages to find an optimal constant workforce. Parlar and Vickson (1982) and Parlar (1983) extended the Parks model using optimal control theory. Aneja and Parlar (1984) also

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[2] The National Wildfire Coordinating Group (NWCG) defines preparedness as "activities that lead to a safe, efficient and cost effective fire management program in support of land and resource management objectives through appropriate planning and coordination." (NWCG terminology adopted 06/12/97) http://www.nwcg.gov/nwcg_admin/terminol.htm.

extended Parks' model using nonlinear programming to estimate optimal staffing of a fire fighting organization by minimizing the cost plus loss per unit time. Boychuk and Martell (1988) evaluated seasonal forest fire fighter requirements with Markov chains utilizing the least cost plus loss framework. Donovan and Rideout (2003) used an ILP to optimize a firefighting resource allocation to a single fire using a cost plus net value change framework. This formulation was used, in part, to evaluate the conceptual feasibility of ILP for addressing optimal deployment decisions.

Simulation models used in preparedness planning include models such as the Fire Economics Evaluation System (FEES) (Mills and Bratten 1982), the National Fire Management Analysis System (NFMAS) (USDA Forest Service 1985), the California Fire Economics Simulator 2 (CFES2) (Gilless and Fried 1998), Level of Protection Analysis (LEOPARDS) (McAlpine and Hirsch 1999), and Wildfire Initial Response Analysis System (WIRAS) (Wiitala and Wilson 2004). These models have important strengths in their ability to simulate the effects of a particular set of firefighting resources and some have been used help managers evaluate initial response problems.

While simulation modeling has been fruitful especially in shown effects of a given set of resources, optimization approaches enable focus on strategic elements of the initial attack problem such as on identifying the optimal set of fire fighting resources. For example, identifying the optimal resource set would require a very large number of simulations such that a manager or modeler would be unlikely to test enough choices to identify the optimal set. While simulation models show certain effects of a particular organization, including its cost, they have been unable to use the resource cost information to directly inform the choice of resources. In contrast, optimization enables us to directly use the cost of deployment and the cost of escaped fires in the modeling decisions affecting the resource allocation problem. Both of these cost considerations are of interest and they are illustrated in the prototype formulation of an ILP shown here that is intended to address the optimal resource set.

Our approach is illustrated with a demonstrative example of how an ILP model can be used to identify and optimize the dispatch of initial response resources in a performance based or cost-effectiveness analysis (CEA) framework. The model uses resource costs and an expected set of fires among other inputs to identify the optimal set of preparedness resources, which fires should be fought, how aggressively fires should be fought and how resource allocations, including the list of available resources, would change across the range of budget appropriations. Because fires that escape initial attack can be costly, we address alternative means of including a proxy for the cost of initial attack escapes in this the ILP formulation. We also demonstrate an approach to modeling simultaneous ignitions and optimal dispatch location. The remainder of the paper is structured as follows: in the next section we present a description and a mathematical formulation of the ILP and this is followed by a demonstrative numerical example to illustrate the capabilities and relationships of the model. The last section provides conclusions and remarks on the limitations and potential extensions of the formulation.

A PERFRORMANC-BASED FIRE PREPAREDNESS ILP

We make the customary assertion of minimizing damage for a given level of expenditure consistent with the least cost plus loss expressions (Rideout and Omi 2001). To compare the effectiveness of alternative initial attack organizations, we assert that funds would be expended to minimize expected damage from unwanted wildland fires. We also recognize that with scarce resources, not all fires are of equal importance to contain because not all resources that could be damaged by fire are of equal consequence. For example typically wildland fires that occur in the wildland urban interface that threaten life and property are of greater importance to aggressively manage than are fires occurring in remote areas such as wilderness. Because acres differ in their importance to protect from wildfire, our formulation provides the ability to proportionally weight acres that might be differentially affected by damaging wildfire. The calculation of loss for a given budget level involves multiplying the area burned from each fire by it's per acre weight to calculate the per acre loss. Figure 1 shows a theoretical CEA frontier for expected loss where all points on the interior of the frontier (southwest) are feasible and they are technically inferior to points that comprise the frontier. The ILP allows us to focus on points that would define the frontier as opposed to interior (inferior) points.

When preparing for a wildfire season, managers know certain details with a high degree of certainty. For example, through the use of geographical information systems, managers can accurately map locations, conditions, and types of fuels that can be used to describe fire activity across the planning unit. Managers can estimate the fires that they may encounter using prediction and forecasting models (Bradley et al. 2000, Prestemon et al. 2002, Westerling et al. 2002, Miller et al. 2003). The data gathered portraying current and future landscape conditions, combined with historical data and causal information can paint a picture of a future fire season. It seems too certain to me. Thus, predictive tools can be used to develop a specific deterministic fire scenario(s) for which a manager would like to be prepared. This set of fires is provided as input to the model and each fire is defined by an initial reporting size and its change in perimeter and area by time period. Perimeter is directly related to cost through resource production rates and the affected area is directly related to performance through expected loss. Other fire behavior characteristics such as flame length and fire intensity can be reflected in the firefighting resources' ability to build fireline. This allows managers to incorporate tactical firefighting standards, such as a fire with flame lengths of four to eight feet can be too intense for a direct attack with hand tools, but bulldozers, engines, and aerial drops can be effective (BLM Standards Ch. 9, 2003). We use the free burning fire containment rule from previous deployment models (for example, USDA Forest Service 1991; Donovan and Rideout 2003) stating that a fire is contained when the total fireline produced by firefighting resources overtakes the fire perimeter. A fire is defined as having escaped if it is not contained during the initial attack period due to a lack of funds to apply to fire fighting resources or lack of sufficient fireline production capability. Constraining the model to manage fires and resources within a fixed budget, is unusual, if not novel in initial attack planning. For example, previous models such as NFMAS and CFES2 simulate preparedness responses across a simulated season by specifying the cost of the seasonal organization prior to simulation and by estimating the cost of deployment as an outcome. In contrast, by operating the integer linear program under a strict budget constraint, it can directly solves for the set of resources to employ during the season, the model solves for loss minimizing deployment as it is required to analyze allocation decisions, including fire management decisions without violating the specified budget. The model is therefore required to make "tough" decisions regarding which fires to fight and how aggressively to fight each one within the budget. By performing sensitivity analysis on budget, the model provides information on resource allocations and fire management by budget level. While this may appear to be similar to the simulation models, because of the way that costs are managed as an input, it is intended to provide an alternative perspective on resource and fire allocation and management.

By minimizing expected loss at a given level of funding, the model allocates scarce firefighting resources to acres that are the most important to protect within a cost constraint. In this way, the model identifies which fires are most important to fight, how aggressively to fight them, and weighs the advantages and disadvantages of escape versus containment. Because some fires are more important to contain than others, it is possible to generate a lower level of resource loss by increasing the number of escaped fires as a localized response and this is illustrated in our example.

Both deterministic and stochastic models are widely used in problems involving the planning for future events. We chose a deterministic formulation for initial prototype development to focus on the key relationships in the formulation and results that optimization can provide. Stochastic elements can be added to subsequent developments as appropriate, but for simplicity of the prototype, we used a deterministic formulation.

The model requires a list of potential firefighting resources that can be allocated to a set of candidate dispatch locations to minimize loss. This list of firefighting resources can, in principle, include all of the resources potentially affected by a planning unit's budget. The model can also help managers test the viability of acquiring new resources by including some that are not currently on the planning unit. Each firefighting resource is defined by a fireline production rate and by its fixed and variable cost. Fireline production is modeled by a cumulative[3] value that is input for each time step of each fire. An advantage of the discrete time step is that the production function does not have to be constant or linear. Thus, production rates

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[3] A cumulative or marginal approach would provide equivalent results.

can reflect fatigue and other disruptions in the production such as water and fuel refills. Arrival times and travel delays, determined by moving each resource from a dispatch point to the actual location of each fire, can also be reflected in these production values by inputting zero chains of fireline production during travel periods. Because fireline production is input by resource and by fire, deployment restrictions, such as resources restricted in wilderness areas can be reflected by inputting zero chains of production for resources on fires that burn in the wilderness areas. The model then uses the production information along with other factors to solve for the optimal deployment.

The costs of initial response resources and of escapes can be important considerations in preparedness modeling. This ILP inputs two types of costs that directly impact optimal deployment: a fixed cost and a variable cost as developed by Donovan and Rideout 2003. The fixed cost is modeled as a one-time charge that is incurred if the resource is deployed to any fire during the season. Each resource's variable cost is modeled as an hourly cost that reflects its operating expenses on each fire, including maintenance, fuel, regular hourly wages, overtime and hazard pay. The cost of escapes is addressed under a separate heading.

Including simultaneous ignitions in the optimization model adds depth and advancement to the analysis. To model simultaneous ignitions we force each resource to choose at most one of the simultaneous ignitions to attack. We assume that resources will not be redeployed to other simultaneous ignitions once containment is achieved. Further, we deploy a monitoring resource to escaped fires to reflect the concept that every fire, contained or not, will receive some monitoring efforts during initial attack.

Mathematical formulation

Minimize Loss

$$Loss = \sum_{i=1}^{I} \sum_{d=1}^{D_e} (W_{id} * f_{id} * A_{id}) \tag{1}$$

Subject to:

$$\sum_{k \in K_r} u_{rk} \le 1 \qquad \forall r \tag{2}$$

$$\sum_{d=1}^{D_e} x_{irkd} \le u_{rk} \qquad \forall i, r, k \tag{3}$$

$$\sum_{d=1}^{D_e} f_{id} = 1 \qquad \forall i \tag{4}$$

$$\sum_{r=1}^{R} \sum_{k \in K_r} \sum_{d=1}^{D} (x_{irkd} * L_{irkd}) \ge \sum_{d=1}^{D} f_{id} * P_{id} \qquad \forall i \tag{5}$$

$$\sum_{d=1}^{D} d * f_{id} \ge \sum_{d=1}^{D} d * x_{irkd} \qquad \forall i, r, k \tag{6}$$

$$\sum_{i=1}^{I} \sum_{r=1}^{R} \sum_{k \in K_r} \sum_{d=1}^{D_e} \left(x_{irkd} * H_{rd} \right) + \sum_{r=1}^{R} \sum_{k \in K_r} \left(u_{rk} * F_{rk} \right) \le B \tag{7}$$

$$\sum_{i \in S_n} \sum_{d=1}^{D_e} x_{irkd} \le u_{rk} \quad \forall n, r, k \tag{8}$$

$$\sum_{r=1}^{R} \sum_{k \in K_r} x_{irkD_e} \ge f_{iD_e} \qquad \forall i \tag{9}$$

I = set of all fires indexed by i.

R = set of all firefighting resources indexed by r.

$\mathbf{K_r}$= set of all potential dispatch points for resource r indexed by k.

$\mathbf{S_n}$= the nth set of simultaneous ignitions. $S_n \subseteq I$.

D = resource and contained fire duration indexed by d.

$\mathbf{D_e}$ = period at which fire escapes. D_e is defined as D+1.

Decision Variables

x_{irkd}: Binary variable, x_{irkd}=1 if resource (r) allocated at dispatch point (k) is deployed for a duration of (d) time periods on fire (i), otherwise x_{irkd}= 0.

f_{id}: Binary variable, f_{id} = 1 if fire (i) burns for a duration of (d) time periods, otherwise f_{id}=0.

U_{kr}: Binary variable, u_{kr} = 1 if resource (r) allocated at dispatch point (k), otherwise u_{kr} = 0.

Parameters

F_{rk}:	fixed cost of allocating resource (r) at dispatch point (k). Fixed cost of allocating the resource at different potential dispatch points could vary.
H_{rd}:	total hourly cost accrued for resource (r) for deployment duration of (d) time periods.
L_{irkd}:	total (cumulative) line produced on fire (i) by resource (r) allocated at dispatch point (k) for a duration of (d) time periods. Same resource allocated at different dispatch points could produce different amount of fires lines for certain fire since it might need to travel different distances to reach the fire.
W_{id}:	weight for the area burned by fire (i) after a duration of (d) time periods.
P_{id}:	total burn perimeter for fire (i) after a duration of (d) time periods.

A_{id}: total area burned by fire (i) for a duration of (d) time periods. Calculated from P_{id}.

B: the upper bound of initial attack cost input to the model.

The objective function (1) minimizes the loss for a given budget. For each specific initial suppress resource, equation (2) restricts its allocation to a single location. Equation (3) restricts that each suppression resource *r* can only be deployed to each fire for a fixed duration. Equation (4) defines the constraint set requiring each fire *f* to last for a particular duration. Equations (5) and (6) are constraints defining conditions of successful containment for each fire. For each contained fire, equation (5) requires that the total length of fireline produced by all suppression resources from different dispatch points must equal or exceed the fire perimeter at the period it is contained. Constraint (6) ensures that fireline will be effective only when during the containment period of any particular fire.

The inequality in (7) is the budget constraint stating that the total cost of all resources deployed to all fires, both hourly and fixed, must be less than or equal to the budget (B). The right hand side of the constraint can be changed to reflect each budget level to be analyzed. Equations (8) are used for modeling resource allocation for fires ignited simultaneously. Simultaneous fires will compete for firefighting resources. A resource can only be deployed to one fire in each group of simultaneous ignitions. Equations (9) ensure that at least one resource is deployed to all escaped fires (f_{iDe}=1). This constraint provides that a resource has to be deployed to fires that are not contained, reflecting the cost of gathering information on fires that may not be contained during the initial suppression period.

Incorporating a Cost for Escaped Fires

While compartmentalizing suppression into IA and EA (assume just two for simplicity) provides managerial clarity for planning, budgeting and operations, if not properly addressed, it can pose a classic externality problem. In the IA preparedness planning context, such an externality can be generated if the cost of IA escapes is not considered in the IA model or decision process. A correct approach, consistent with the Coase Theorem (Coase 1960) would be to maximize the sum of the net benefits across both program components (IA and EA) when considering resource allocations to IA preparedness planning. Simultaneously modeling both in their entirety would, in principle, provide the correct set of costs to the IA analysis. In this way we could solve for the optimal number of escaped fires. The problem is that there is no precedent for modeling large fires in this context and there is no precedent for modeling IA and EA simultaneously.

In lieu of a credible simultaneous solution, we can employ a proxy for the cost of escaped fires into the IA analysis. Consequently, we tested three alternative approaches to incorporating a proxy for the cost of escaped fires. To begin, consider that the objective function can be separated into two parts where the first part represents the loss during the initial suppression periods and the second part represents a penalty for escapes.

We formulated and tested three objective functions representing alternative approaches to including a proxy for the cost of escaped fires. Of particular interest is how each objective function formulation will influence the allocation of initial attack resources and fire containment. Objective function (11) penalizes each escaped fire by using a large constant penalty “M”. As M becomes large, this objective function effectively maximizes the initial attack success rate; an often used performance metric.

$$Minimize \quad \sum_{i=1}^{I}\sum_{d=1}^{D}(W_{id} * f_{id} * A_{id}) + M * \sum_{i=1}^{I} f_{iD_e} \tag{11}$$

In function (12), escaped fires are penalized by a value proportional to its loss right before escape. The rational for this is that it reflects the last information known to the IA model regarding the potential resource damage from an escape. It also reflects the restriction of the scope of the problem to IA preparedness.

$$Minimize \quad \sum_{i=1}^{I}\sum_{d=1}^{D}(W_{id} * f_{id} * A_{id}) + \sum_{i=1}^{I}(W_{iD} * f_{iD_e} * A_{iD}) \tag{12}$$

Objective function (13) combines (11) and (12) to penalize any escaped fire by using a constant penalty combined with the loss before fire escaped.

$$Minimize \quad \sum_{i=1}^{I}\sum_{d=1}^{D}(W_{id} * f_{id} * A_{id}) + \sum_{i=1}^{I}(W_{iD} * f_{iD_e} * A_{iD}) + M * \sum_{i=1}^{I} f_{iD_e} \tag{13}$$

Demonstrative Example

A demonstrative example is designed to show how the model addresses optimal placement and dispatch of resources in a CEA context at different budget levels. We begin by defining a fire scenario used in the optimization routine that includes 10 fires with two of them, F_9 and $F_{10,}$ occurring simultaneously. For simultaneous ignitions, we make the simplifying assumption that no suppression resources can be assigned to both. This assumption can be relaxed to allow some resources to service multiple simultaneous fires, but such relaxation does not add to the substance of our findings or formulation. We also assume eight time periods for modeling purposes that are measured in hours. The duration can take any time step and the time step is not required to be uniform. The initial perimeter of each fire represents the size of each fire when it is discovered. Perimeter of each fire will grow linearly at different speeds during the 8-hour initial suppression periods (Table 1).

Table 2 displays the loss by each fire during each of the 8-hour periods without any suppression effort. Because we are using the free burning fire containment rule, any fire shape could be chosen, but for simplicity, we chose a 2:1 ellipse (Mees 1985). We calculate the area burned for each period for each fire based on the initial fire size and growth rate of each fire listed in Table 1. If the fire is not contained within the eight hours, it is defined as escaped for modeling purposes and a resource is deployed to monitor the fire for the entire initial attack duration.

The loss can be expressed in any currency, monetized or non-monetized so long as a consistent currency is applied. This occurs because the solution to the ILP is related only to the relative weights and it is independent of the units in which the objective function is measured. We therefore keep the loss and cost expressions separate in the event that a non-monetized expression is desired. We increased the per acre weighted loss of each fire by time period to reflect the idea that the fire may be more important to contain at higher intensity and complexity levels often associated with growing fires.

Our list of fire fighting resources was selected to illustrate key model features of optimal allocation and dispatch while recognizing that agency planning units would be considerably more complex. For demonstration we model three kinds of resources: resources that are relatively inexpensive and have relatively low production rates, such as a handcrew, resources that are moderately expensive, but produce greater line production such as an engine and we include an expensive resource that is highly productive. The production rates were based on the Fireline Handbook, National Wildfire Coordination Group (NWCG) Handbook 3 (PMS410-1, NFES #0065). To demonstrate the model's ability to evaluate optimal resource allocation, we modeled the same type II handcrew dispatched from two different locations, HC1.A and HC1.B. The difference in dispatch locations is represented in the arrival time to fires and the subsequent fireline production to control each fire; all other aspects of the resources are the same. At each budget level, the optimizer can choose at most one of the two instances to determine the best location for the handcrew. The cost and productivity of each kind of resource is listed in Table 3. The productivity of each resource

Results and Discussion

The results of the model formulation using the demonstrative example are discussed in two parts: effects on resource allocation and fire containing, and with respect to the alternative objective functions used to include a cost of escaped fires.

Resources and Fires

The detailed containment period for each fire and the allocation and dispatch schedule for each resource are shown in Table 5 based on a budget level of \$21M. At this budget level all fires can be contained and there was no difference among the alternative objective functions. All fires, except for the simultaneous fires (F_9 and F_{10}) were contained within either the first or the second periods. There are two advantage of containing a fire at earlier periods. First, there is less damage as denoted by lower loss; second, less fireline is needed to contain the small fire. Results also show, at the budget level of \$21M, that handcrew 1 will be allocated to dispatch point B. Handcrews 2, 3, and engine 3 were also allocated and dispatched. Other resources were not dispatched at this budget level. Even at this highest tested budget, the technically superior resources, the helicopter and the dozer were not dispatched as they are not cost-effective. This shows how optimization can both suggest a set of cost effective resources as well as their location.

As identified in constraints (5) and (6), the necessary and sufficient condition of containing fire *i* at period *d* is that the total length of fireline produced for fire *i* at or before the period *d* has to be equal or longer than the perimeter of fire *i* at period *d*. This formulation allows using fireline produced before period *d* to contain fire at that period and it will not prevent any earlier withdraw of suppression resource before a fire is finally contained. For example, at the budget level of $21M, handcrew 2 will only be dispatched for one period to the Dollar fire even though this fire will last for two periods (Table 5). Model results also reflect the slack between fireline production and fire perimeter for some fires (Table 5). To make the scheduling more conservative, we can explicitly build certain level of redundancies into model formulations. For example, we can assume the fire line produced needs to be at least 10% longer than the fire perimeter to efficiently contain a fire.

<u>Results with Respect to Objective Functions</u>

Resource scarcity is reflected in the budget level provided to the model and this is an important factor in determining the resource allocations and the dispatch of initial attack resources. We tested 11 budget levels between $15M and $25M. All 10 fires can be contained at budgets of $21M or above within the 8-hour initial suppression period when fires F_9 and F_{10} are modeled as simultaneous. Figure 2 shows that the fire containment schedules are insensitive to the choice of objective function at these budget levels. However, as scarcity increases as represented by lower budgets, fires escaped and model results were sensitive to how the cost of escapes is modeled in the objective function. Resource scarcity is exacerbated by the simultaneous ignitions which introduce an opportunity cost for resource use. With simultaneous fires the cost of deployment includes both the variable cost plus the opportunity cost for reducing damage on the competing fire. Additional tests showed that after removing the assumption that fires F_9 or F_{10} occurred simultaneously, a 100% success rate of initial suppression was achieved with a much lower budget level of \$18M.

Results from the model at different budget levels were used to produce the cost effectiveness frontiers in Figure 2a. Each point on the frontier corresponds with a unique deployment of resources that minimize the loss during the initial suppression period at the specified budget level. Three frontiers were produced based on objective functions (11, large constant cost), (12, damage at escape) and (13, combination). By using objective function (11), if budget level is not high enough to contain all fires, the model will contain as many fires as possible. That is, it maximizes initial attack success rate. This objective function will always equal or increase the number of contained fires with increases in the budget. However, because it treats all fires as equal for containment with a constant penalty, it fails to distinguish between important and unimportant fires. For example, model results show under a budget level of \$20M, the model could contain either F_9 or F_{10} fires at period two. By using objective function (11), F_9 would be contained since containing it will result in an objective function value of 6.7+M, which is less that the objective function value of 8.4+M from containing F_{10} (Table 2). This is an inferior solution because the more important F_{10} escaped.

Objective function (12) added a penalty to each escaped fire that is proportionate to each fire's loss at escape. Given the initial attack scope of the analysis, this might be the best, albeit imperfect, information available to the model regarding escapes. Weighted size reflects the last known information from initial suppression regarding values at risk, the size of the fire and the likely cost of managing fire in an extended suppression setting. Here, with a budget level that is insufficient to contain all the fires, containment decisions are not determined by the success rate of initial suppression but by the relative importance between fires at escape. Test results show as the budget level increased from \$15M to \$16M, the number of escaped fires increased from three to five (fig. 2b). However, the total loss during the initial suppression period decreased from 1771 to 1429 (fig. 2a). This reflects the fact that, with a \$1000 budget increase, the model would shift the initial suppression efforts from containing a group of five less important fires to a group of three more important fires. This is a localized result reflecting the possibility of encountering the economically inferior fire. Such a result can occur whenever the fires are modeled reflecting a differential importance of containment.

Objective function (13) applies both escapes costs form objective functions (11) and (12). It will penalize any escaped fire, regardless of containment importance, by using a large constant penalty M and it penalizes each escape based on its loss just before escape. Model results show by using this objective function, as the budget level increased, the success rate of initial suppression consistently increased (fig 2b). In addition, if the option existed between containing a less important fire and a more important fire, the model will always contain the more important fire. For example, for budget levels between \$17M to \$20M, if function (12) is used to guide the decision between containing either F_9 or F_{10} fire, F_{10} will always be chosen for containment (Table 2) because it is more important than F_9 (Table 4).

One advantage of the optimization approach to IA modeling is the ability to incorporate a cost for escaped fires in the resource allocation process. An alternative approach, which requires more information, would be assigning an estimated weight to each escaped fire to reflect its cost. The key of the second approach is how to estimate the relative importance between escaped fires. This paper tested an approach to weight each escaped fire by its loss at escape. This "baseline" of weighed size at the time of escape can also be adjusted upward by multiplying the loss by a constant *"K"* that is greater than one to increase the estimated cost of escapes. The corresponding formula to penalize the escaped fire will then be expressed as:

$K * \sum_{i=1}^{I} (W_{iD} * f_{iD_e} * A_{iD})$. Since increasing the value of *K* will not change the relative importance between groups of escaped fires, in many cases the containment decisions will not change as the value of *K* increased. This is also the case of the test example of this paper. In some cases where values of *K* affect the containment decision, bigger *K* would make the model excessively consider the loss at escape and thereby stifle the consideration of fire effects during the initial suppression period. The influence of K is demonstrated in Figure 3 through a simple example. Suppose a budget level only allows us to contain one of the two fires A and B. ΔL is the absolute difference of losses between containing A and containing B during the initial response period; and $K \times \Delta L'$ is the absolute difference of penalties by letting A or B escape. The net gain of containing A and letting B escape is equal to $(K \times \Delta L' - \Delta L)$. Fig. 3a shows a common case with $\Delta L' > \Delta L$. Therefore, for any $K \geq 1$, $(K \times \Delta L' - \Delta L) \geq 0$ and fire A will be contained. Fig. 3b shows a possible situation with $\Delta L > \Delta L'$. This could represent a case that it takes initial suppression resources a longer time to reach A due to transportation conditions or fire locations. In this case, if *K=1,* $(\Delta L' - \Delta L) \leq 0$ and the model will contain fire B. However, when K is so large that $K \times \Delta L' - \Delta L \geq 0$, the model will contain fire A. Above analysis can be applied to decisions between containing different groups of fire. The impact of K is not determined by the number of fires in each group. Instead, it will depend on the $\Delta L'$ and ΔL in each group of fires.

Conclusion

The ILP model developed in this paper provides an approach to optimally allocate and dispatch initial attack resources. The non-monetized measure of weighted area protected (or weighted area burned) is used to evaluate the performance of initial suppression. Research integrated different criteria associated with fire behavior, resource performance and budget limitation to schedule the optimal allocation and dispatch of initial suppression resources. Fires are assumed to grow over time and the weighted area burned is used to determine each fire's relative importance to contain at different stages of development. Cost is input to economize resource use and as a spending constraint. Resources have varying fire line production capabilities. Compared with previous optimization approaches, this model also addressed multiple fire events, simultaneous ignitions, multiple dispatch locations and new resource acquisition.

With the same set of fires and available resources, budget level is an important factor determining both the optimal initial suppression schedules and the performance of suppression efforts. Cost effectiveness point can be identified by using the ILP model to reflect the efficient initial suppression schedule at each budget level. As long as the budget level is high enough to contain all fires, model will be able to minimize the weighted area burned from all fires without ambiguities. However, if the budget is not enough to contain all fires, ambiguity might exist in estimating the externality of escaped fires. Different objective functions are tested in this research with each function penalizing escapes differently. By penalizing each escape through a large constant M, the suppression success rate will always be improved as budget level increases. However, more important fires will not always be contained. An alternative approach is to add a penalty to each escaped fire proportional to its loss at escape, the relative importance of fires during the initial suppression period will always be kept and used to make containment decisions. However, as the budget level increased, the initial suppression success rate could decrease. A compromise between success rate and loss can be made by combining both objective functions even though perfectly considering all the externalities from escape is often difficult.

For the ILP model developed, the detailed resource allocation and dispatch schedules depend on the prediction of the set of fires, their locations, growth, and the weight assigned to each unit area burned by each fire. Potential mistakes can happen when predicting the behavior of each fire, which could influence the allocation and dispatch schedules for initial suppression resources. However, for strategic level budget determinations or performance measurements, we can potentially create a series of fire scenarios with each scenario representing a potential set of fire conditions. By using multiple fire scenarios, managers could potentially determine a scope of required budget levels. Future development could also change the deterministic model to incorporate stochastic elements, such as a range of likely fire occurrences or stochastic production rates.

While the cost estimates are made as a consequence of a set of deployment rules and resources the cost estimates are external to the decision method. An advantage of such an approach is that the deployment rules may simulate dispatch behavior. Develop costs of acquisition and deployment as external to the deployment decisions.

Notes: Cost effective simulation would presume that the resource list is efficient and that the dispatch rules are efficient. If not efficient, then simulation effects would not be cost effective—

they would over estimate cost needed for given accomplishment. Cost efficiency of dispatch rules not established. Optimization could be used to test for cost effective dispatch rules.

For simplicity and to focus on the illustration of economic relationships in the model, we used a single set of potential fires. We note that multiple fire sets could be analyzed or a stochastic analysis could be performed.

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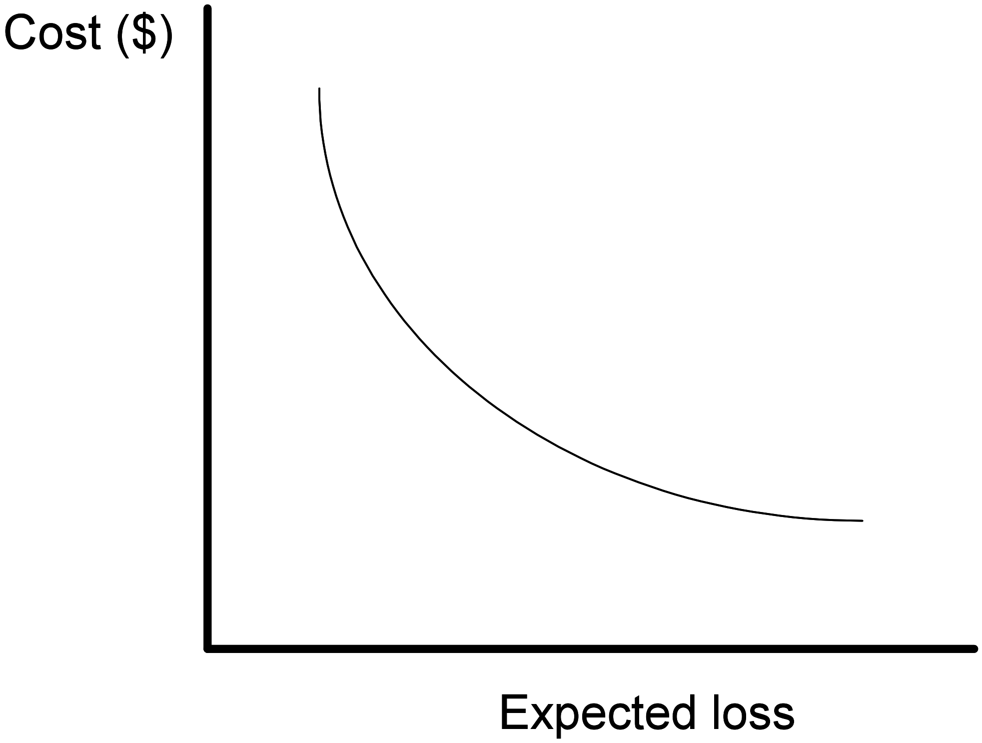
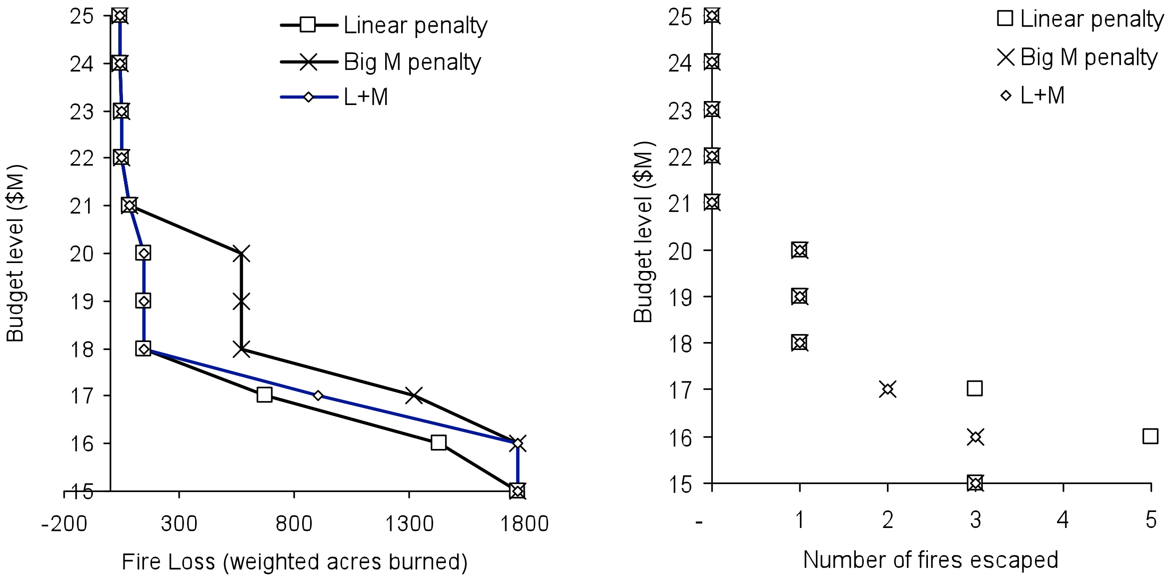
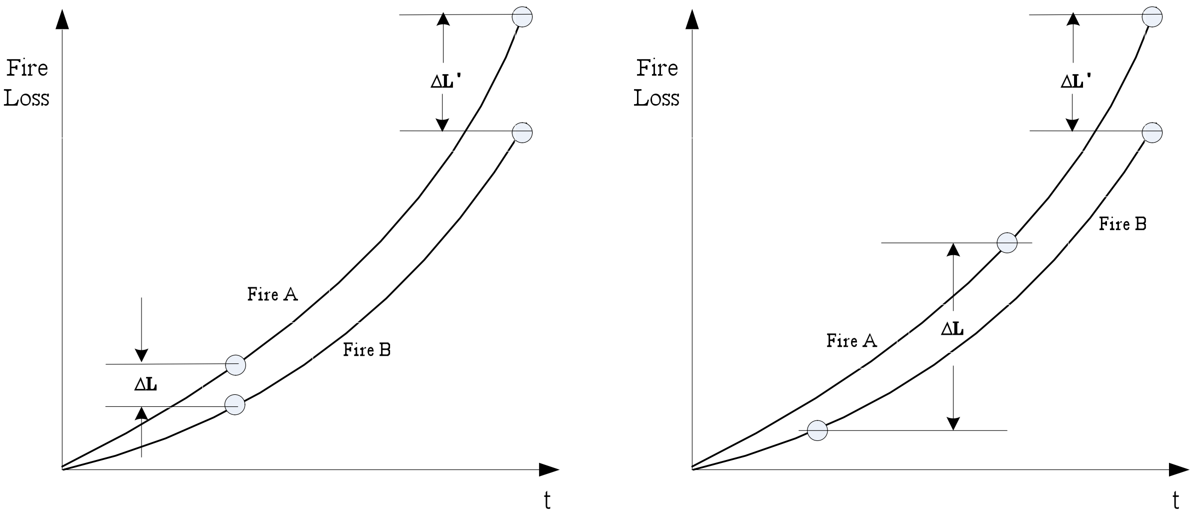


Figure 1. Theoretic cost effectiveness frontier for expected loss.



(a) (b)

Figure 2. Compare the results from initial attacks at different total budget levels based on either linearly increase the perimeter of any escaped fire by one period or using a very large penalty for each escaped fire. (a) Weighted acres burned during the first 8 periods; (b) the number of escaped fires during the first 8 period.



(a)

(b)

Figure 3. Suppose a budget level only allows us to contain one of the two fires A and B. ΔL is the absolute difference of fire loss between containing A and containing B during the initial suppression period; and K×ΔL' is the absolute difference of penalties by letting A or B escape. The net gain of containing A and letting B escape is (K×ΔL' - ΔL). (a) shows that if ΔL' > ΔL, then for any K ≥1 fire A will be contained. (b) shows that when ΔL > ΔL', if *K=1*, fire B will be contained; if *K* is so large that K×ΔL' -ΔL ≥ 0, fire A will be contained.

Table 1. Fire Attributes

Fire	Initial Perimeter (ch)	Rate of Change in Perimeter (ch/hr)
F_1	8	9
F_2	24	21
F_3	19	11
F_4	9	16
F_5	15	14
F_6	23	10
F_7	19	20
F_8	11	12
F_9	30	7
F_{10}	15	17

Table 2. Expected loss by each fire at each period without initial attack. Fires F_9 or F_{10} are assumed to occur simultaneously.

Fire	Expected loss at each period P1 through P8							
	P1	P2	P3	P4	P5	P6	P7	P8
F_1	0.1	2.0	6.8	13.7	25.2	54.4	76.9	119.0
F_2	2.5	13.3	36.5	98.0	219.2	315.8	564.4	765.6
F_3	2.0	11.9	34.9	59.2	117.8	163.9	251.8	338.2
F_4	1.4	12.5	41.1	88.2	155.7	233.6	361.9	566.8
F_5	1.6	6.2	26.1	49.1	101.3	179.6	284.7	371.5
F_6	2.8	11.5	20.8	40.2	62.1	99.6	134.1	174.4
F_7	0.5	4.3	17.9	32.5	61.9	147.1	229.0	429.7
F_8	0.1	2.0	17.8	36.8	126.1	280.1	385.3	558.6
F_9	2.8	6.7	11.4	19.8	30.9	43.3	63.9	92.4
F_{10}	1.8	8.4	20.3	64.9	131.4	191.6	314.4	513.7

Table 3. Firefighting resource costs and production rates.

Resource	Fixed Cost ($)	Hourly Cost ($)	LP Rate (ch/hr)
hc1.A*	2,050	250	9
hc1.B*	2,050	250	9
hc2	2,030	250	9
hc3	1,000	100	3
Eng1	8,000	400	16
Eng2	8,500	400	16
Eng3	5,000	300	12
Dozer	18,000	900	30

* Handcrew 1 (hc1) can be located at either dispatch point A or B with different arrival times to each fire.

Table 4. Periods at which each fire can be contained at different budget levels by using different strategies to penalize the escaped fires. ‘E’ represents an escaped fire. Fires F_9 or F_{10} are modeled as occurring simultaneously.

Name of fire	W_{iD} penalty for EF							Big M penalty for EF							W_{iD} & big M penalty for EF						
	15	16	17	18	19	20	21	15	16	17	18	19	20	21	15	16	17	18	19	20	21
F_1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
F_2	E	2	2	2	2	2	2	E	E	E	2	2	2	2	E	E	E	2	2	2	2
F_3	2	E	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
F_4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
F_5	3	E	E	2	2	2	2	3	3	2	2	2	2	2	3	3	2	2	2	2	2
F_6	2	E	E	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
F_7	E	E	2	2	2	2	2	E	E	2	2	2	2	2	E	E	2	2	2	2	2
F_8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
F_9	3	E	E	E	E	E	5	3	3	2	2	2	2	5	3	3	E	E	E	E	5
F_{10}	E	2	2	2	2	2	2	E	E	E	E	E	E	2	E	E	2	2	2	2	2

Table 5. Duration of which each resource will be deployed at a budget level of \$21,000. Fires F_9 and F_{10} are modeled as occurring fires simultaneously.

Name of Fires	Duration (hr)	FP (chain)	LP (chain)	Duration each resource allocated for each fire (hr)								
				HC1.A	HC2.B	HC3	HC4	Eng1	Eng2	Eng3	Heli	Dozer
F_1	1	8	9	-	1	-	-	-	-	-	-	-
F_2	2	45	50	-	2	2	2	-	-	2	-	-
F_3	2	30	34	-	2	1		-	-	2	-	-
F_4	1	9	10	-	-	-	-	-	-	1	-	-
F_5	2	29	32	-	-	2		-	-	2	-	-
F_6	2	33	35	-	2	2	2	-	-	-	-	-
F_7	2	39	39	-	2	2		-	-	-	-	-
F_8	1	11	13	-	1	1	1	-	-	-	-	-
F_9	5	58	59	-	-	-	-	-	-	5	-	-
F_{10}	2	32	32	-	2	2	2	-	-	-	-	-

Document 6

PM Objective Function and Escapes

Report

Title: The FPA-PM Objective Function and Escaped Fires: A Briefing on the Sensitivity
Testing and Robustness of the Objective Function
Authors: Douglas B. Rideout, Andrew G. Kirsch, Yu Wei
Date: April 24, 2006

Description

This report directly responds to the findings of the science review regarding the objective function used in FPA-PM and initial attack success rate and is closely related to the paper under tab five. It tests the objective function used in FPA-PM relative to the criticisms, statements and implications regarding the objective function and initial attack success rate.

The paper concludes that the findings and the statements of the science review on this topic were largely inappropriate or incorrect.

The FPA-PM Objective Function and Escaped Fires:

A Briefing on the Sensitivity Testing and Robustness of the Objective Function[1]

Fire Economics & Management Laboratory
Department of Forest, Range and Watershed Stewardship
Colorado State University, Fort Collins, CO 80523

April 24, 2006
Working Draft Version 1.3

Wildland fire organizations customarily divide the fire suppression problem into stages of management. US federal land managers organize the suppression of unwanted fires into the three stages of initial attack (IA), extended attack (EA) and large fire management. Compartmentalizing the problem allows organizations to focus on the functioning and funding of different levels of fire management.

While compartmentalizing the problem into IA and EA (assume just two for simplicity) provides necessary managerial clarity for planning, budgeting and operations, it can pose a classic externality problem. The correct approach maximizes the sum of the net benefits across both program components (IA and EA). If we could simultaneously both in their entirety, we would know the cost of EA and it could be included in the IA analysis. Only in this way, can we solve for the optimal number of escaped fires. The problem is that the current FPA model was designed to improve seasonal preparedness resource allocation and budgeting for only the initial response (IR) portion of Preparedness, leaving the analysis of EA for a later development phase.

This is identical to the classic pollution problem of a firm producing widgets while polluting the water. If the polluting firm is allowed to use the water at no charge or penalty, then we would expect the firm to over produce widgets and to dump excessive pollution into the stream. The overall cost of producing widgets would be excessive when the cost of pollution is considered. This is known as an externality in the literature and remedies are well known. The principle used to evaluate such remedies was provided in a classic article by Ronald Coase and by the famous “Coase Theorem.” The principle is understood by considering the incentives provided by joint ownership of the two resources. Owing both the factory and the water internalizes the cost of the effluent in the production of widgets. This application of the Coase Theorem is equivalent to maximizing the overall net benefits produced by the factory and the water. This solution is not directly available in the current FPA-PM model because the scope is limited to IA. Specifically, we do not have the benefit and cost information available from modeling the EA problem for use in the IA calculations. Other well-known solutions involve applying penalties or standards on the polluting agent as a proxy for the “Coasian” solution.

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[1] Prepared by Rideout, Kirsch and Wei.

We begin with four principles that directly apply to IA modeling:

1. Basic economic theory of cost minimization dictates that there is an optimal number of fires that should escape, just as there is typically an optimal amount of pollution for the polluting firm. A direct corollary is that higher IA success rates do not always minimize total cost, even when the cost of EA is included in the analysis.
2. The optimal number of escapes is unknown. We do not have knowledge of the EA benefits and costs —it was beyond the scope of Phase I.
3. There will always be IA escapes because it is too costly and inefficient to reach 100% containment.
4. IA analysis should have a penalty to reasonably compensate for the cost of suppressing EA fires and for the physical damage of EA fires.

If the IA analysis is addressed in isolation of the EA problem, and the costs (physical damage and suppression costs) of fires that escape IA to become EA events are unrecognized, then we have a bad approach and an inappropriate solution. Because FPA-PM was forced to address the IA problem in isolation, the PM model was developed with a proxy to remedy externality of escaped fires. The objective function was also developed as a strategic level expression of the protection of value at risk across a broad landscape. In the FPA-PM model, these values are at risk from a hypothetical array of fires based on fire history on the landscape. In this context, fires exist solely as a vehicle to address the broader strategic seasonal analysis. There was no expectation that the model would be used to address the management and containment, of individual events.

The management and science reviews of FPA-PM suggest sensitivity testing of alternative objective functions with special regard to initial attack success rate. These reviews questioned the integrity of the objective function; especially regarding initial attack success. These reviews raise potentially serious issues and concerns. The reviews also suggested changing the objective function, but they did not consider the current penalty programmed into FPA-PM to remedy the escaped fire externality.

As suggested, we tested the current FPA-PM objective function against some alternative objective functions, each designed to penalize the IA objective function for escaped fires. Therefore, this paper addresses the penalty used in FPA-PM for escaped fires and alternative ways of introducing this penalty and its implications for interpreting the review process. The results of our testing[2] are summarized with a discussion and a clear set of conclusions.

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[2] A fully developed paper including test conditions, data and charts is in preparation. Our expected completion date is early summer 2006.

Sensitivity Testing Philosophy and Objective Functions

We tested the following four objective functions (Appendix A) while ignoring fire use as a matter of simplification because our focus here is on containment of unwanted fires.

1. **Current FPA-PM objective function "(18+1)"**
   Minimize weighted acres burned and penalize escaped fires by adding "one" weighted acre to the weighted fire size at the time of escape.
2. **Add a large constant penalty "M"** to each escaped fire.
   A large acre penalty is added to the objective function and applied every time a fire escapes. The same penalty is applied to every escaped fire. A large or "Big M" is equivalent to maximizing IA success rate.
3. **Add a penalty based on the weighted acres burned at the time of escape**. Here we added a **different penalty to each fire** that was proportionate to each fire's weighted size at escape. Given the IA scope of analysis, this is the best information available to the model regarding the escape. Weighted size reflects the last known information from IA regarding values at risk, the size of the fire and the likely cost of managing fire in an EA setting. This "baseline" of weighed size at the time of escape can be adjusted upward by adjusting the value of the constant "K" from one to a large number to increase the estimated cost of escapes.
4. **We added "Hard Constraint" to contain a specific number of fires.** This is the most straight forward way of modeling a predetermined, or "mandated" or "target" IA success rate within the FPA-PM framework. Physical production limitations may cause this model to be infeasible with high levels of the constraint. This is not a change to the objective function and it implicitly suggests changing the way that containment is calculated or modeled in the FPA-PM framework.

Findings and Discussion

Objective function (3) best approximates the internalization of escape costs with the information available to the model. It therefore provides a suitable proxy for the penalty of escapes. Objective function (3) provides a "Coasian" benchmark for testing alternative objective functions. Three results were obtained from testing (3)[3].

1. The value of K >=1 has no substantive effect on the number of fires that escape and
2. the value of K>=1 has no substantive effect on the mix of fires that escape and
3. because a very high penalty (large K) is at work for all values of K, the penalty imposed on escapes is as aggressive as can reasonably be achieved consistent with addressing the protection of values at risk.

Insensitivity of the results with respect to the value of K in this test example can be explained by the following example. When FPA-PM is run, it results in a group of fires that have been contained

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[3] In the rare case where values of K > 1 affect the containment decision, it is likely undesirable to allow K to take on such a value. Where the containment decision is affected by large values of K, the decision will likely be distorted because the objective function will excessively consider the weighted acre burned at escape and thereby stifle the consideration of fire effects during the containment period. In this event, it is best to set the value of K to one.

and a group of fire that have not. First, suppose that two groups of fires are assessed and the model only has enough funds to contain one group. One group will be contained and the other will escape. Next, if the difference in WAB between two groups of fires at escape has already been the determining factor for containment decisions, increasing the value of K will change the absolute value for containment importance for both groups, but it will not change the relative importance between the two groups. There is no resulting change in containment.

Comparing Objective function (1) with objective function (3) provides another crucial finding. ***Objective function (1), as used by FPA-PM (Appendix A), produces effectively[4] the same effect on escaped fires as objective function (3)***. ***Therefore, the current FPA-PM objective function best remedies the potential externality that might be imposed by the cost of escapes.*** Further, because (1) is effectively equivalent to (3) [(1) closely approximates (3) when K=1] we directly find that the FPA-PM objective function is very aggressive with respect to containment. In fact, the objective function cannot be more aggressive without losing important information regarding values at risk. The FPA-PM objective function provides a simple way to appropriately and aggressively account for the cost of escaped fires.

Test results also provide an important finding regarding Objective function (2). ***Objective function (2) which administers the same penalty for each escaped fire, is equivalent to maximizing IA success rate when the value of M is large.*** In effect, maximizing IA success rate destroys the information provided to the model on values at risk through the weighting system. Large M, or maximizing containment, is equivalent to making all fires of equal importance to contain when common knowledge is otherwise. Both the theory and the results show that this is an undesirable and potentially costly objective function because it can allow for and encourage important fires to escape while containing relatively unimportant fires (see also Appendix B). Maximizing IA success provides a strong incentive to contain the wrong fires, because it will focus on the cheap and easy ones and they are not always important. These findings will hold so long as there is scarcity in the model, meaning that the cost constraint is sufficiently binding. In the event that the cost constraint is not binding, suggesting that there is no scarcity of resources, then (1) will produce the same results on containment as (2). Therefore, any fires found to escape at very high budget levels are directly attributed to something else in the system such as the modeling of containment effort. This is straightforward test to perform.

Objective function (4), which enables a "hard wire" of the number of fires contained, has the advantage of simplicity, but it does not address the root issue. Use of (4), provides a mechanism to force containment in lieu of addressing containment issues. The dangers of using (4) are: 1) generation of a high rate of infeasible solutions especially for rates suggested as "de facto policy" and 2) disabling sensitivity to the protection of values at risk. (see Appendix B for an example)

The reviews suggest that the objective function may have policy implications regarding how escaped fires are treated. Important features were introduced to the FPA-PM model to address the current policy as expressed in the 1995, 2001, and 2003 federal interagency documents. The FPA-PM objective function directly introduces protection of values at risk across a broader spectrum of values that was not previously available in initial attack modeling. It also introduces a feature for

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[4] While it is mathematically possible to produce a difference, our test results did not produce one. Our results were identical for objective functions (1) and (3).

the befit of wildland fire use. Reflecting the protection of values at risk in the objective function directly reflects the new policy documents, including the 2003 implementation policy document.[5] Introducing wildland fire use represents a significant movement in federal IA modeling toward Appropriate Management Response. The FPA-PM objective function reflects current policy by aggressive containment and by directly reflecting the protection of values at risk; including ecosystem values. These important advances are inconsistent with maximizing initial attack success as in objective function (2) which would make the objective function blind to variations in values at risk.

CONCLUSIONS

Sensitivity testing of the FPA-PM objective function suggests three important conclusions:

1. The FPA-PM objective function directly incorporates protection of values at risk in addition to aggressively and appropriately penalizing for escaped fires. In this way, the FPA-PM objective function reflects the federal interagency policy documents of 1995, 2001 and 2003 in ways that maximizing IA success rate could not.
2. The FPA-PM objective function appropriately and aggressively penalizes escaped fires and it is not the source of "excessive" escapes.
3. Issues of IA success are best addressed through analysis of the containment computations. Changing the objective function to increase the number of escapes without addressing containment mechanisms misses the point. Changing the objective function will risk producing a different and potentially costly mix of fires to contain because the objective function already includes the appropriate incentives to contain the correct set of fires.

Evaluation of the sensitivity testing results of alternative objective functions and current policy provide rationale to strongly support the current FPA-PM objective function regarding the mix of fires that might escape IA efforts in the model. Test results confirm that the FPA-PM objective function is appropriately aggressive with respect to containment.

If the model produces 18-hr containment rates that are "too low,[6]" even at the highest possible cost limits, then the containment effort (fireline production by resources and their interaction with fire perimeter) or the definition of IA success should be assessed; not the penalty for escapes currently in the objective function.

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[5] From the 2003 "Interagency Strategy for the Implementation of Federal Wildland Fire Management Policy (p23), the definition of initial attack is: "Initial Attack – An aggressive suppression action consistent with firefighter and public safety and values to be protected."

[6] Too low is subjective because there are currently no data on fires contained in 18 hours to support such a claim.

Appendix A: Objective functions tested

1. Penalize each escaped fire by adding 1 acre to the weighted area burned at the end of initial attack period. The OF is:

   $$Minimize \quad \sum_{i=1}^{I}\sum_{d=1}^{D}(W_{id} \times f_{id} \times A_{id}) + \sum_{i=1}^{I}(W_{iD} \times f_{iD_e} \times (A_{iD} + 1))$$

   This reflects the IA portion of the OF used in the current FPA. The additional 1 acre makes sure that there always some additional benefit of containing a fire if the budget is available. The information of relative importance of fires before escaping will be maintained and therefore important fires will likely be contained.

2. Penalize each escaped fire by using a large constant penalty "M". The OF is:

   $$Minimize \quad \sum_{i=1}^{I}\sum_{d=1}^{D}(W_{id} \times f_{id} \times A_{id}) + M \times \sum_{i=1}^{I} f_{iD_e}$$

   Where terms are defined as usual except that M is the per escaped fire penalty. As M becomes very large, this OF effectively becomes maximizing initial attack success rate where important fires may not be contained. It treats all escaped fires as the same by penalizing them all with the same M (regardless of the weight or size).

3. Penalize each escaped fire by assuming a linear increase of its weighted size at the time of escape. This objective function is:

   $$Minimize \quad \sum_{i=1}^{I}\sum_{d=1}^{D}(W_{id} \times f_{id} \times A_{id}) + K \times \sum_{i=1}^{I}(W_{iD} \times f_{iD_e} \times A_{iD})$$

   Fires with higher weighted acres burned at escape would be more important to be aggressively managed during the IA period. K is a constant that can be varied from at least one to a large number.

4. Adding a hard constraint to O.F. 3 to restrict that the number of fires (or percentage) to escape cannot be more than *N*. Then the objective function and additional constraint will be:

   $$Minimize \quad \sum_{i=1}^{I}\sum_{d=1}^{D}(W_{id} \times f_{id} \times A_{id}) + K \times \sum_{i=1}^{I}(W_{iD} \times f_{iDe} \times A_{iD})$$

   $$St:$$

   $$\sum_{i=1}^{I} f_{iDe} \le N$$

   "N" physically restricts the number of fires that would escape.

Appendix B: Test Results

We tested the four objective functions on a fictitious fire scenario and extensive sensitivity testing of the modeled parameters. The modeled results are below with a discussion of the findings. For this paper refer to the following example in the discussions:

Fire	WAB @ escape
A	5
B	10
C	11
D	19
E	17

Table 1

1. **Objective function three**, provides an economically consistent benchmark: the value of the constant ‘K” does not affect the number of escapes and it does not affect which fires escape if the difference of WAB between fires at their escape has already been the determining factor.

   The reason for this is difficult to understand, but it is because the proportionate penalty of escapes is unchanged in the analysis. Because K is the same for all fires, changing the value of K won’t influence the relative importance of the escaped fires.

   We use a five-fire example for demonstration (Table 1). If any fire A, B, C, D and E is contained, we assume the WAB of that fire is zero. If any of the five fires escaped, the WAB for each escape is shown in table 1. Suppose at a given budget level, either three smaller fires A, B, C can be contained, or two larger fires D, E can be contained, then no matter what the value of K is, the model will try to contain fires D and E because this gives a total WAB of K*26. It will not contain fires A, B and C because it will create a total WAB of K*36, which is always greater than K*26.

   The conclusion that K does not affect the containment decisions might not hold under rare circumstances. For example, changing the above example by assuming that if any fire A, B, and C is contained, the WAB of each fire is zero; if any fire D and E is contained, the WAB of each fire is 10. This could represent the case that there are much longer dispatch distances to both D and E. In this example, if K=1, fire A, B and C will be contained since the WAB is 0+36 = 36, which is smaller than containing D and E with a WAB of 20+26 = 46. However, if K=3, fires A, B and C will not be contained because the total WAB is 0+3*36 =108, which is larger than the WAB of 20+3*26 = 98 by containing D and E. However, in this case, using a large K, i.e. 3, might not be desirable since it causes more actual WAB during the initial attack period. In addition, it would cause a lower initial attack success rate.

2. **Objective function one** is effectively identical to objective function three for K equal to one. Remember, in most cases, the value of K is irrelevant to containment.

   By using the same five-fire example in table 1, the model will always contain fire D and E because this will give a total WAB of 29 = 26+3. It will not contain A, B and C because it will create a total WAB of 38 = 36+2.

3. **Objective function two** (big M only) treats all fires the same at escape and is effectively the same as maximizing initial attack success rate assuming M is very large. If M is large enough, the weights become negligible, letting important fires escape to increase the success rate.

   For example, if M=1000 and the budget level allows us to contain either fires A,B,C or D and E, the model will choose to contain A,B, and C for a WAB of 2036. The model will not choose to contain the important fires (D, and E) because the WAB will be 3026. This is apparently not what we want.

4. **Objective function (constraint) four** forces the model to either contain the specified number of fires or to go infeasible. Hard-wiring the success rate means sacrificing the containment of important fires.

   By using the same 5 fires example, if upper bound for the number of escaped fire is set to 3, the model will contain D and E and the total WAB is 26. Decreasing the number of escaped fires to 2 the model will contain A, B and C, and the total WAB is 36. Here it shows that a higher success rate would create containments with a higher WAB (lower is better).

Appendix C: Why IA Success in FPA-PM Should Differ from Practice

There are three principle reasons why IA success rate should not be expected to approximate success rates in practice. They are:

1. While the model was constructed to be consistently cost effective, real life fire management is not. The job of tactically managing unwanted fires is to initially achieve containment. This may produce IA success rates higher than those in the strategic model that is focused on seasonal performance and budgeting, not individual fire management.
2. The model used a “hard” budget constraint. Unit managers’ work during the season with a “semi” unconstrained budget. Well known tools of severity funding, and the involvement of a “militia of non-fire funded personnel who are trained to fight fire as collateral duty, and co-operators will provide a higher IA success rate than should be expected in a cost-constrained model.
3. The metric of success used by many agencies is more liberal than the FPA metric which is based upon a strict 18 hour period. Agencies differ in their criteria for IA success where it is common to see 48 hour periods or even acreage definitions.

While additional factors that make the comparison if IA success in FPA-PM incongruent with practice, these three likely account for the greatest expected differences. While the extent of each is unknown, it is not unreasonable to suggest that each one might account for about a 10% difference. If the current IA success rate is 95%, then a reasonable expectation of comparison for the FPA-PM analysis would be in the neighborhood of 65%. The implication of this is not that we should expect a well functioning model to attain 65% IA success, but that it is unreasonable to expect that a well functioning PM model should achieve a success rate in the neighborhood of 95-100 percent. It is unproductive to hold FPA-PM to an unreasonable standard of 95-99% IA success. Instead, translating success in the model with that observed in practice will improve understanding of the model and better enable those interested in containment results to focus on the containment calculation.

Document 7

FPA Symposium

PowerPoint Presentation

Title: Economics of Performance Measures
Authors: Douglas B. Rideout, Andrew G. Kirsch, Stephen Botti
Date: April 25-26, 2006

Description

This was presented at the FPA symposium on the emerging new paradigm of land management as a context for fire management and policy. The economics of current and proposed performance measures for fire management are discussed.

Fire Program Analysis Prototype Symposium
Boise Airport Main Terminal Building
Snake River Conference Center
Boise, ID
April 25-26, 2006

Workshop Objectives:

- Familiarize Prototype personnel with each other and with the FPA development team
- Inform FPA Prototype Areas of the background, theory and system requirements of FPA Phase 2
- Further define Prototype Area tasks and develop action items
- Identify FPA Prototype Area milestone dates
- To help the FPA team understand the prototype areas' status and special management needs

Tuesday, April 25, 2006

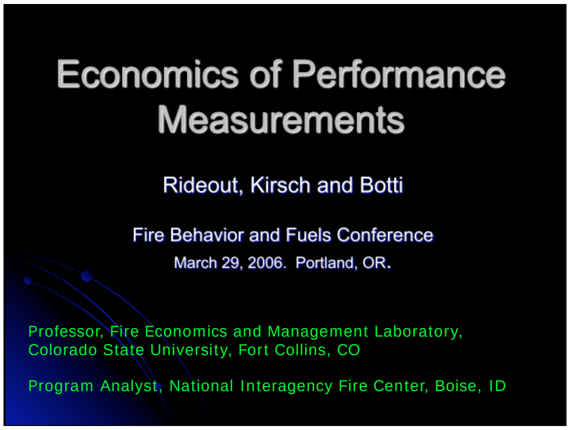
0800	Opening Comments and Participant Introductions –
0815	Logistics, Facilitator Introduction and Ground Rules, Identify Meeting Participant Representatives
0845	Prototype Presentation – Alaska
0915	Prototype Presentation – Central Florida
0945	**Break**
1000	Prototype Presentation – Central Oregon
1030	Prototype Presentation – Color Country
1100	Prototype Presentation – Southern Sierra
1130	**Lunch**
1245	Phase 1 After Action Review – J.R. Epps
1315	Management/Technical Review Results – Steve Botti
1330	**Break**
1345	Existing Prototype Review/Discussion – Prototypes/FPA Core Team
1430	Prototype Expectations/Timelines – Wally Josephson
1500	System Development/Business Process – Michele Tae/Steve Carty
1600	Daily Wrap-up
1630	**Adjourn**

1830 Mixer: Location – Saleen's House

Fire Program Analysis Prototype Symposium
Boise Airport Main Terminal Building
Snake River Conference Center
Boise, ID
April 25-26, 2006

Wednesday, April 26, 2006

0800	**Comments from prior Day**
0815	Philosophical Background – Doug Rideout
0915	Purpose and Scope of FPA Phase 2 – Jeff Manley
0945	**Break**
1000	To Be Process and Integrations – Howard Roose
1045	Conceptual Architecture – Steve Carty, IBM
1145	**Lunch**
1315	Functional Prototype(s) and Rapid Prototyping – Andy Kirsch/Craig Thompson
1415	Desired Condition Concept – Lou Ballard
1445	**Break**
1500	Data Needs (Desired Condition and LMP) – Mike Benscoter/Terri Knauth
1515	LANDFIRE Presentation – Henry Bastian
1545	Question and Answers – Lou Ballard
1615	Where do we go from here? – Nikki Saleen
1645	Closing Remarks – Aden Seidlitz
1700	**Adjourn**



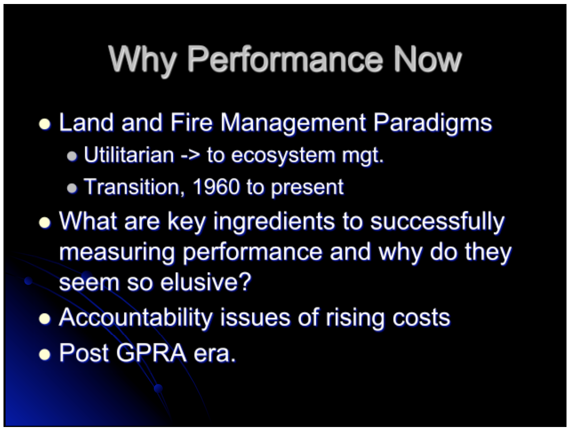
Economics of Performance Measurements

Rideout, Kirsch and Botti

Fire Behavior and Fuels Conference
March 29, 2006. Portland, OR.

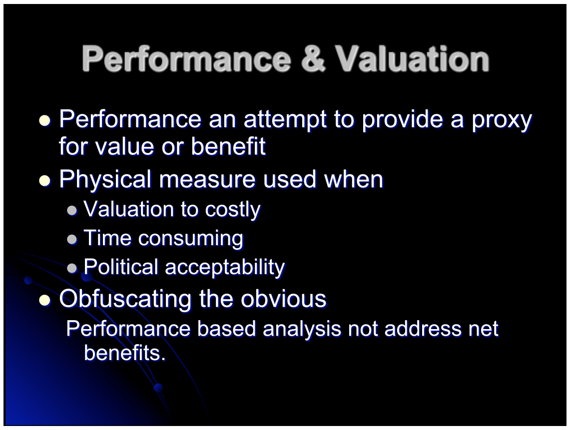
Professor, Fire Economics and Management Laboratory,
Colorado State University, Fort Collins, CO

Program Analyst, National Interagency Fire Center, Boise, ID



Why Performance Now

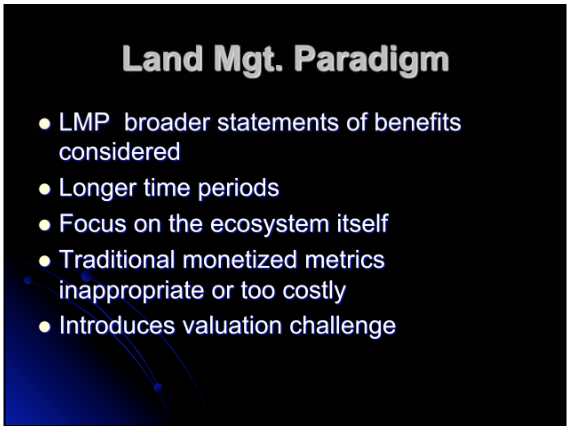
- Land and Fire Management Paradigms
  - Utilitarian -> to ecosystem mgt.
  - Transition, 1960 to present
- What are key ingredients to successfully measuring performance and why do they seem so elusive?
- Accountability issues of rising costs
- Post GPRA era.



Performance & Valuation

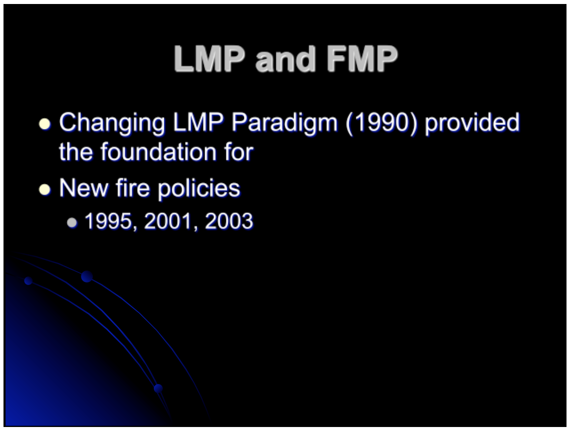
- Performance an attempt to provide a proxy for value or benefit
- Physical measure used when
  - Valuation to costly
  - Time consuming
  - Political acceptability
- Obfuscating the obvious

  Performance based analysis not address net benefits.



Land Mgt. Paradigm

- LMP broader statements of benefits considered
- Longer time periods
- Focus on the ecosystem itself
- Traditional monetized metrics inappropriate or too costly
- Introduces valuation challenge



LMP and FMP

- Changing LMP Paradigm (1990) provided the foundation for
- New fire policies
  - 1995, 2001, 2003

Ecosystem Paradigm & Fire

- Fire playing a more
  - Central &
  - Expanded role
- Higher costs
- More accountability

Public Accountability

- GAO
- 1994 fire season S. Canyon
- Yellowstone 1988 review
- 2002 large fire seasons
- GRPA 1993

New Approaches Needed

- New fire management systems consistent with the new paradigm of land management and
- Consistent with the new policies which reflect the new land mgt. philosophy
- Moving away from traditional metrics associated with the old paradigm

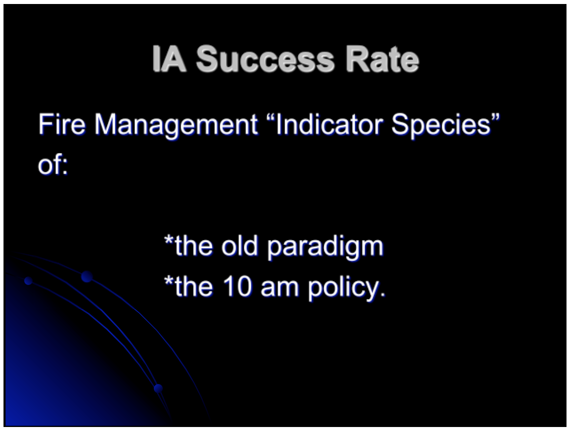
Understanding a Paradigm Shift

- A change from one way of thinking to another
  - Applies to Science
  - Applies to Management
    - Utilitarianism to Ecosystem Mgt.
  - Long and difficult characterized by periods of regression

Resistance to Change
Initial Attack Success Rate

Q: What is the largest indicator or resistance to change to the new paradigm of ecosystem management in fire?

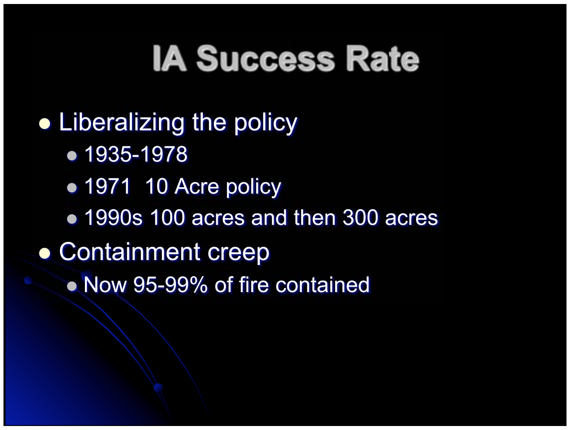
A: A relic of the 10am containment policy known as initial attack success rate.



IA Success Rate

Fire Management “Indicator Species” of:

*the old paradigm
*the 10 am policy.



IA Success Rate

- Liberalizing the policy
  - 1935-1978
  - 1971 10 Acre policy
  - 1990s 100 acres and then 300 acres
- Containment creep
  - Now 95-99% of fire contained

IA Success and Cost

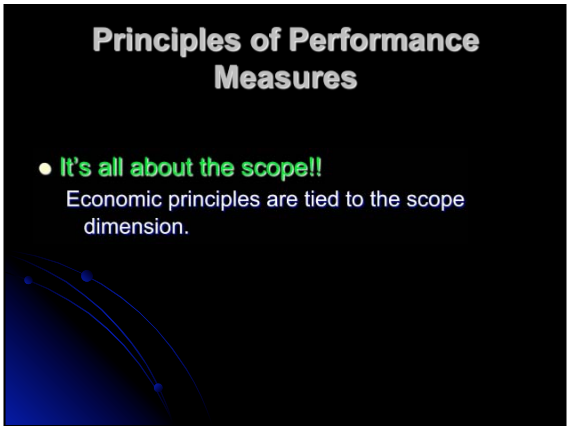
- IA Success correlated with suppression costs
  - Federal Bureaus spending over 900 million per year suppress remaining 2%
  - How could this be when IA is so successful?
- IA success correlated with enormous costs of fuels builds up.
  - Federal bureaus spending 500 million to correct
  - How could this be when IA is so successful?

Trouble in Paradise

- Not address differences in fires
- Not all fires the same importance to contain
  - Fires in WUI may be more important to suppress than wilderness fires
  - Sometimes it is better to contain fewer fires – WUI example –lightening bust in wilderness
- Not all acres important to treat in fuels

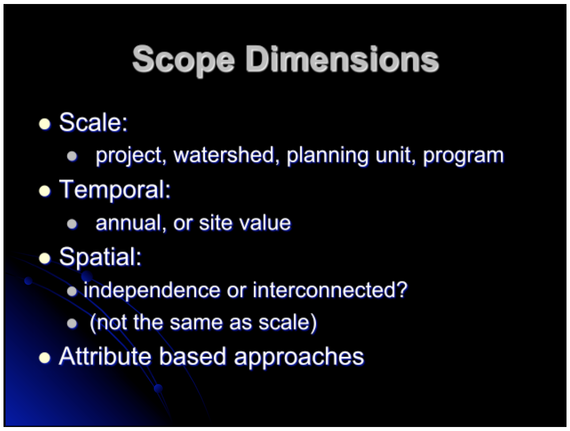
IA Success

- All fires of same cost to contain
- Inconsistent with difficult choices managers make – they know some fire more important and they act accordingly, they know some acres are more important to treat.
- How do we improve performance measures to incorporate this logic?



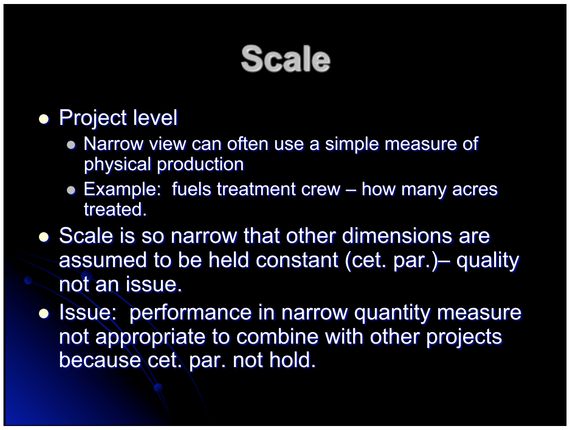
Principles of Performance Measures

- It's all about the scope!!
  Economic principles are tied to the scope dimension.



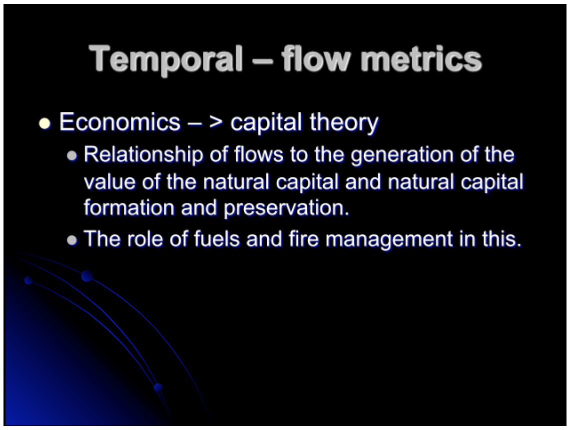
Scope Dimensions

- Scale:
  - project, watershed, planning unit, program
- Temporal:
  - annual, or site value
- Spatial:
  - independence or interconnected?
  - (not the same as scale)
- Attribute based approaches



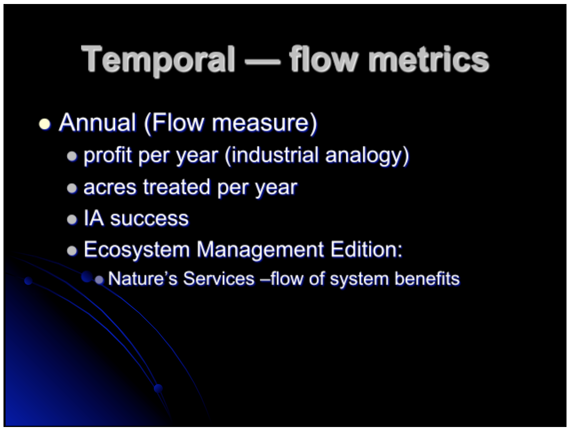
Scale

- Project level
  - Narrow view can often use a simple measure of physical production
  - Example: fuels treatment crew – how many acres treated.
- Scale is so narrow that other dimensions are assumed to be held constant (cet. par.)– quality not an issue.
- Issue: performance in narrow quantity measure not appropriate to combine with other projects because cet. par. not hold.



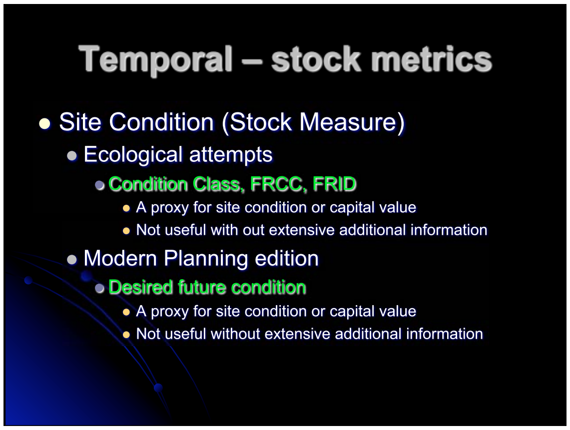
Temporal – flow metrics

- Economics – > capital theory
  - Relationship of flows to the generation of the value of the natural capital and natural capital formation and preservation.
  - The role of fuels and fire management in this.



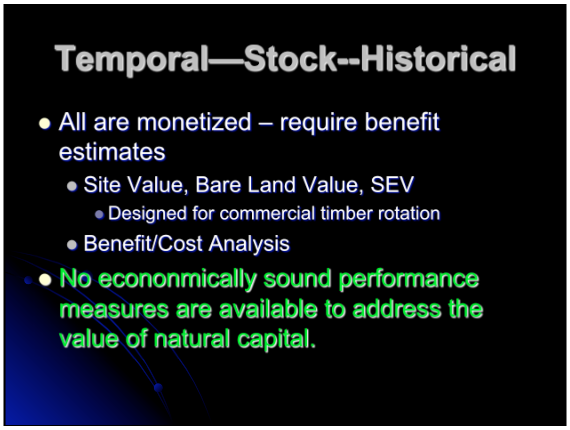
Temporal — flow metrics

- Annual (Flow measure)
  - profit per year (industrial analogy)
  - acres treated per year
  - IA success
  - Ecosystem Management Edition:
    - Nature's Services –flow of system benefits



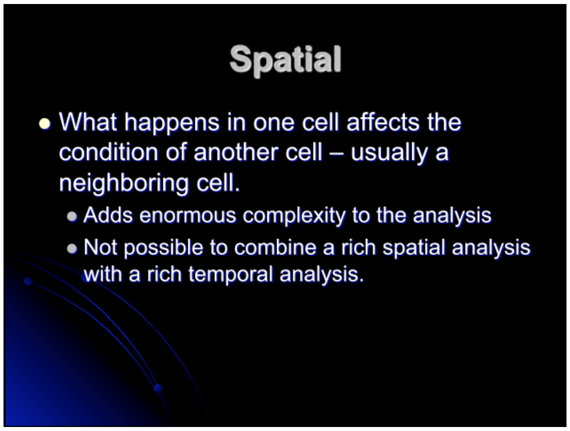
Temporal – stock metrics

- Site Condition (Stock Measure)
  - Ecological attempts
    - Condition Class, FRCC, FRID
      - A proxy for site condition or capital value
      - Not useful with out extensive additional information
  - Modern Planning edition
    - Desired future condition
      - A proxy for site condition or capital value
      - Not useful without extensive additional information



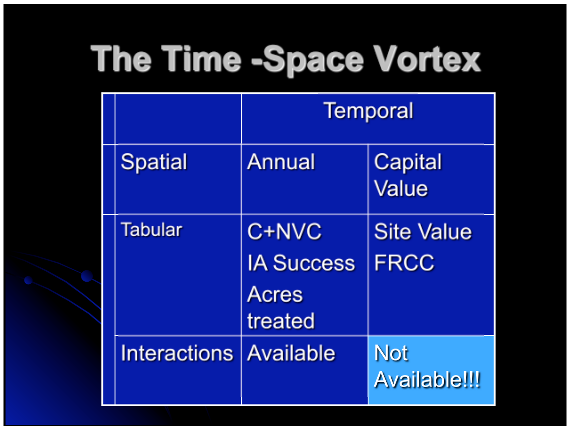
Temporal—Stock--Historical

- All are monetized – require benefit estimates
  - Site Value, Bare Land Value, SEV
    - Designed for commercial timber rotation
  - Benefit/Cost Analysis
- No econonmically sound performance measures are available to address the value of natural capital.



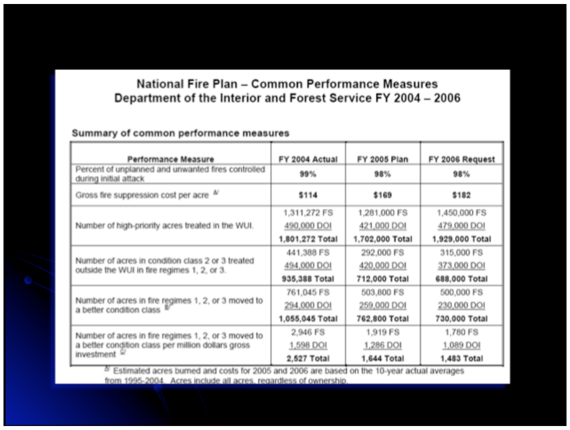
Spatial

- What happens in one cell affects the condition of another cell – usually a neighboring cell.
  - Adds enormous complexity to the analysis
  - Not possible to combine a rich spatial analysis with a rich temporal analysis.



The Time -Space Vortex

	Temporal	
Spatial	Annual	Capital Value
Tabular	C+NVC IA Success Acres treated	Site Value FRCC
Interactions	Available	Not Available!!!



National Fire Plan – Common Performance Measures
Department of the Interior and Forest Service FY 2004 – 2006

Summary of common performance measures

Performance Measure	FY 2004 Actual	FY 2005 Plan	FY 2006 Request
Percent of unplanned and unwanted fires controlled during initial attack	**99%**	**98%**	**98%**
Gross fire suppression cost per acre [a]	**$114**	**$169**	**$182**
Number of high-priority acres treated in the WUI.	1,311,272 FS 490,000 DOI **1,801,272 Total**	1,281,000 FS 421,000 DOI **1,702,000 Total**	1,450,000 FS 479,000 DOI **1,929,000 Total**
Number of acres in condition class 2 or 3 treated outside the WUI in fire regimes 1, 2, or 3.	441,388 FS 494,000 DOI **935,388 Total**	292,000 FS 420,000 DOI **712,000 Total**	315,000 FS 373,000 DOI **688,000 Total**
Number of acres in fire regimes 1, 2, or 3 moved to a better condition class [b]	761,045 FS 294,000 DOI **1,055,045 Total**	503,800 FS 259,000 DOI **762,800 Total**	500,000 FS 230,000 DOI **730,000 Total**
Number of acres in fire regimes 1, 2, or 3 moved to a better condition class per million dollars gross investment [c]	2,946 FS 1,598 DOI **2,527 Total**	1,919 FS 1,286 DOI **1,644 Total**	1,780 FS 1,089 DOI **1,483 Total**

[a] Estimated acres burned and costs for 2005 and 2006 are based on the 10-year actual averages from 1995-2004. Acres include all acres, regardless of ownership.

Conclusions

- Current performance metrics are not economically sound
  - Perverse management incentives
  - Do not represent true performance of the fuel and suppression programs
- Economic advancement is needed
  - issues of ecosystem management
  - natural capital formation and management

Document 8

Fire Use Workload Estimation

Journal Article

Title: A Managerial Approach to Estimating Wildland Fire Use Workload
Authors: Douglas B. Rideout, Robin M. Reich, Pamela S. Ziesler
Journal: Western Journal of Applied Forestry, accepted for publication in 2009

Description

This is an abstract and reference for an article on fire use workload estimation that will be published in the Western Journal of Applied Forestry in 2009.

Abstract

Increasing recognition of the role of fire in natural ecosystems has increased the use of wildland fire as a management tool. Although wildland fire use (WFU) has been practiced for decades, it is emerging as an organized program. As such, the analytics of WFU, from a management sciences perspective, are largely undeveloped at a time when there is a growing need to inform program managers and support modeling efforts aimed at more cost effective fire management programs. Conventional initial attack modeling relates workload to fire perimeter; but there currently is no analogue for WFU events. This paper takes the first step in providing a companion estimation of WFU workload. WFU workload is estimated as a function of basic information on fire size and duration by using a regression tree analysis. Workload scores for wildland fire use management and monitoring were estimated separately. These estimates explained about 68 and 60 percent of the variation in the management and monitoring scores, respectively. The estimated scores were sensitive to fire size, although duration played an important role, especially on larger events. For example, fires in the same size class often received higher workload scores with increasing duration. Workload estimates from the management regression tree were then associated with average resource usage. The form of the association indicated that as workload estimates increased, average resource usage increased exponentially. Estimating workload scores as a function of size and duration, which are readily available from simulation models, and then associating the scores with resource usage supports efforts to address WFU effort and cost management.

Reference

Rideout, D.B., R.M. Reich, and P.S. Ziesler. 2009 (Accepted for Publication). A Managerial Approach to Estimating Wildland Fire Use Workload. Western Journal of Applied Forestry TBD:xxx-xxx.

Document 9

National Tradeoff Analysis Phase II

Report

Title: National Tradeoff Analysis
Authors: John Sessions, Michael Bevers, Douglas B. Rideout
Date: October 23, 2006

Description

This is the national tradeoff analysis paper submitted to the science team for its paper on Phase Two. This paper includes the goal programming approach to budgeting the set of annual fire plans that would be forwarded by all of the planning units. It also shows in a tabular form some basics of goal programming.

NATIONAL TRADEOFF ANALYSIS
Draft 3, October 23, 2006
Sessions/Bevers/Rideout

Introduction

The objective of the National Tradeoff Analysis is to assist decision makers at the national level in (1) understanding the tradeoffs between fuel treatment investments, initial attack investments, and large fire suppression costs and (2) making decisions involving expenditures considering fire program components, regional differences, and goals of the land managing agencies.

Following national and regional guidance on the development of alternatives, each Fire Planning Unit (FPU) would prepare a range of alternatives that represent different mixes of fuel treatments, and initial attack organizations (preparedness) considering the goals and management plans of the agencies within each FPU. For each FPU, an estimate of large fire escapes will be developed through initial attack simulations. For western forests, a fire spread model will be used to estimate a large fire size distribution. Large fire suppression costs would be estimated using fire size and other landscape variables and a large fire cost frequency distribution would be developed. Along with the fire size distribution would be a frequency distribution for large fire burned area in the Wildland Urban Interface (WUI) for each FPU. Distributions of other landscape measures may also be derived including valuable habitat lost, and acres moved toward desired future condition. Other measures such as percentage of escaped fires could also be tracked. For eastern forests, where large fires are rare, all fires could be simulated as initial attack or extended initial attack.

Given the development of 5 to 10 *or* more plans at each FPU, what is a useful way for national-level decision makers to sort through the investment opportunities?

Alternative Methods

Maximizing or Minimizing a Single Goal

One method is to choose a single goal to maximize or minimize at the national level, such as to maximize initial attack success or minimize large fire suppression costs and then to establish constraints for the other attainment measures. The decision variables are which alternative plan should be chosen for each FPU to maximize or minimize the national goal while achieving at least a minimum level of the other goals which are represented as hard constraints. If a solution cannot be found, i.e. the identification of an alternative for each FPU that, in sum over all FPUs, satisfies all of the national constraints, the solution is labeled infeasible and one or more constraints must be changed and the problem resolved. If the problem is infeasible, it is not always obvious which constraint is preventing achievement of the minimum output levels.

Minimizing Deviations from Multiple Goals

An alternative approach is to establish a target for each goal and to minimize the sum of the deviations from the targets for all the goals. This technique is called "goal programming". Since the goals are often not in the same "currency", the deviations are then scaled and perhaps weighted to indicate relative priorities. Use of the method requires that (1) a decision maker must establish a target for each goal, and (2) that the decision maker must decide the scale or weight to be applied to each goal. Sometimes the deviations from targets are raised to powers so that the "penalty" for non-achievement increases as the distance from the goal becomes greater. If all goals can be satisfied, the sum of the deviations is zero. Goal programs have an advantage in that the problem is never "infeasible" in the sense that a solution cannot be found. Instead, if all goals cannot simultaneously be achieved, the deviations from the goals are "minimized" consistent with the weighting factors. Goal programming allows decision makers to explore the decision space through changing either the targets or the weighting of the deviations, or both, to favor particular goals. A disadvantage of goal programming when all targets are satisfied, i.e. that the decision maker is not informed of potentially better solutions, can be avoided by increasing at least one target until not all targets can be met. On the other hand, when competing goals exceed scarce resources, none of the goals may be reached so this may not be an issue.

<u>Example Targets at National Level</u>

1. Fuel treatment costs to treat x% of landscape over 5-year period, $/year
2. Annual Preparedness Budget for 5 years after fuel treatments implemented, $/year
3. Expected suppression cost for large fires, $/year
4. Wildfire cost to be exceeded only one year in ten, $/year
5. Expected acres in WUI burned at high intensity, acres/year
6. Acres in WUI burned at high intensity to be exceeded only one year in ten, ac/year.
7. Expected percent of fires suppressed during initial attack, fires suppressed/fire starts x 100

Table 1. Example Inputs and Outputs Passed Up From FPU's

Input/Output		FPU 1				FPU 138			
		Alt 1	Alt 2	Alt 3	…	Alt1	Alt 2	Alt3	…
Fuel treatment,	$mm/yr	0.5	1.5	3.0		0 .6	1.7	4.0	
Preparedness,	$mm/yr	1.6	1.6	1.2		2.0	2.0	1.5	
Wildfire cost	avg $mm/yr	3.5	2.7	2.2		4.0	3.5	2.5	
Wildfire cost, one year in ten	$mm/yr	7.0	6.5	3.5		8.5	7.0	5.0	
WUI burned	avg ac/yr	550	900	200		750	500	200	
WUI burned one year in ten	ac/yr	1500	1000	300		2000	1250	350	

Fire starts	avg total	74	69	76	195	186	177
Fires suppressed at Initial Attack	avg total	71	67	75	188	182	175

Example Objective Function

As an example assume that the following seven considerations are important to decision makers: (1) fuel treatment costs per year, (2) preparedness, (3) expected annual wildfire cost, (4) wildfire cost exceeded one year in ten, (5) expected WUI acres burned, (6) WUI acres burned exceeded one year in 10, and (7) percent of fires suppressed during initial attack. (Note: Care must be used in the interpretation of wildfire cost one year in ten (4) and WUI acres burned one year in ten (6). Since each FPU sends up information about wildfire cost and WUI acres burned which are exceeded one year in 10 in their respective FPU, even given national weather, this cannot be exactly translated to the national target only being exceeded one year in 10 unless the fires among FPU were perfectly correlated. If extreme fire years among FPU's are not perfectly correlated, the national result will be less. But the purpose of suggesting measures such as (4) and (6) for the objective function is to permit decision makers to explore the sensitivity of budget allocations that consider a measure of extreme events as well as the mean.)

We could express these considerations as goals and establish targets or desired achievement levels. We then want to identify the set of FPU alternatives that comes closest to minimizing the deviations or under-achievement of the targets.

Table 2. Example of National Targets

Fuel treatment,	$mm/yr	200
Preparedness,	$mm/yr	400
Expected Wildfire cost	$mm/yr	900
Wildfire cost, one year in ten	$mm/yr	1500
Expected WUI burned	m ac/yr	10
WUI burned one year in ten	m ac/yr	14
Fires suppressed at Initial Attack	avg %	98

In the example below, we choose to minimize the "squared" deviations from the targets so that the penalty is exponentially higher for large underachievement of goals than for small underachievement of goals. The *w*'s are weights that express the relative importance for the goal as well as act as scaling factors. In this example, the deviations are *only counted* if we have underachievement of our goals.

$$\begin{aligned}\text{Minimize}\quad & w1\ (200\text{-fuel treatment costs from FPUs})^2 + w2\ (400\text{-preparedness costs from FPUs})^2 \\ & + w3\ (900\text{-wildfire costs from FPUs})^2 + w4\ (1500\text{-One in ten wildfire costs from FPUs})^2 \\ & + w5\ (10\text{-WUI m-acres burned from FPUs})^2 + w6\ (14\text{-One in ten WUI m-acres burned from FPUs})^2 \\ & + w7\ (98\text{-initial attack success from FPUs})^2\end{aligned}$$

To explore the decision space, the decision makers increase or decrease the weights, the targets, or both. For example the higher the weight, $w6$, the more attention that will be placed on reaching the goal of not burning more than 14,000 acres in the WUI in more than one year in ten. The output is the choice of an alternative for each FPU that most closely achieves the goals for the specific weighting of the goals and the targets.

Additional Goals and Constraints

Additional goals and constraints can be added to reflect regional and national agency priorities as long as the alternatives passed up from the FPU's include this detail. For example, for each alternative, the cost by agency for fuel treatments and preparedness could be passed up along with the other inputs and outputs. Regional or national targets by agency are then added as additional goals to the national model.

Framing the Analyses and Presenting Results

In order to present results meaningfully, it is useful to frame the analyses. One approach is to use a method known as preemptive goal programming to initially explore in an automated series of "runs" the most achievement possible for each performance measure given the constraints, costs and performance estimates in the system. The results of all these runs can be saved, and estimated expected and extreme (e.g., 90th percentile) values of performance measures can be presented graphically to show the full range of efficient decisions available for a given level of budget. These results can then be used to set scaling and weighting factors as well as targets for subsequent runs that help decision makers explore more intermediate, less extreme solutions of interest.

Remaining Issues

Some fire program elements may have joint costs. For example, resources used in certain fuel treatments may simultaneously also support preparedness. Joint costs cannot theoretically be divided between elements. To the extent that joint costs are important, they may need to be put in a separate category, identified in each FPU alternative, and carried upward to the national model.

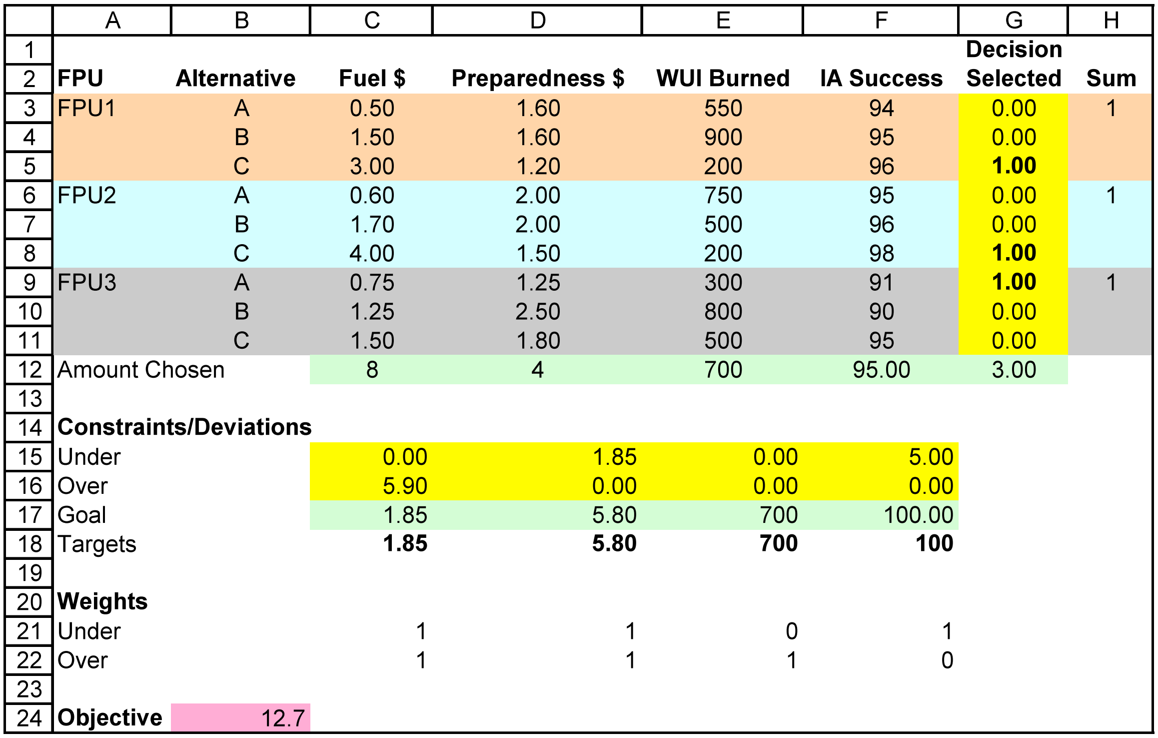
The issue was noted above that sums of 90th percentile estimates from FPU simulations are not equivalent in general to 90th percentile values at the national level. Estimating national-level probability distributions of performance measures in the proposed system would require correlating simulations nationwide. Methods such as chance-constrained goal programming might then be used to improve national-level risk analysis, but the resulting system would likely be too large and complicated for practical application.

Hardware and Software

Solution time is fast and hardware requirements are small. Solution times on a common laptop would be expected to be less than 1 minute. Expected software development would be less than $30,000.

APPENDIX: Solved examples.

This section provides a tabular representation of the example developed in the body text with minor modifications. The spreadsheet picture shown below summarizes the problem and how solutions can be generated.



	A	B	C	D	E	F	G	H
1							**Decision**	
2	**FPU**	**Alternative**	**Fuel $**	**Preparedness $**	**WUI Burned**	**IA Success**	**Selected**	**Sum**
3	FPU1	A	0.50	1.60	550	94	0.00	1
4		B	1.50	1.60	900	95	0.00	
5		C	3.00	1.20	200	96	**1.00**	
6	FPU2	A	0.60	2.00	750	95	0.00	1
7		B	1.70	2.00	500	96	0.00	
8		C	4.00	1.50	200	98	**1.00**	
9	FPU3	A	0.75	1.25	300	91	**1.00**	1
10		B	1.25	2.50	800	90	0.00	
11		C	1.50	1.80	500	95	0.00	
12	Amount Chosen		8	4	700	95.00	3.00	
13								
14	**Constraints/Deviations**							
15	Under		0.00	1.85	0.00	5.00		
16	Over		5.90	0.00	0.00	0.00		
17	Goal		1.85	5.80	700	100.00		
18	Targets		**1.85**	**5.80**	**700**	**100**		
19								
20	**Weights**							
21	Under		1	1	0	1		
22	Over		1	1	1	0		
23								
24	**Objective**	12.7						

The input data from Table 1 and Table 2 was repeated and FPU3 was added to populate the spreadsheet. We also reduced the number of national targets to four. These input data are listed in cells A2 through F11.

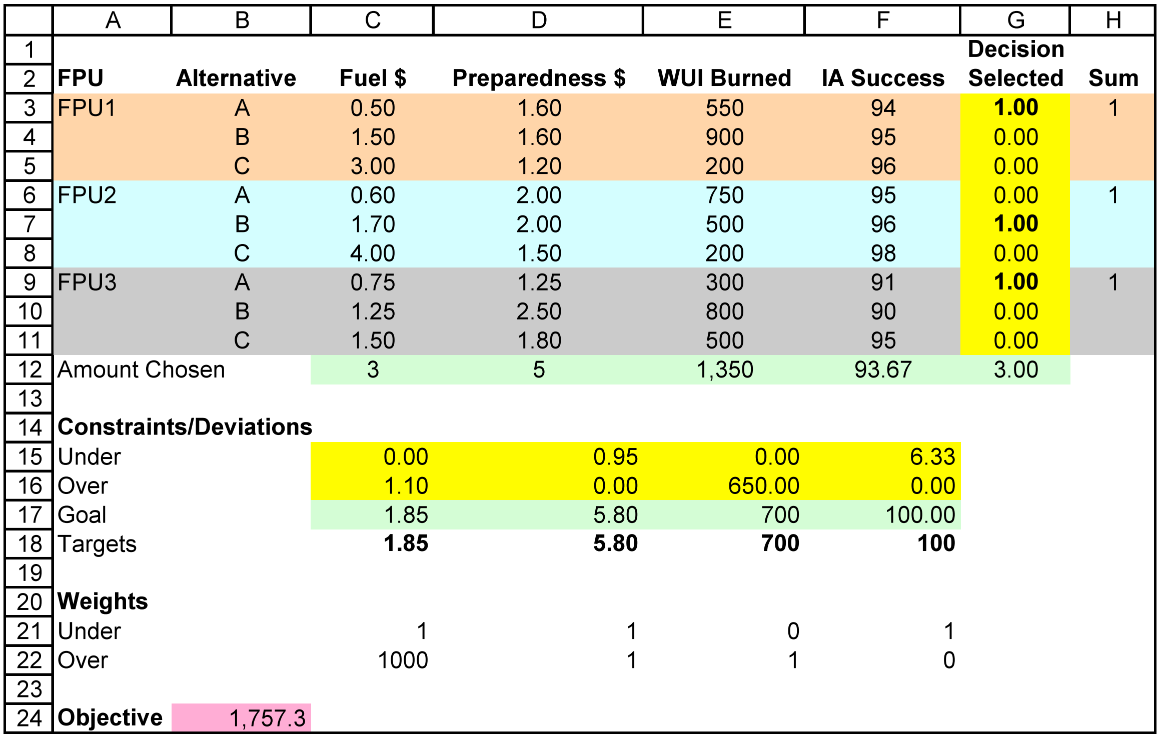
The national targets for this example are listed in row 18 (their amounts differ from those in Table 2). The deviations from the goals are shown in rows 15 and 16 and a set of goal weights appear in rows 21 and 22.

The goal weights on the fuels and preparedness budgets were set to 1.0 for both over and under achievement of the target budget. This penalizes the objective (B24 minimization of the sum of weighed deviations) for movement away from the target budget for each program component. The weight on WUI acres was set to 1.0 for burning more acres than the goal target of 700 acres. The weight on under achieving IA success (F21) was set to 1.0 to penalize for underachievement of the target IA success rate of 100 percent (F18).

For this example, one project must be selected per FPU to represent the equivalent of an annual program. For example, the fuel alternative for a given FPU could represent the annual fuel program and the annual preparedness program.

The projects selected by the goal program are shown by the 1.0 indicated in column G. With the data given, the collection of projects that best meets the weighted goals (B24) are projects C, C, and A for FPUs 1,2, and three respectively. The WUI goal was exactly met, while others were compromised.

Given the structure of the goal program, and a given set of target values, the decision maker can alter the weights to obtain different solutions. Suppose, for example, that the weigh on overspending on the fuels budget were increased from one to 1,000. The results of this are shown in the second Excel picture.



	A	B	C	D	E	F	G	H
1							**Decision**	
2	**FPU**	**Alternative**	**Fuel $**	**Preparedness $**	**WUI Burned**	**IA Success**	**Selected**	**Sum**
3	FPU1	A	0.50	1.60	550	94	**1.00**	1
4		B	1.50	1.60	900	95	0.00	
5		C	3.00	1.20	200	96	0.00	
6	FPU2	A	0.60	2.00	750	95	0.00	1
7		B	1.70	2.00	500	96	**1.00**	
8		C	4.00	1.50	200	98	0.00	
9	FPU3	A	0.75	1.25	300	91	**1.00**	1
10		B	1.25	2.50	800	90	0.00	
11		C	1.50	1.80	500	95	0.00	
12	Amount Chosen		3	5	1,350	93.67	3.00	
13								
14	**Constraints/Deviations**							
15	Under		0.00	0.95	0.00	6.33		
16	Over		1.10	0.00	650.00	0.00		
17	Goal		1.85	5.80	700	100.00		
18	Targets		**1.85**	**5.80**	**700**	**100**		
19								
20	**Weights**							
21	Under		1	1	0	1		
22	Over		1000	1	1	0		
23								
24	**Objective**	1,757.3						

Rerunning the goal program will now indicate the selection of projects A, B and A with no overspending on the fuels budget. The cost of this in terms of other goals is revealed by reductions in IA success to 94 percent, an increase in WUI acres burned and an increase in preparedness cost. In this way, goal programming can aid with managing the tradeoffs between program performance and spending targets.

Document 10

Probabilistic Approach to Phase II

Report

Title: A Probabilistic Approach to Strategic Fire Management

Description

This is the paper on the probabilistic approach to fire program analysis consistent with the unified theory addressed above in tab three. This paper is a more pragmatic depiction of the probabilistic approach than the book chapter under tab three. This approach was dismissed by Tom Quigley in our meetings because he incorrectly associated it with optimization.

Abstract / Introduction

This is an outline of key elements of a probabilistic framework of fire program component management. This material supports a general or philosophical approach that could be developed in a variety of ways. Several early prototypes have developed this theory in different ways. The probabilistic framework presented here is not intended as a specific formulation; instead, it supports the potential for more specific model development and formulation.

Historically, models in fire management have been “event based” where hypothetical fire events or “event scenarios” are tactically managed in the hope of providing strategic modeling analysis. These models have focused on tactical management as an indirect means of addressing strategic or program management. A probabilistic approach enables the analyst to directly address strategic management and to avoid “stove piping.” A direct strategic analysis is facilitated by modeling a probabilistic surface and its response to management variables such as fire program components.

A Probabilistic Approach to Strategic Fire Management

This is an outline of key elements of a probabilistic framework of fire program component management. This material supports a general or philosophical approach that could be developed in a variety of ways. Several early prototypes have developed this theory in different ways. The probabilistic framework presented here is not intended as a specific formulation; instead, it supports the potential for more specific model development and formulation.

Historically, models in fire management have been "event based" where hypothetical fire events or "event scenarios" are tactically managed in the hope of providing strategic modeling analysis. These models have focused on tactical management as an indirect means of addressing strategic or program management. A probabilistic approach enables the analyst to directly address strategic management and to avoid "stove piping." A direct strategic analysis is facilitated by modeling a probabilistic surface and its response to management variables such as fire program components.

1. Probabilistic surface approach supports flexible and integrated analysis

1.1. ***Fire probability directly integrates program components:*** The probabilistic approach enables program components such as suppression, fuels and prevention to address common metrics of performance. Planning for each component will take into consideration predicted fire probability distributions. By including other factors associated with potential losses or benefits, the performance of each component can be reflected through fire probabilities. Tradeoffs among components can also be analyzed through fire probabilities. Integrated analysis can help avoid "stove piping" of individual program component analysis.

1.2. ***Fire probability can take advantage of the strengths inherent in the integration of simulation and optimization models:*** The Probability based approach can use advances in simulation, optimization and Bayesian network methods as a means of estimating and managing landscape fire risk. The role of simulation could include is not limited to:

- Capturing complicated non-linear relationships in fire behavior.
- Capturing impacts from factors such as topological, weather, and vegetation conditions etc. to the fire behavior.
- Simulation of multiple fire events to reflect stochastic factors in fire management.
- Create performance functions at a strategic level.
- Validation of the effectiveness of fire management by simulating fire events in landscapes before and after management activities are applied.

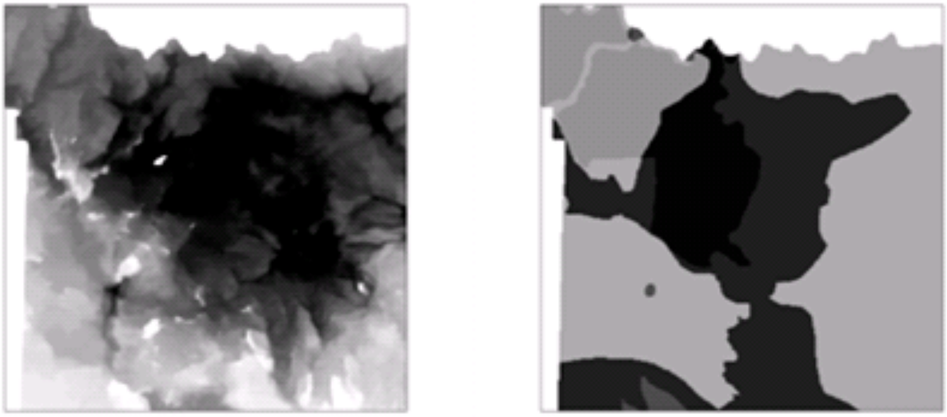
Optimization models are suitable to capture well-structured relationships and to conduct systematic searches for good solutions. The basic function of such models is to provide efficiency oriented analytical tools to solve difficult decision problems. Roles of optimization should include but are not limited to:

- Capturing strategically important spatial and temporal relationships.
- Integration of key management concerns (fire loss, budget, locations etc.) of fire management into an integrated but well structured system to support performance based sensitivity analysis.

1.3. ***Scalability of results**:* Because the process is defined by an underlying spatial probability surface, the probabilistic model has the potential capability to be applied at fine or large scales. The approach also supports scaling finer or larger to connect with analysis performed at a different, but compatible spatial scale.

2. A potential structure of the probabilistic model

2.1. Program components operate on a common "platform" or a common specification of the production function. The platform represents the estimated probability of burning created from simulation. Other spatially explicit information such as fire intensity and indicators of relative resource values can also be added into analysis. For example, in Fig. 1(A) a pixilated probabilistic landscape surface indicating the relative probability of burning by cell is illustrated. Darker cells indicate higher probability of burning. In Fig 1(B) the same is shown but now cells indicate the importance of loss (gain) from burning. Simulation methods can support the construction of the change in the response surface relative to decision variables such as program component levels.



(A) (B)

Figure 1. Distribution of relative fire probability and the value to be protected at high intensity fires.

2.2. Simulation of fire events can be used to address and estimate the relationship between probabilities and fire events. For example, simulations before treatments compared with simulations after treatments can provide basic data from which to associate probabilities with changes in program component levels. While this may seem problematic, the same issue (estimating probabilities and relating changes in probabilities to management variation) is at work implicitly or explicitly on all of the modeling options to be considered.

2.3. The surface is applied across the geographic area where the scale can be tailored to fit the requirements of the problem. Management units can be pixels or polygons also depending upon the requirements of the problem. Management units may or may not include spatial interaction depending upon the specification of the problem. For example, at finer scales, it might be more important to capture the spatial interaction between units.

2.4. At the scale that cellular relationships are important, detailed cellular interaction can be simulated through fire behavior models. Cellular relationships can be generalized to construct an optimization model. Site specific management activities will influence a much broader landscape through cellular relationships.

2.5. A hierarchical probabilistic modeling structure would support bottom-up and/or top-down approaches.

2.6. Results of management schedules could be validated through the next iteration of fire event simulation.

2.7. Probability can be estimated by intensity level—probability of high intensity fires and probability of low intensity fires. The potential for fire loss can be specified at different intensity levels.

3. Management Variables: program components

3.1. Specification of probabilities as a function of management/program components such as P = f(suppression, fuels, prevention+…) and other physical characteristics.

3.2. Individual or "own" effects

3.2.1. Implies that for cells where the marginal product (reduction in probability from a change in management) is reduced by increasing level of program component (for damaging fires). An own effect is for each program component.

3.2.2. "Own Interactions" by knowing individual interactions, the model can consider the choice between applying fuels treatment or suppression to efficiently allocate the application of components. That is, a probabilistic approach directly addresses the question of the best use of program component by addressing questions such as: is purchasing more fuels management or more suppression by cell and by "landscape" more effective? This reflects a major advance over event-based applications which currently require sequential (as opposed to simultaneous) considerations of program interactions.

3.2.3. Cross Effects: The model allows for cross effects to directly address the potential complementarities of the components. For example, how does fuel treatment affect the marginal productivity of suppression? While these kinds of interactions are available in principle, they are difficult to directly model in any application. While the probabilistic approach enables such considerations they may require future development.

4. Results

4.1. Net Loss Function:

Net loss due to fire can be calculated across the landscape by pixel and or summed across the landscape to provide detailed or broad scale metrics of overall performance. Many additional metrics of performance can also be addressed. For example, addressing expected loss in the wildland urban interface can be addressed by associating WUI with particular cellular locations. Initial attack success rate, is not directly addressed in the model formulation because such a metric requires event-based calculations or at least a proxy for them. However, IA success rate will still be indirectly influenced through the control of fire probability and through pre and post simulations.

4.2. Allocation of Resources: the model directly allocates program components spatially thus avoiding issues of ownership or jurisdiction. The spatial attention to management supports involvement of the States.

4.3. "Smart Cloud" of Management Options: By combining simulation with optimization, relationships such as the marginal productivity of program components can be modeled with appropriate estimates of error to produce a smart cloud of results that can be presented for assessment. Additional sensitivity analysis can be performed to generate a set of smart options for consideration by managers and or policy makers. Such smart analysis would apply to applications at fine or large scale.

4.4. **An integrated and flexible analytical system to conduct performance based analysis and support cost effective decisions:** With the ability of integrating multiple fire program components and connecting event based simulations with strategic optimization, this system will be able to support fire management analysis at various scales from different aspects.

Document 11

Cost Considerations for Phase II

Report

Title: Modeling Costs in Fire Program Analysis
Authors: Doug Rideout, John Sessions
Date: October 21, 2006

Description

This is the material on cost considerations prepared by myself and John Sessions for the Science Team paper. This paper addresses cost issues such as joint costs, prototype modeling and the costs of large fires.

Modeling Costs in Fire Program Analysis

Doug Rideout and John Sessions
October 21, 2006

Fire Program Analysis, Phase 2 is intended to address the integration of program components in a single analysis. This broadening of the scope of analysis introduces at least two new and important cost considerations: the treatment of costs by program and the estimation of the suppression costs of large fires. They are addressed in the following.

Costs by Program Component and the Joint Cost Consideration

National fire programs include at least three important program components: preparedness, fuels management and prevention. . The interaction among components includes three elements: interactions in productivity, interactions in cost and budget sharing (Rideout et al. In press). Previous fire management models did not attempt to address the integration of program components. For example, the preparedness costs used in CEFS2 currently do not consider that those preparedness costs are likely shared with the other program components. This cost sharing refers to the economic condition known as "joint costs." When costs are joint, this means that a cost item will promote more than one activity or outcome. For example, a fire engine may be used in both fuels management and in preparedness planning. The fundamental economic principle of joint costs is that there is no logical way to assign, or break up joint costs among its different purposes. Assigning joint costs is economically arbitrary and therefore misleading.

In many joint cost problems there are also separable costs. These cost are not joint and are can be separated by purpose or activity. Fire management systems are characterized by joint and separable costs.

How important are joint costs to Fire Program Analysis modeling? The answer depends upon several considerations, but one is the extent that costs are joint. For example, how much of the costs of preparedness promote the other program components? Because there has been no analysis of this problem, we interviewed subject matter experts at the National Interagency Fire Center in Boise, ID to obtain a sense of the magnitude of jointness among the program components. Experts consistently responded that the extent that the cost of any one program component was shared by 60-95% with some other program component. In addition to the three key program components (fuels, preparedness and prevention), joint costs are well recognized across considerations of scale, such as the distinction between initial attack fires and large fires. For example, retardant aircraft are often used on both kinds of incidences. Therefore, we suggest that joint cost considerations are likely important when modeling any of the cost components.

Questions are often raised such as "If we place another dollar in the preparedness program, will that be more effective than placing another dollar in the fuels program?" The answer to such a question is complicated by the extent of jointness between the programs.

Addressing Joint Costs

There are several ways to address the joint cost problem. An economically sound approach would identify cost pools as shown in the table below:

Program Component	Separable Costs	Joint Costs
Preparedness	$$	Joint $$
Fuels	$$	
Large fires	$$	
	$$	

Noting that the “$$”s denote dollar allocations to the pools with no attempt to sort the joint costs by component, but to carry them along as common to their programs. Also note that while the joint costs are shown as a single group that sub-groups of jointness can occur (but not shown here).

The first step to toward managing joint costs is to identify how much of cost is joint versus separable. In most fire management activities, anecdotal evidence suggests **a reasonable first approximation would identify fixed costs a joint and variable costs as separable.** Fixed costs would refer to the cost of having a resource available for the season regardless of it’s usage, while variable costs are a function of the extent of use.

A second step is to assess the program components to see if there are distinguishing features that might affect the division between joint and separable costs. For example, fuels treatments can be attained through prescribed fire, mechanical treatments, or through chemical applications (or some combination). Fuel treatments through prescribed fire have a high joint cost with preparedness while fuel treatments obtained through mechanical means likely do not. They may have a joint cost element through harvesting systems—or perhaps with the timber program.

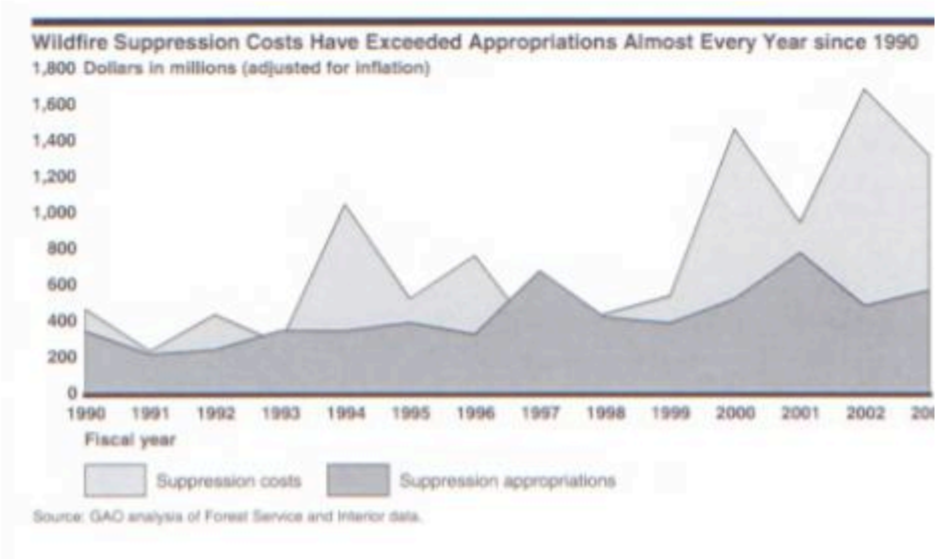
Also helpful can be the use of contracting information where contractors will often separate charges by component. Although not perfect, this can also provide some guidance on both joint and separable costs.

Prototype modeling suggestions

Because this has not been attempted before in the fire program, some prototyping of alternatives could be considered. First, the fixed and variable costs should be identified and the variable costs should be treated as separable costs. The fixed costs should be treated as joint with at least one other program component. For the joint costs, two prototyping approaches could be considered. First, and the most economically sound, is to keep a joint cost pool, or joint cost pools by program group(s). The second is to make the arbitrary rounding rule for dividing costs by program component. The second approach should only be prototyped if it can be compared with the first approach to examine the extent that assigning costs does not provide excessive misinformation.

COST OF LARGE FIRES

The cost of large fires is a central element of any integrated fire management system. Designing and constructing a cost-effective analytical management model, as is intended through the Fire Program Analysis Project (FPA) suggests modeling cost effective approaches to the analysis of large fires. While the magnitude of the large fire problem is well recognized, the illustration below from a recent US Government Accounting report (US GAO 2004) shows both the magnitude of suppression costs and how it has increased with time.



Source: GAO analysis of Forest Service and Interior data.

Analysis of suppression costs for the most recent season suggests that they were considerably higher than any of the points represented in the GAO chart. These costs do not include the cost of resource and property damage.

This suggests that there are minimally two important issues of relevance to FPA: first, to enable the FPA modeling system to estimate the cost of fires that escape the initial attack simulation, and secondly, to the extent that FPA is intended to address cost effectiveness, to at least acknowledge and distinguish cost estimation efforts form cost management efforts. The importance of the cost management effort was expressed this year by Undersecretary Mark Rey and Deputy Secretary Lynn Scarlet (Rey and Scarlett 2006) as:

> *"…our efforts to contain the costs of large fires. Large fire events are costly and Congress has routinely expressed its concerns about rising fire suppression costs. We share those concerns and are working to address suppression costs."*

There have been many research efforts to develop a sound econometric theory for expressing, estimating, and to ultimately better manage these costs. Despite such efforts, and like the problem of joint costs, there is currently no accepted process that we can readily draw upon for modeling in FPA. The reason for this is that the problem is inherently complex and characterized by great variation and difficulty in specifying an underlying theoretic production relationship and economically sound framework. Therefore, instead of identifying a specific solution, we will identify potential approaches and considerations recognizing that some may provide useful avenues for prototype development and some may provide considerations germane to any approach this ultimately pursued.

Cost estimation research has taken several avenues of inquiry including:

1. In sample estimates that used to specify and quantify relationships within the sample data,
2. Predicting and/or forecasting the cost of particular fires, and
3. Managing the cost of large fires.

In all of these efforts, acquiring historical data is an important and usually cumbersome step. Cost data on fire and fuels management is well-known to have quality issues that are time consuming to remedy. Nonetheless, fuel treatment data can be obtained through the NFPORS system while suppression data can be obtained though the FIRECODE system. In addition, individual fire records are usually required such as those known as the DI 1202 and the FS5100-29 records.

In sample data and forecasting

While each of these is related, they imply different perspectives on the large fire cost problem. In sample estimation processes, to date, have focused on the working with a positive correlation between fire cost and fire size. The cost estimates are typically adjusted for other significant variables related to physical or social setting, such as fuel type or proximity to housing. These studies, such as the one explained below by Gebert et al. (In press) (GCY) are useful for identifying the variables that affect cost, but they have not been very reliable for predicting the cost of individual fires (note the confidence interval in prediction in GCY).

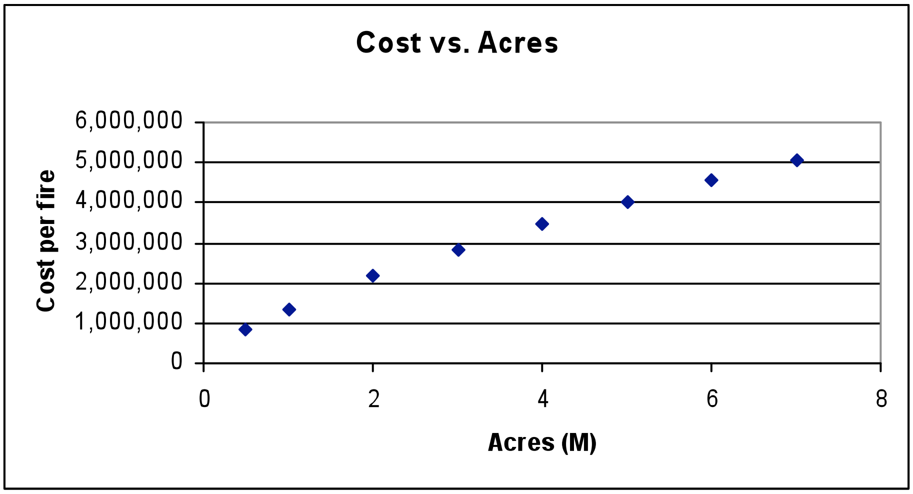
A recent data analysis by GCY is summarized in the draft manuscript. "Estimating suppression expenditures for individual large wildland fires". The data base involved 1550 fires greater 100 acres involving expenditures of almost $2 billion. GCY did find suppression costs differ by region, but also developed regression models that related fire suppression cost to (1) fire size, (2) slope, (3) flame length, (4) fuel type, (5) total housing value within 20 miles of fire ignition, and several other variables. These are all variables which we could evaluate during landscape fire simulations. Although the error terms are large, the relationships may still be useful.

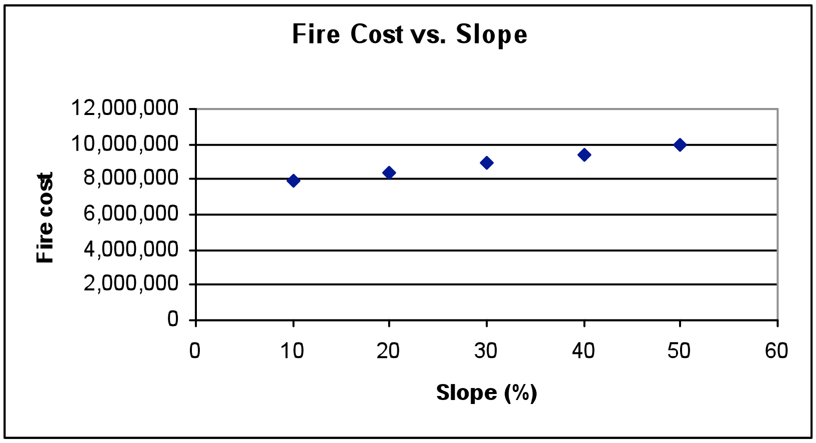
In sum, GCY state:

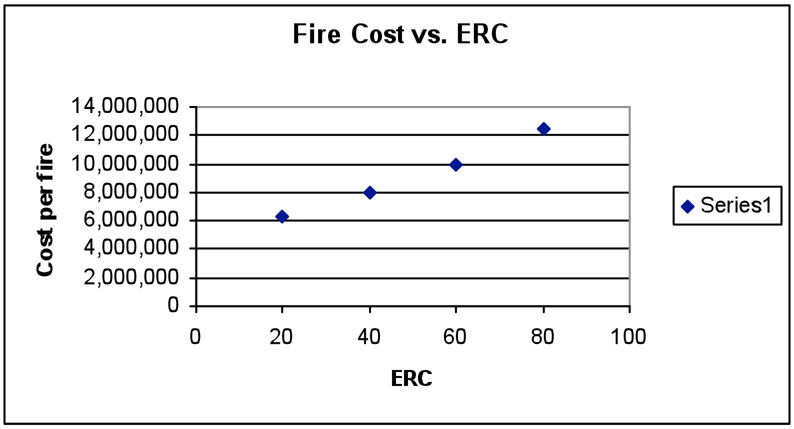
Suppression Expenditures/area burned = fn (area burned, environment, values at risk, resource availability, initial suppression strategy, delay).

Sensitivity to Key Independent Variables

Key predictors of suppression cost were found to include: fire acreage, intensity, fuel type, slope, housing value, slope and energy release component (ERC). Also used were eastern U.S. versus western U.S. A complete list and specification of the regression model is shown in the appendix. The following illustrations show model behavior across a single independent variable. For each illustration the following were held constant: Region is west, acres is 500, intensity is 4, fuel type is timber, housing is 1800000, slope is 20%, energy release component is 45.


Cost vs. Acres
Cost per fire
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
0
2
4
6
8
Acres (M)


Fire Cost vs. Slope
Fire cost
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
0
10
20
30
40
50
60
Slope (%)


Fire Cost vs. ERC
Cost per fire
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
0
20
40
60
80
100
ERC
◆ Series1

The relationship between housing values within 20 miles of the ignition point and suppression cost could potentially provide a linkage between fuel treatments and the WUI. We were going to present some examples of changing housing values but the input units and ranges need to be clarified. For the examples we ran, the incremental fire suppression costs far exceeded housing values when housing values > 0.

Forecasting models have taken other forms such as including a two step process. These models have sometimes used time series to forecast acres burned and then used acres to predict costs. And a third related approach has been to specify the problem as one of joint production where the outcomes are modeled as acres burned plus resources damaged.

A central issue with all of these is that while they have been differentially useful in establishing some relationships, they have been problematic in addressing the cost element of large fires as a decision variable in that correlations from historical data to not imply causation. Understanding the current cost structure can be an important step, cost management of large fires

In approaches described above treat the cost of large fires as an outcome that can only be managed through the adjustment of program inputs. In a more general sense, managing large fires as a consequence suggests that the cost of large fires could be specified as a function of other program elements as well as physical conditions etc. For instance, and consistent with elements of the modeling effort we might treat large fire costs (LFC) as:

LFC = f(preparedness, fuels, prevention, aviation resources used, roaded, fire size, etc.)

For example fuel management options that reduce fire intensity and thereby reduce the resistance of fires to control can, in principle be modeled to address the tradeoff between fuels management costs and LFC.

An additional cost element is likely the multi-jurisdictional event involving fire management coordination and cost pooling across fire management agencies including States and potentially private cooperators.

And to date, such an approach has some pragmatic appeal, but does not recognize that the large fire itself can be directly managed and therefore its costs can be more directly managed. The larger question is will simulations of marginal changes in fire programs while addressing the cost of large fires as an outcome address the cost containment issues raised by Rey and Scarlett?

Directly managing the cost of large fires

The key to managing the cost of large fires involves two elements: managing the fire and incentives for managing costs. During a large fire event, there are many important decisions to be made regarding the use of very expensive fire fighting resources and regarding the values to be protected. The ability to manage these fires and their cost goes to the heart of the large fire cost containment problem and to the ability of systems, including FPA to address cost effective solutions and approaches. During a particular event key choices emerge such as the option to engage in point protection instead of perimeter management. In some instances this has the potential to greatly reduce costs while protecting important points of value. In other instances aggressive line building along just a single flank may be adequate. The opportunity for more creative approaches to cost management is recognized through the technique known as "Appropriate Management Response" that is consistent with the new fire management policies (1995, 2001 and 2003) and intended to provide wildland fire mangers with an increased set of fire management options. In contrast, large fire simulations assuming standard or even historical responses and management are unlikely to address the cost management issues well. However, the management of large fires has the potential to build on the strengths of simulation approaches. At this point, modeling direct management of large fires does not seem to be an available option for FPA. The kind of cost function consistent with economic theory, and consistent with both direct and indirect management of large fires would be of the form:

> Damage = f(LFC, preparedness, fuels, prevention, aviation resources used, roaded, fire size, etc.)

To recognize that costs spent on large fires can be managed and that they are a means to a larger end. This formulation is consistent with the literature on fire economics (fore example, Rideout (In press and Rideout 1990)

What modeling approaches should FPA address regarding large fire costs?

Despite great effort, understanding, managing and modeling the costs of large fires has not kept pace with the importance and magnitude of this growing problem. Because the ability to estimate the costs of individual large fire events is very imprecise, the modeling implications are worth considering.

1. Accurately or precisely simulating the size or intensity (including distributions) of large fires is not required for cost purposes because cost estimates are too imprecise to take reliable advantage of such simulations. In short, precise simulations will not improve the precision of cost estimates.
2. Prototyping by using regional average costs, perhaps stratified by broad size classes, should be considered as an option with some stratification by variables identified by CGY.
3. Prototyping by using a cost function similar to that developed by CGY should be considered and the precision of this compared with a simpler approach suggested in (2).

Literature Cited

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Rideout, Douglas B., Yu Wei, Andrew Kirsch and Stephen J. Botti. (Forthcoming). Toward a Unified Economic Theory of Fire Program Analysis. In: The Economics of Forest Disturbances: Wildfires, Storms and Invasive Species (Forestry Sciences). Thomas Holmes, Jeff Prestemon and Karen Abt. Eds.. Kluwer. (Manuscript available upon request)

United States Government Account Office. 2004. Wildfire Suppression: funding transfers cause project cancellations and delays, strained relationships, and management disruptions. GAO-04-61268pp.

Appendix: Detail from the GCY manuscript.

We suggest three important notes of caution in using the predictions from this study.

1. The authors caution that the error term for prediction is very large. From the authors: For instance, for the FY 2005 fires, the mean predicted value was $317 per acre with a plus or minus one standard deviation (68 percent) range of $88 to $1,132. This large range in predicted costs must be recognized when using these models for wildland fire decision support.
2. The authors discuss re-transformation bias. Retransformation bias can occur because the estimations were made in log-log form thus requiring the anti-log to arrive at estimates in un-logged form.
3. The dependent variable in this study is suppression cost (ln of per acre) as a function of acres (ln). Caution is required because for any given fire, increases in expenditure might be used to reduce fire size.
4. The cost estimations are made only from Forest Service data.

Appendix: Critical tables from publication paper

Table 1. Variables used in development of regression equations; dependent variable = Ln(expenditures/acre)

Fire characteristics	Variable definition	Source
<u>Size</u>		
Ln(total acres burned)	Natural log of total acres within the wildfire perimeter	NIFMID
<u>Fire Environment</u>		
Aspect	Sine and cosine of aspect at point of origin in 45 degree increments	NIFMID
Slope	Slope percent at point of origin	NIFMID
Elevation	Elevation at point of origin	NIFMID
Fuel type	Dummy variables representing fuel type at point of origin. Grass=NFDRS fuel model A,L,S,C,T,N; Brush=NFDRS fuel model F,Q; Slash=NFDRS fuel model J,K,I; Timber=NFDRS fuel model H,R,E,P,U,G; brush4(reference category)=NFDRS fuel model B,O..	NIFMID
Fire intensity level	Dummy variable for fire intensity level category 1-6 (fil 1 = reference category)	NIFMID
Energy release component	Energy release component calculated from ignition point using nearest weather station information (cumulative frequency)	Calculated

Values at Risk		
Ln(distance to nearest town)	Natural log of distance from ignition to nearest census designated place	Calculated
Ln(total housing value 5)	Natural log of total housing value in 5 mile radius from point of origin (census data)/100,000	Calculated
Ln(total housing value 20)	Natural log of total housing value in 20 mile radius from point of origin (census data)/100,000	Calculated
Reserved areas	Dummy variables indicating whether fire was in a wilderness area, inventoried roadless area, or other special designated area (reference category = not in reserved area)	Calculated
Ln(distance to reserved area boundary)	If in a reserved area, natural log of distance to area boundary	Calculated
Detection time		
Ln(detection delay)	Natural log of hours from ignition time to discovery time	Calculated
(Ln(detection delay))^2	Square of ln of detection delay	Calculated
Suppression Strategy		
Initial suppression Strategy	Dummy variables representing initial suppression strategy (confine, contain, control) – reference category = control	NIFMID
Resource availability		
Ln(average deviation)	Natural log of the difference between the number of fires burning in the region during the period of the specified fire compared to the average in that region during the same time of year	Calculated
Region	Dummy variables for NFS region (reference category for western model = Region 1, for eastern model = Region 9	NIFMID

Table 3. OLS regression models, western and eastern (Dependent variable = ln(suppression expenditures/acre), R^2(west)=0.44, R^2(east)=0.49, n(west)=1141, n(east)=409)

Variable	Regions 1-6		Regions 8-9	
	Coefficient	P-value	Coefficient	P-value
Ln(total acres burned)	-0.3238	0.000	-0.1941	0.006
Fire Enviroment				
Aspect (cosine)	-0.1675	0.005	0.1009	0.263
Aspect (sine)	-0.1066	0.149	-0.4388	0.000
Slope	0.0057	0.003	0.0065	0.059
Elevation	Not in model		Not in model	
Grass	-0.5703	0.000	-0.5339	0.015
Brush	-0.3613	0.075	2.0391	0.026
Slash	0.2817	0.175	0.3503	0.261
Timber	0.5032	0.001	0.4981	0.038
Fire intensity level 2	0.8442	0.000	0.2206	0.265
Fire intensity level 3	1.3224	0.000	0.8458	0.000
Fire intensity level 4	1.6930	0.000	1.0424	0.000
Fire intensity level 5	1.8715	0.000	0.8160	0.010
Fire intensity level 6	1.7865	0.000	1.6956	0.000
Energy release component	0.0113	0.000	0.0047	0.112
Values at risk				
Ln(distance to nearest town)	Not in model		0.3029	0.014
Ln(total housing value 5)	0.0059	0.686	0.0329	0.188
Ln(total housing value 20)	0.1131	0.000	0.1703	0.098
Wilderness area	-0.2123	0.151	0.6703	0.017
Inventoried roadless area	0.1453	0.311	0.5806	0.213
Other SDA	0.1788	0.363	-0.6272	0.208

Wild x Ln(distance to boundary)	-0.4309	0.000	0.7580	0.002
IRA x Ln(distance to boundary)	0.0861	0.272	-0.1413	0.622
SDA x Ln(distance to boundary)	-0.0905	0.313	-0.2781	0.187
Detection time				
Ln(Detection delay)	0.0353	0.171	-0.1859	0.000
Square of Ln(Detection delay)	-0.0184	0.037	0.0581	0.001
Suppression strategy				
Initial suppression strategy – confine	Not in model		0.6958	0.000
Initial suppression strategy – contain	Not in model		1.0056	0.002
Resource availability				
Ln(Average deviation)	-0.0970	0.093	Not in model	
Region				
Region 2	-0.5398	0.016		
Region 3	-0.0792	0.643		
Region 4	0.1283	0.446		
Region 5	0.9631	0.000		
Region 6	0.9697	0.000		
Region 8			0.8122	0.000
Constant	4.587	0.000	0.3919	0.699

Document 12

Documentation of Phase II Issues

Report

Title: Economic Considerations on Values, Cost and Cost-Effectiveness
Authors: Doug Rideout
Date: November 22, 2006

Description

This is a short paper on costs, values and cost effectiveness analysis that would be associated with the Science Team proposal for development of FPA Phase II. This paper was forwarded to the leadership of the DOI to inform and warn them of serious issues emerging with the direction FPA.

Preface

This is intended to provide candid assessments on elements of the current alternatives and to suggest ways in which alternatives could be strengthened to enhance the long-term credibility of FPA. It does not provide an overall assessment of the IST-based alternatives, with perhaps the exception of alternative one.

Economic Considerations on Values, Cost and Cost-Effectiveness

Prepared by Doug Rideout for Nina Hatfield[1]

November 22, 2006

Nina: In late September you solicited my assessment on values, costs and of cost effectiveness relative to the deliberations of the "science team."(IST). With better definition of the methods and of the proposed alternatives, I have prepared this considered response to your questions. I have also included statements on some closely related issues in the appendix beginning on page three. I appreciate your questions and I thank you for the opportunity to respond. –Doug.

Preface: This is intended to provide candid assessments on elements of the current alternatives and to suggest areas ways in which alternatives could be strengthened to enhance the long-term credibility of FPA. It is not provide an overall assessment of the IST-based alternatives, with perhaps the exception of alternative one.

Syntax:

> Management options – fuels, preparedness, etc., options prepared for and analyzed by FPA model.
>
> Proposed alternatives -- FPA project alternatives--currently there are five based on the IST deliberations. Because there is currently is no IST report this refers to the alternatives as currently described in FPA materials.

Conclusions

1. Valuation: Valuation needs considerable improvement and I am optimistic much of this can be addressed in ways that would improve each of the proposed alternatives.
2. Cost: Modeling cost as an output poses challenges and limitations that should be recognized. Such limitations can be compensated for by comparisons of management options and by installing an incentive structure to reward units for forwarding well designed management options. This would improve each of the proposed alternatives.

   Cost control of large fire costs is problematic when cost is modeled as an output. Applied research efforts focused on management and control of large fire costs should be considered in the prototyping efforts to address this difficult but important issue.
3. Cost Effectiveness: The IST-based alternatives enable **relative** cost effectiveness analysis (see cost effectiveness analysis section below).

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[1] This paper has benefited from the suggestions of several colleagues: some from the IST, some from academia and some from NIFC including some by Donna Scholz. The content is my responsibility.

Considerations

Values: The IST-based alternatives minimally address valuation[2] yet, the protection and enhancement of values provides the ultimate rationale for a fire program. Economic credibility requires that valuation methods and approaches are better developed and that values are appropriately used in the analysis. While this is not an easy task, Donna and I have discussed this and I am optimistic that we can enhance this aspect of each proposed alternative. There are potential entry points for valuation information, but specification of which values and how they would be used needs development.

Costs**:** Costs are addressed differently at the unit level versus the national analysis. At the unit level, where management options are proposed and forwarded for national analysis, the costs of simulated options are analyzed by comparison of the options, but costs are not used in the construction of management options. This enables an "accounting" of costs as a consequence of management options. This is similar to the way costs were addressed in IIAA other legacy systems. Treating costs as an output is simple and pragmatic, but contrary to OMB project direction that costs would be input with program effectiveness output. An economic concern of the current approach is that it handicaps the system by disabling the direct use of cost in the construction of management options. This concern cannot be fixed given the underlying structure of the alternatives, but the benefits of the cost-accounting approach may outweigh the costs, except with respect to the analysis of large fires. At the national level, the proposed goal programming approach could treat overall program costs as inputs or as "flexible targets" and I think this is an advantage.

Control and direct management of rising suppression costs; especially the costs of large fires has been identified as a matter of national importance. Little is known of program level management of large fires including the direct management of large fire costs, but modeling direct management means addressing the cost of large fires as an input[3]. Cost analysis of large fires can be greatly improved, such that research efforts reflecting direct control measures, perhaps through prototyping, could be considered. Producing fruitful results on this kind of analysis includes risk and they cannot be guaranteed.

Cost Effectiveness Analysis**:** Cost effectiveness analysis requires that management options include both cost and effectiveness estimations; but this is **in**sufficient to suggest cost effective solutions. Cost effective solutions require that effectiveness is obtained at minimum cost (without waste). The IST based alternatives do not intend to produce efficient or optimally designed management options, (costs and values are not directly used in the design of management options). Therefore, the cost effectiveness suggested by all of the alternatives is appropriately considered "**relative cost effectiveness**." We might say that one management option is more cost effective than another. We should not imply that any options reflect minimum cost construction.

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[2] See for example, the results of the U.S. EPA deliberations on FPA. Their system chart for the FPA process (included) demonstrates how others have identified the central purpose of valuation and the richness with which a credible valuation might be considered.

[3] Modeling the cost of large fires as an output is a bit like having a tiger by the tail. While this has some effect on the tiger and its direction, we would be dragged along to go where the tiger goes. Modeling cost as an input is like getting the tiger by the "jugular" which is considerably more difficult, but it enables direct control. Both are difficult and I believe that neither has been modeled successfully in previous efforts.

Appendix of Related Considerations

Conclusions

4. <u>Status Quo</u>: Simulating management options that suggest material departures from the status quo needs to be resolved as a modeling requirement. To the extent that such options are deemed important to analyze, clear procedures for addressing departures need to be established. I am optimistic that there are ways to accomplish this that would enhance each alternative.
5. <u>Fuels</u>: Analysis of fuels programs is not addressed in the current FPA materials and this has the potential to raise many issues considering the diversity of agency perspectives and missions.
6. <u>Alternative One</u>: Alternative one (lowest alternative) may not be credible.

Considerations

<u>Status Quo and Beyond</u>**:** Approaches based upon current organizations and of incremental changes reflecting the status quo are pragmatic. However, certain national level issues seek strategic direction implying analysis beyond the status quo. The first consideration is whether analysis beyond the status quo is something that FPA should include. If so, then the structure and rules for generating management options and resource sets that would be simulated needs specification as these are likely critical to the simulated results. This would improve each of the proposed FPA alternatives.

Analysis of options beyond the status-quo depends upon redesigning the resource sets and management options for input to the simulations. There are several possible ways to go about this. One would be to, re-engineer the FPA-PM model as it is better suited to generating strategic cost-effective organizations that depart from the status-quo. These cost effective organizations would then be tempered with judgment and input for simulation analysis. Analyzed through simulation along with other options this could serve as a stimulus for structured analysis beyond the status-quo. It would enable the analysis of potentially more efficient preparedness organizations.

<u>Fuels:</u> Methods for constructing and modeling fuels program options are not currently addressed. Management options would include a fuels management approach and its effects would be simulated to relative to outcome metrics including the EEPS. This leaves the construction of the fuels management approaches unspecified and subject to interpretation, especially if “agency-specific tools for fuels are accommodated by all alternatives” as stated in the most recent briefing. With considerable diversity across the agencies, including diverse agency missions, there would likely be alternative interpretations of how fuels programs at the unit level would be analyzed.

<u>Alternative One</u>: Although information on the structure of alternative one is scarce, the overall approach may lack credible analytic methods. It appears to rely heavily upon subjective assessments making its economic integrity questionable.

Managerial Control and Judgment: The IST based alternatives rely heavily upon managerial control and judgment at the planning unit, where management options are designed outside of the scope of analysis and at the national level where the proposed goal programming method is intended for use as a tool for sorting through options. Perceived strengths of this are in ownership and in the reliance upon judgment. The strength of the system includes the ability to sort through numerous options in a structured way. The potential weakness is in what may be viewed as a lack of objectivity. This can be offset, to some extent, by structuring the simulation options in cost effective ways (addressed above) and by providing consistent national incentives for the construction of options.

Document 13

EPA Draft Paper on FPA

Report

Title: Summary of Workshop on "Integrating Ecological and Economic Risks and Values in Wildfire Management" held October 22 – 25, 2006 at the Johnson Foundation's Wingspread Conference Center in Racine, Wisconsin Submitted by The Society of Environmental Toxicology and Chemistry North America in partial fulfillment of EPA Grant No. X830975010

Description

This is a paper produced by the Society of Environmental Toxicology and Chemistry North America in cooperation with the US EPA on an approach to FPA Phase Two. The paper is contained here because I was an active participant in the paper and in the deliberations that played a role in guiding the construction of this paper. The paper contains relevant findings and the outline of a conceptual approach to FPA Phase Two that is distinguished from those of the Science Team. This paper was produced by a science team addressing the same problem as the FPA science team. Their findings and approach to the problem differ in important ways. Two teams of scientists have addressed the FPA Phase Two problem and arrived at different conclusions.

Summary of Workshop on "Integrating Ecological and Economic Risks and Values in Wildfire Management" held October 22 – 25, 2006 at the Johnson Foundation's Wingspread Conference Center in Racine, Wisconsin

Submitted by

The Society of Environmental Toxicology and Chemistry North America

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Workshop Background and Goals

In October, 2003 the Society of Environmental Toxicology and Chemistry sponsored an expert workshop, held in Pensacola, Florida, to examine the integration of ecological risk assessment and socioeconomic valuation. The workshop's findings (Stahl et al., eds., in press) included a set of general principles for organizing and integrating the valuation process (Heninger et al., in press). The 2003 workshop organizers determined that a second workshop should be held that would apply those principles to the design of an integrated problem formulation (PF) process, and that this could best be accomplished through a detailed case study. The allocation of federal funding for wildfire management in the U.S. was selected as an appropriate problem for study, for three reasons. First, the scope of the wildfire problem is large and rapidly growing. Second, effective allocation requires the collection and integration of information on social, economic and ecological risks. Third, an analytic system currently being developed by the National Interagency Fire Center to address this need, the Fire Program Analysis (FPA) system, could serve as a model for case study evaluation.

An initial phase (Phase I) of development of the FPA System to address fire preparedness had been completed in early 2006. The Phase I system estimates wildfire risks across all U.S. federally-owned lands by landscape parcel, within each of 138 Fire Planning Units covering the conterminous USA, and it weights the wildfire risk to each parcel according to a set of socioeconomically and ecologically relevant criteria combined with historic fire occurrence. It then aggregates this information nationally and optimally allocates funds for the pre-placement of firefighting resources. At least one further phase is planned because the Phase I system only considers firefighting response to existing fire occurrence patterns and does not examine how funds used for the management of wildland fuels alter the landscape-level risks. Work on Phase II is currently underway, and a number of basic design decisions need to be made to shape the Phase II approach. Therefore, a workshop to test the integrated PF approach using the complex issues pertaining to wildfire management as a case study was held in October 2006 in Racine, Wisconsin.

Approach

In ecological risk assessment, according to EPA's guidelines (EPA 1998), PF is "a process for generating and evaluating preliminary hypotheses about why ecological effects have occurred, or may occur…." The products of PF include (1) assessment endpoints that reflect management goals, (2) conceptual models showing hypothesized relationships between stressors and endpoints and (3) an analysis plan for testing and quantifying those relationships. The stage is set for PF by a planning dialogue between risk assessors, risk managers (i.e., decision-makers) and, as appropriate, other interested parties, to clearly articulate management goals, management decisions to be made, and assessment scope.

A PF process capable of jointly evaluating social, economic and ecological aspects of a decision would need to include all these elements and expand upon them. Using the findings of the 2003 Pensacola workshop, seven key questions were identified that could guide an expanded PF process:

1. What is the problem or decision being addressed?
2. What is the management context of the problem or decision, (i.e., values and stakeholders, purpose, scope, authority)?
3. What are the management alternatives?
4. What are the endpoints, including system ecological and economic properties and values?
5. How should expected changes in the endpoints (resulting from management actions) be quantified?
6. How will the various endpoint changes be valued and integrated for use in making decisions?
7. How will the outcomes, and the effectiveness of the management actions, be evaluated?

The goal of the 2006 Racine workshop was to test the usefulness of these questions for elucidating an assessment strategy for determining how human activities (including management actions) affect social, economic and ecological outcomes of wildfire in the US. An eighth, evaluative question was stated as follows: What has this case study revealed about the seven-question process?

In conference calls conducted over a 6-month period prior to the workshop, the organizers used an iterative process to simultaneously begin addressing these questions, construct a conceptual model of the wildfire management problem, and expand the list of workshop invitees. These included SETAC members whose primary interest was in developing improved approaches for environmental management, scientists and managers from federal agencies and other governmental bodies involved in wildfire management, and professionals from interested nongovernmental organizations and academia. Invitees' specialties included ecological risk assessment and management, wildfire risk assessment and management, forest ecology and management, economics, and the social impacts of wildfire. Once invited, all were encouraged to participate in subsequent conference calls. A steering group was formed to establish a four-day workshop agenda. The workshop was held October 22-25, 2006 at the Wingspread

Conference Center in Racine Wisconsin. The invitee list, agenda and conceptual model are provided in Appendices 1, 2, and 3.

The complete findings of the workshop will be described in a journal article manuscript to be submitted to the SETAC journal *Integrated Environmental Assessment and Management*. What follows is a brief summary of major findings. These findings were also included in a presentation to the 2006 Annual Meeting of SETAC North America, held November 5 – 9 in Montréal, Québec.

Findings

Workshop findings are summarized below according to the 7 guiding questions and the eighth, evaluation question. For each question, some major observations are listed with respect to (a) the wildfire management problem and (b) future applications of this process to other environmental management problems.

1. What is the problem or decision being addressed?
    a. Wildfire management case

        The decision problem was stated as follows: "How should limited public resources be allocated to minimize the risks to social welfare posed by wildfires in the US?" "Public resources" refers to federal, state and local governmental resources potentially applied to wildfire management, and it includes funds, equipment and personnel. "Social welfare" includes any social, economic or ecological contributions to human well-being.

    b. Issues for future application

        Definitions of the decision problem should more clearly specify the temporal and spatial scales involved. The lack of such specificity in the above definition occasionally caused confusion during workshop discussions.

2. What is the management context of the problem or decision, (i.e., values and stakeholders, purpose, scope, authority)?
    a. Wildfire management case

        An early session in the workshop was devoted to presentations on management goals and stakeholder values from six different perspectives: community, congressional, ecological, federal, industry and state. Values from these perspectives were aggregated for inclusion in the conceptual model.

    b. Issues for future application

        A key observation applicable to the wildfire management case and likely to many others was the importance of historical drivers contributing to the current context. Many environmental problems are deeply rooted in longstanding social and ecological patterns, which must be recognized as part of integrated assessment.

3. What are the management alternatives?

   a. Wildfire management case

      Alternatives for wildfire management entail combinations of the following management actions:

      Fuels Management
      - Chokepoint identification
      - Mechanical fuel reductions
      - Prescribed fire
      - Technical assistance to communities

      Preparedness
      - Positioning of resources (equipment, personnel, etc.)
      - Prevention & public education
      - Technical assistance to communities

      Appropriate Management Response
      - Monitoring
      - Initial attack
      - Extended attack
      - Large fire response
      - Wildland fire use

      Stabilization and Rehabilitation
      - Emergency stabilization
      - Seeding
      - Invasive species eradication

   b. Issues for future application

      These various actions are interdependent. For example, resources expended for fuels management affect the amounts and locations of preparedness resources needed. Any analytic plan that does not account for interactions between available management actions for an environmental problem will be incapable of identifying optimal allocations of effort.

4. What are the endpoints, including system ecological and economic properties and values, that should be assessed?

   a. Wildfire management case

      While social, economic and ecological values cannot be strictly separated, the following values were identified:

      Social Values
      - Life, physical & emotional health and quality of life
      - Environmental quality (air, water, etc.)
      - Cultural
      - Community development, equity, stability and self-determination

      Economic Values
      - Property

- Infrastructure
- Agricultural
- Extractive resources (timber, etc.)
- Recreational

Ecological Values

- Habitat
- Wildlife
- Vegetation
- Soils
- Productivity
- Diversity, integrity, composition
- Other services

To transform these values into assessment endpoints, it would be necessary to express each of these in terms of a specific entity and a measurable characteristic of that entity. Our workshop did not take this additional step.

b. Issues for future application

A key issue affecting the selection and use of endpoints is the determination of whether or not multiple endpoints that are correlated to one another should be combined under a single expression. We did not come to consensus regarding the implications of "binning" correlated outputs.

5. How should expected changes in the endpoints (resulting from management actions) be quantified?

a. Wildfire management case

Data and models are available for modeling wildfire risks at the landscape level. For example, LANDFIRE, a shared project between the wildland fire management programs of the U.S. Department of Agriculture Forest Service and U.S. Department of the Interior, produces "consistent and comprehensive maps and data describing vegetation, wildland fuel, and fire regimes across the United States." RAVAR simulates fire spread and structure locations. These tools are capable of informing estimates of risk to many mapped resources of social, economic or ecological importance. Many other models of processes such as fire behavior, fire spread, and forest stand development are also used to inform fire risk assessments. The FPA system currently is examining alternative approaches which would, respectively, map probability densities or use event-based simulations. The former approach lends itself better to optimization approaches and to combining different elements of a management strategy (e.g., fuels treatment and preparedness) whereas the latter is better able to simulate and track distributions of potential effects.

b. Issues for future application

Some social values such as equity and community cohesiveness are difficult to express in geographic terms that lend themselves to risk mapping and therefore they are likely to be omitted from many models and assessments. For the fire management case, it is difficult to meet the needs of more local managers for realism and use of locally-available data while also conducting a national analysis with adequate consistency to support optimization. There may be some irreducible trade-offs to be made to address management needs at such different spatial and temporal scales. This difficulty may occur for other national problems.

6. How will the various endpoint changes be valued and integrated for use in making decisions?

   a. Wildfire management case

      Approaches that could be used for valuing endpoint changes and integrating those values could be drawn from economics or the decision sciences, or they could be hybrid or ad hoc approaches. The existing FPA (Phase I) approach used a consensus of local program managers to cardinally rate the relative importance of 9 – 12 different kinds of landscape parcels in each of 138 Fire Planning Units (FPUs) in the U.S. The procedure then optimally allocates preparedness funding among FPUs accordingly, but this procedure requires modification if the joint effects of different management actions are to be addressed.

   b. Issues for future application

      We found it very difficult, in the context of this workshop, to adequately address the problem of selection of valuation/integration methods due to the complexity of the problem. Without the development of other kinds of decision aids or weighting workshop participation much more heavily toward economics and the decision sciences, it may be unrealistic to expect to settle this question during a PF workshop.

      We also found some disagreement among participants about (a) the requirement that the analytic result have an economic interpretation and (b) which methods yielded economically interpretable results.

7. How will the outcomes, and the effectiveness of the management actions, be evaluated?

   a. Wildfire management case

      A set of measures for determining effectiveness of wildfire management programs is being developed. To date, however, most of these are implementation measures, which document levels of activity in program elements, rather than outcome measures more closely related to the protection of values and achievement of goals.

   b. Issues for future application

      In general it is important to make an adequate distinction between activity measures and outcome measures and to ensure that outcomes can be measured.

Evaluation: What has this case study revealed about the seven-question process?

Breakout groups evaluated this question and reported their results. The following is a selection of points brought out:

- The seven questions did a very good job of helping the group scope a very difficult decision problem.
- It needs to be made clear who the questions are for.
- The questions require additional detail, such as subsidiary questions eliciting information on spatial or temporal scale.
- The founding of these questions on ecological risk assessment concepts was considered beneficial, and it would be helpful to more explicitly show how this risk-based process differs from other similar processes (e.g., NEPA).
- Incorporating more of the language of ecological risk assessment (e.g. using the term "risk characterization" in Question 5) could improve the seven questions.
- The explicit focus on values, in relation to other parts of the management problem, was beneficial.
- The seven questions should more explicitly mention the conceptual model development process (e.g., conceptual model development begins following Question 1).
- Question 5 should acknowledge that not all endpoints can be quantified, but sometimes qualitative information about effects can be valuable.
- Question 7 should deal more with *how* measurement information should be used for adaptive management than *what* should be measured.
- There was discussion about whether the questions should include the identification of a preferred alternative.

References

Stahl RL, Kapustka L, Munns W, Bruins R, editors. Forthcoming 2007. *Valuation of ecological resources: integration of ecological risk assessment and socioeconomics to support environmental decisions.* Pensacola (FL): Society of Environmental Toxicology and Chemistry (SETAC) jointly published by Taylor & Francis.

Heninger, B., G. Biddinger, C. Joy, C. Kling, D. Reagan, T. Schmidt**.** In press. General principles for organizing and integrating the valuation process. Chapter 6 in R. Stahl, L. Kapustka, W. Munns and R. Bruins, eds., *Valuation of Ecological Resources: Integration of Ecological Risk Assessment and Socio-economics to Support Environmental Decisions*. Taylor and Francis, New York.

USEPA. 1998. Guidelines for Ecological Risk Assessment. . EPA/630/R095/002F, Risk Assessment Forum, United States Environmental Protection Agency, Washington, D.C., USA.

Appendix 1: Workshop Participants List

Steve Botti
Fire Program Planning Manager
National Interagency Fire Center
3833 S. Development Ave.
Boise, ID 83705-5354
Tel: 208-387-5210
E-Mail: stephen_botti@nps.gov

Steve Brink
Vice President
Public Resources
California Forestry Association
Suite 1830
1215 K St.
Sacramento, CA 95814
Tel: 916-444-6592
Fax: 916-444-0170
E-Mail: steveb@cwo.com

Randy Bruins
Supervisory Biologist
National Exposure Research Laboratory
Ecological Exposure Research Division
United States Environmental Protection Agency
MS-642
26 W. Martin Luther King Dr.
Cincinnati, OH 45268
Tel: 513-569-7581
Fax: 513-569-7609
E-Mail: bruins.randy@epa.gov

David Cleland
Research Ecologist
Southern Research Station (R-9)
United States Department of Agriculture Forest Service
68 S. Stevens St.
Rhinelander, WI 54501
Tel: 715-365-1103
E-Mail: dcleland@fs.fed.us

Chester Joy
Senior Analyst
National Resources and Environment
Government Accountability Office (GAO)
441 G St., NW
Washington, DC 20548
Tel: 202-512-8157
Fax: 202-512-8354
E-Mail: ches.joy@verizon.net
joyc@gao.gov

Larry Kapustka
Golder Associates, Ltd.
Suite 1000
940 Sixth Ave., SW
Calgary, AB T2P 3T1
Canada
Tel: 403-260-2265
E-Mail: larry_kapustka@golder.com

Danny Lee
Director
Eastern Forest Environmental Threat Assessment Center
Southern Research Station
United States Department of Agriculture Forest Service
PO Box 2680
Asheville, NC 28802
Tel: 828-257-4854
Fax: 828-257-4840
E-Mail: dclee@fs.fed.us

Valerie Luzadis
Associate Professor
Faculty of Forest and Natural Resource Management
College of Environmental Science and Forestry
State University of New York (SUNY)
307 Bray Hall
One Forestry Dr.
Syracuse, NY 13210-2788
Tel: 315-470-6693
Fax: 315-470-6535
E-Mail: vluzadis@esf.edu

Laura Falk McCarthy
Program Director
Western Forest and Fire Restoration
Global Fire Initiative
The Nature Conservancy
212 E. Marcy St.
Santa Fe, NM 87501
Tel: 505-988-1542, ext. 213
E-Mail: lmccarthy@tnc.org

Wayne Munns
Associate Director for Science
National Health and Environmental Effects Research Laboratory
Atlantic Ecology Division
United States Environmental Protection Agency
27 Tarzwell Dr.
Narragansett, RI 02882
Tel: 401-782-3017
E-Mail: munns.wayne@epa.gov

Naureen Rana
Project Manager
Pinchot Institute for Conservation
Suite 100
1616 P St., NW
Washington, DC 20036
Tel: 202-797-6580
E-Mail: nrana@pinchot.org

Douglas P. Reagan
President
Doug Reagan and Associates, LLC
350 Gordon Dr.
Castle Rock, CO 80104
Tel: 303-688-1716
Fax: 303-688-1716
E-Mail: douglaspreagan@aol.com

Doug Rideout
Professor of Forest Economics and Finance
Department of Forest, Rangeland, and Watershed Stewardship
Warner College of Natural Resources
Colorado State University
Fort Collins, CO 80523-1472
Tel: 970-491-7234
E-Mail: doug@warnercnr.colostate.edu

Matt Rollins
Ecologist, Science Lead for LANDFIRE
Fire Sciences Laboratory
Rocky Mountain Research Station
United States Department of Agriculture
Forest Service
5775 US W. Highway 10
Missoula, MT 59808
Tel: 406-329-4960
E-Mail: mrollins@fs.fed.us

Greg Schiefer
Assistant Executive Director
Society of Environmental Toxicology
and Chemistry
1010 N. 12th Ave.
Pensacola, FL 32501-3370
Tel: 850-469-1500, ext. 22
Cell: 850-384-8138
Fax: 850-469-9778
E-Mail: schiefer@setac.org
Web: www.setac.org

Peter Woodbury
Research Associate
Department of Crop and Soil Sciences
College of Agriculture and Life Sciences
Cornell University
Ithaca, NY 14853
Tel: 607-255-1448
E-Mail: pbw1@cornell.edu

Mike Zupko
Executive Director
Southern Group of State Foresters
PO Box 930
Winder, GA 30680
Tel: 770-267-9630
Cell: 770-853-6696
E-Mail: sgsfexec@mindspring.com

The Johnson Foundation Staff

Christopher Beem
Program Officer
Democracy and Community, Family
Tel: 262-681-3344
Fax: 262-681-3325
E-mail: cbeem@johnsonfdn.org

Wendy S. Butler
Program Assistant
Tel: 262-681-3321
Fax: 262-681-3325

The Johnson Foundation
33 E. Four Mile Rd.
Racine, WI 53402
www.johnsonfdn.org

Appendix 2: Workshop Agenda

Program

Sunday, October 22, 2006

3:30 p.m. Hospitality
Living Room/Guest House

Welcome to Wingspread
Christopher Beem
Program Officer
The Johnson Foundation

4:00 p.m. Plenary Session
Living Room/The House

Introductions, Goals, Conference Overview

Randy Bruins
Supervisory Biologist
National Exposure Research Laboratory
Ecological Exposure Research Division
United States Environmental Protection Agency

Greg Schiefer
Assistant Executive Director
Society of Environmental Toxicology
and Chemistry

5:30 p.m. Hospitality
Wingspread

6:00 p.m. Dinner

7:00 p.m. Adjournment

Evening Hospitality
Living Room/Guest House

Monday, October 23, 2006

Breakfast is available from 6:30 to 8:15 a.m.
in the Living Room of the Guest House.

8:30 a.m.
Living Room/The House

Plenary Session

Ground Rules

Facilitator:
Douglas P. Reagan
President
Doug Reagan and Associates, LLC

8:45 a.m.

Perspectives on the Main Question, Including Value to Protect and Goals to Achieve

How should public resources (including resources for fuels reduction and initial attack) be allocated to minimize the risks to social welfare (including life and health, built and other cultural assets, and ecological and other natural resources) posed by wildfires in the United States?

Community
Naureen Rana
Project Manager
Pinchot Institute for Conservation

Congressional
Chester Joy
Senior Analyst
National Resources and Environment
Government Accountability Office (GAO)

Ecological
Laura Falk McCarthy
Program Director
Western Forest and Fire Restoration
Global Fire Initiative
The Nature Conservancy

Monday, October 23, 2006 (continued)

Federal Agency
Steve Botti
Fire Program Planning Manager
National Interagency Fire Center

Forest Industry
Steve Brink
Vice President
Public Resources
California Forestry Association

State
Mike Zupko
Executive Director
Southern Group of State Foresters

10:15 a.m. Break

10:30 a.m. Plenary Session (continued)

Review Session Goals and Problem Statement in Light of Perspectives

11:00 a.m. Review Conceptual Diagram and Clarify as Needed to Meet Our Goals

Wayne Munns
Associate Director for Science
National Health and Environmental
Effects Research Laboratory
Atlantic Ecology Division
United States Environmental Protection Agency

11:30 a.m. Overview of FPA Model
Steve Botti

Monday, October 23, 2006 (continued)

12:00 noon Wingspread	Hospitality
12:15 p.m.	Luncheon
1:15 p.m. Living Room/The House	Plenary Session Question 6: How Will the Endpoint Changes Be Valued and Integrated for Use in Making Decisions? **Valerie Luzadis** Associate Professor Faculty of Forest and Natural Resource Management College of Environmental Science and Forestry State University of New York (SUNY)
3:15 p.m.	Break
3:30 p.m.	Plenary Session (continued) Question 4: What are the Endpoints, Including System Ecological and Economic Properties and Values?
5:30 p.m.	Quick Check of the 7-Question Process
5:45 p.m.	Leisure
6:15 p.m.	Tour of Wingspread *(optional)*
6:30 p.m. Wingspread	Hospitality
7:00 p.m.	Dinner
8:00 p.m.	Adjournment
Living Room/Guest House	Evening Hospitality

Tuesday, October 24, 2006

	Breakfast is available from 6:30 to 8:15 a.m. in the Living Room of the Guest House.
8:30 a.m. Living Room/The House	Plenary Session Question 5: How Should Expected Changes in the Endpoints–Resulting from Management Actions–Be Quantified? **Matt Rollins** Ecologist, Science Lead for LANDFIRE Fire Sciences Laboratory Rocky Mountain Research Station United States Department of Agriculture Forest Service
10:30 a.m.	Break
10:45 a.m.	Plenary Session (continued) Question 3: What Are the Management Alternatives? **Mike Zupko**
12:15 p.m. Wingspread	Hospitality
12:30 p.m.	Luncheon
1:30 p.m. Living Room/The House	Plenary Session Questions 1 and 2: Final Review of Decision Being Addressed and Its Context • Question 1: What is the problem or decision being addressed? • Question 2: What is the management context of the problem or decision (i.e., values and stakeholders, purpose, scope, authority)?

Tuesday, October 24, 2006 (continued)

2:30 p.m. — Question 7: How Will the Outcomes and the Effectiveness of the Management Actions Be Evaluated? (How Will They Know It Is Working?) How Will This Information Be Fed Back Into the Process to Make Needed Adjustments?
Laura Falk McCarthy

3:15 p.m. — Break

3:30 p.m. — Small Group Breakouts

- What has this case study revealed about the 7-Question process?
- How well did this process help address the fire management problem?
- Are there other questions that should be addressed?
- Do the 7 questions work to achieve the goal of effectively guiding integrated environmental decision making?

Group 1:	Board Room
Group 2:	Studio
Group 3:	Lower Level B

4:45 p.m. — Plenary Session
Living Room

Small Group Reports

5:30 p.m. — Leisure

6:30 p.m. — Hospitality
Wingspread

7:00 p.m. — Dinner

8:00 p.m. — Adjournment

Evening Hospitality
Living Room/Guest House

Wednesday, October 25, 2006

	Breakfast is available from 6:30 to 8:45 a.m. in the Living Room of the Guest House.
9:00 a.m. Living Room/The House	Plenary Session Outlining of Journal Article and Writing Assignments
10:30 a.m.	Break
10:45 a.m.	Plenary Session (continued)
12:00 noon Living Room/ Guest House	Buffet Luncheon
1:00 p.m.	Conference adjourns
	Transportation departs

Appendix 3: Conceptual Model