Management Review Team Report
Of the
Fire Program Analysis (FPA) Preparedness Module

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Executive Summary

In 2001, Congress directed the Departments of Interior and Agriculture to develop a coordinated and common system to determine readiness and improve the allocation of fire resources to improve effectiveness and efficiency. Subsequently, the two Departments embarked on a project titled Fire Program Analysis (FPA) that would cover all aspects of the fire program for the five federal natural resource agencies with fire management responsibilities – the Forest Service, the Bureau of Land Management, the National Park Service, Fish and Wildlife Service, and the Bureau of Indian Affairs. The first module of this project, covering one component of fire preparedness, is nearing completion.

Recently, the two Departments jointly chartered a two-part mid-course review of the FPA project: a scientific review of the model and a management review of its use. The Scientific Review Team met in December 2005 and issued a report identifying several critical issues. The Management Review Team, consisting of representatives from four of the five agencies and a State Forester, met in February 2006 and incorporated many of the scientific team's findings, issues, and recommendations in its work, summarized in this report. The Management Review Team endorses the visions and goals of FPA: creating an interagency approach to budget analysis that looks across administrative boundaries at the landscape scale. However, the Team has identified some challenges to meeting that vision.

The Management Review Team report identifies key questions and offers recommendations for consideration. The team believes these questions need to be addressed to make the FPA vision successful. We do not make these recommendations lightly, nor should they be interpreted as a lessened commitment to the FPA vision. We also want to recognize that those working on the FPA project have demonstrated outstanding commitment and dedication to this effort. The FPA Development Teams (Steering Team, Core Team, and Implementation Team) have been staffed with highly dedicated people who have taken a can-do attitude to resolving model and FPU user group problems as they are identified and have worked very hard to develop a process and model to meet ambitious deadlines. However, these deadlines may have placed more emphasis on model development than on some necessary process and policy issues. These issues need to be resolved to ensure that further model development is consistent with the FPA vision.

Implementing these recommendations will be challenging. It will require significantly more leadership and management oversight, direction, and support to ensure that FPA is successful. It will also require managing and renegotiating stakeholder expectations, including those who may be expecting us to use model results in the near future. However, we reaffirm that the overarching vision and goals of FPA are sound, and believe that the long term success of having a coordinated and common system that improves effectiveness and efficiency requires that the issues and questions identified in both the scientific and this management review need to be addressed before moving forward.

Introduction

The Management Review Team (MRT) was charged with conducting a mid-course review of the Fire Program Analysis (FPA) Preparedness Module (PM). The MRT included agency representatives from four federal natural resource management agencies under the Departments of Interior and Agriculture, and a representative from the National Association of State Foresters.

The report "Developing an Interagency, Landscape-scale Fire Planning Analysis and Budget Tool" (the Report) is recognized as the document that set the vision for developing FPA[1]. The MRT used various references as benchmark standards for review: the Report, the FPA Scientific Review Team (SRT) report, direction from the Office of Management and Budget (OMB), and Congressional Appropriations Reports. The team also interviewed FPA program leaders and field users within respective agencies.

The Report provided a clear vision, goal and objective which are as follows:

> ***FPA Vision** — The federal fire management agencies use a compatible fire program analysis and budgeting process that incorporates cost efficiencies and effectiveness while addressing the full spectrum of fire management activities.*
>
> ***Goal** — Within five years (2004), the federal fire management agencies will implement a compatible fire program analysis and budgeting analysis system to facilitate planning and program analysis on a landscape scale, across agency boundaries.*
>
> ***Objective** — Create a compatible, objective-driven, performance-based fire program analysis and budgeting system using a structured analysis and design process covering the full scope of activities, useable at a landscape level and across administrative boundaries.*

The MRT also had the task of reviewing the FPA Scientific Review Team report and giving meaning to it within the context of the management review. The FPA steering committee asked the SRT seven questions related to the FPA model. The MRT finds that the SRT did a credible job of answering the questions and accepts the SRT report as an appendix to this report.

[1] Developing an Interagency, Landscape-scale Fire Planning Analysis and Budget Tool - Report to the National Fire Plan Coordinators: U.S.D.A. Forest Service & U.S. Department of the Interior can be found in the appendix of this report.

Key Questions

The MRT was tasked with a "high level" management review within a short time frame. We decided that posing key questions would be of most value to the senior leadership that chartered the team. Following are seven key questions the Management Review Team identified as part of the review process. Each of the questions has a narrative providing background of why the MRT thought it was important along with recommendations for consideration.

Question 1: Is the modeling approach used in FPA operationally feasible, institutionally sustainable, and consistent with existing fire policy?

After a review of the scientific review report, the MRT has significant concerns about moving ahead with Phase 1 of FPA-PM until it has been determined that the most appropriate modeling approaches are being used for an interagency fire program analysis and budgeting tool. The analysis tool must be grounded, not only in the appropriate science, but also in the appropriate level of complexity for agencies to operate. It appears the FPA development team heard concerns from users that the model did not address many facets of fire program management. In response, they did their best to build assumptions and rules into FPA to account for these concerns. This has resulted in a highly complex model that will be difficult for agencies to sustain with trained staff at the FPU level, especially if the FPA-PM model will only be used periodically. Maintaining trained staff for the legacy systems was difficult enough for agencies, and it appears FPA will be even more of a challenge.

The science report questions the 'objective function' being used in FPA. The science team also suggests that FPA may not model the current wildland fire suppression policy. For example, is using an optimizing algorithm for maximizing Weighted Acres Managed (WAM) congruent with current fire management policy? Is it better to use an algorithm that minimizes acres burned or minimizes escaped fires? Does using the latter better reflect the current fire suppression policy and make it easier for state and federal managers to understand the outputs from FPA? These are significant and fundamental questions that need to be addressed.

Currently the FPA computer optimization model can take as many as 10 to 20 hours to complete a run. Furthermore, the science review suggests we should be examining multiple fire season events to determine how sensitive the optimized run, or optimized mix of resources, is to changes in fire season event scenarios. This could result in making hundreds of runs which would tax the ability of agencies to sustain such work and would require a significant investment in computation time. It is a concern that the single fire season event FPA examines may produce a resource mix and budget allocation that could significantly differ from another fire season event. Without examining multiple fire season events, the ability to determine the optimal mix of resources over a range of seasons would remain an unanswered question and pose an element of unknown risk to the solution.

The following are a few key statements from the science review report that caused us to ask these questions. To assure these statements are not taken out of context, readers should consult the full science report which is an appendix to this report.

"A big limitation of the current model is its computational requirements, …"

"… optimal resource configurations obtained from the model with a single fire event scenario should be tagged with the qualification that they don't necessarily maximize expected WAM given the variability in fire event scenarios."

"How well the Initial Attack (IA) containment modeling approach used in FPA will perform remains an untested question that careful simulations might help address. Indeed, many of our comments have suggested the use of a simulator."

"The initial attack module is designed to take a fairly comprehensive and detailed approach to fire organization planning that has resulted in large optimization models. Whether a more incremental approach, perhaps using simulation optimization or other methods, would be either more appropriate for decision making or more easily integrated with Phase 2 modules remains to be seen."

Recommendation:

(1.0) Establish an FPA Interagency Oversight Group (IOG), composed of: an agency scientist, a unit level agency administrator, a senior agency administrator, an agency fire director, an agency budget director, and a NASF representative. This group will assist the Wildland Fire Leadership Council (WFLC) in management oversight of FPA development. This oversight group would also charter the science panel mentioned in recommendation 2.0 below, and other ad hoc groups as needed. This group, comprised of a broader spectrum of agency management, would replace the intermediary role currently played by the National Fire and Aviation Executive Board (NFAEB).

Question 2: How should questions raised by scientists and users about consistent measurement standards in FPA be addressed?

One of the critical components of the FPA process is the ability to compare information across landscape and Fire Planning Unit (FPU) boundaries. If we cannot do that, then continued work on the FPA system is of limited value. This is a major theme in the Report and the Federal Wildland Fire Policy from 2001. We have two concerns regarding how this was incorporated into the existing FPA-PM module: the use of weighted acres managed (WAM) as the objective function, and the effect of different weighting factors applied across different FPUs.

Is WAM the appropriate objective function, or is there a better one? WAM may be well-grounded in economic theory, but it is not consistently understood by fire managers and those outside the fire community. While reducing the planning and budgeting process to a "single currency" certainly facilitates the modeling environment, it has proven difficult to explain the concept of WAM to land managers and others. Due to the complexity in the development of WAM, it may be difficult to see how various land management objectives are addressed in WAM. For example, there is not a direct correlation between WAM and the number of acres managed on the ground - you can have more "WAM" than acres in the FPU. In addition, reconciling WAM objectives with traditional measures such as initial attack success rates has been challenging. This issue has been compounded by the incomplete modeling of initial attack, using an 18 hour timeframe as compared to a more traditional Initial Attack (IA) success time measure.

We share the science team's concern about using WAM as the objective function. It is obviously inappropriate if the use of WAM as the objective function is determined to be inconsistent with current policy – policies are made carefully by senior officials and not by model developers. Policy makers might prefer for FPA to have the capability to choose from multiple objective functions that could be used to investigate different scenarios and consequences of alternative policies.

There have been significant concerns from the field and the science team's report about using FPA output to compare results between FPU's. Although this centers on the use of wildland urban interface (WUI) as a calibration factor, there are also concerns about the weighting process with regards to standardization of attributes across FPUs. The science report further describes this issue:

> *"An unexplored issue associated with the National model is the sensitivity of its results to differences in weighting systems across the FPUs. The weighting system assumes that areas with wildland-urban interface are assigned a weight of one, and other areas are weighted in relation to WUI. If FPUs define and value WUI differently, then comparison of WAM across FPUs may not be valid. For example, one FPU could assume that WUI values are really high so that weights in other areas are relatively low. Conversely, another FPU with the same amount of WUI could assume that WUI values are moderate so that weights in other areas are relatively high. The weights employed in an FPU may affect the slope of the curve showing WAM versus budget, which in turn, will affect the allocation of resources across FPUs at the national level."*

Recommendation

(2.0) Convene an ad hoc science panel that reports to the IOG, to answer questions like: Is the modeling approach used in FPA appropriate? Are there other approaches or types of models that might be significantly more effective and economical? Is the optimization modeling approach used in FPA appropriate for the high risk wildland fire management environment? How should FPA consider risk management? Does the current use of weighting factors allow for meaningful comparison across FPUs?

Question 3: Can critical issues and questions be resolved within the implementation timeline expected by OMB and Congress?

As noted in the following Congressional report language, Congress directed the agencies to develop a *focused* budgeting system that: is common across all federal agencies, identifies efficiencies, ties to resource values, and provides a mechanism for sharing resources with federal and non-federal partners. The quotes below are offered as evidence of Congressional intent:

> *House Report 107–234 (FY 2002 Appropriations Act) Oct 11, 2001:*
>
> *"The managers remain concerned about the variation in methods by which the Departments calculate wildfire fighting readiness and how the Departments plan their distribution of firefighting resources to attain efficiency. The managers direct the two Departments to develop and implement a coordinated and common system for calculating readiness which includes provisions for working with the shared fire fighting resources of the States and other cooperators and considers values of various resources on both Federal and other lands."*
>
> *House Report 107–564 (FY 2003 Appropriations Act) July 11, 2002*
>
> *"The Committee is aware that the Forest Service and the four Interior bureaus participating in Wildland Fire Management activities use different systems and procedures for determining their readiness for control of wildfires. We have been informed that the Departments have been engaged in efforts to design and develop tools for fire program managers that would be used by the Forest Service and all of the Interior bureaus. The Committee is encouraged that the Departments have been working together to develop common systems to plan their activities; however, we are concerned that a complex system may require significant funding and take many years to develop. The Committee therefore directs the Departments to design and develop a focused automated system for preparedness resource planning to replace the systems currently in use by the fire management agencies. The Committee believes that a limited system can be designed and implemented by the end of fiscal year 2004. The development and design of the information technology system for fire preparedness will be conducted according to standard Federal regulations for planning, budgeting, acquisition and management of capital assets. The Committee further directs that the agencies deliver quarterly progress reports that describe project status and provide updated cost information."*

The FPA-PM process does provide for a common system across all federal agencies that is tied to resource values and focuses on optimizing efficiencies. However, there are concerns that the results generated from the FPA-PM Phase 1 do not accurately identify efficiencies that can be gained because it only looks at a small piece of the preparedness program as shown in Figure 1.

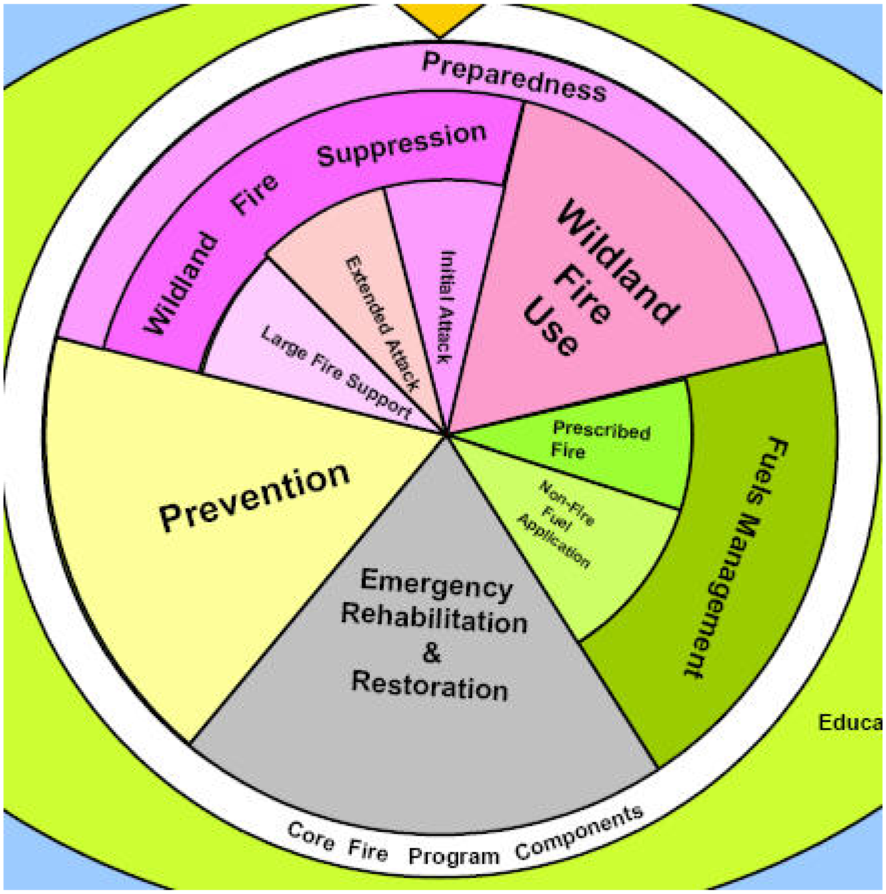

Figure 1-- A depiction from the FPA charter showing what the PM module was to include. Phase 1 only includes first 18 hours of initial attack and a portion of wildland fire use. Extended attack and large fire support are not complete.

In addition, it is unclear if accurate comparisons can be made between FPU's because of the current weighting approach (see Science Team's report question 2). There are concerns that the model is more complex and time consuming than necessary to meet the objectives identified by Congress. Both of these topics warrant further investigation.

There are also concerns about whether non-federal resources are included in a way that meets Congressional expectations. While the initial development of the model included non-federal resources, later guidance was interpreted to exclude these non-federal resources in the modeling *(October 21, 2005 FPA White Paper, December 1, 2005 FPA White Paper).* It was determined that the complexity of the program greatly increases when non-federal resources are included.

Although not specifically modeled in FPA, we currently have a great number of cooperative agreements in place to share resources between federal and non-federal entities. The FPA process, through the formation of the FPU groups, has the potential to identify additional opportunities for collaboration and to improve efficiencies. We believe the question about including non-federal resources is significant.

Recommendations:

(3.1) Task the IOG referenced above in recommendation 1.0 to reevaluate the model as to whether it will meet Congressional expectations. The process of developing interagency FPU's and working together to manage the fire program is valid, should be continued, and represents the strength of the FPA process.

(3.2) Develop clearly articulated briefing papers for the Department/Congressional/OMB on the current status in meeting the Congressional direction and strategies for moving forward. Provide candid assessment of the challenges that remain before we can be successful. Briefings should be presented by the executive level and focused on FPA as an interagency fire program analysis and budget *process*, not just the FPA-PM model.

(3.3) Develop a briefing package for line officers. They should include both internal and external messages to share with employees and Congressional delegations. Before this can be a success, the benefits of FPA must be clearly understood and accepted by internal users and external stakeholders.

Question 4: How prepared are the Department of the Interior agencies and the Forest Service to implement FPA results that could lead to significant changes in funding levels across agencies, programs, and FPUs?

One of the fundamental assumptions about FPA is that it would suggest a re-distribution of fire fighting resources and funding within and/or between Fire Planning Units (FPU) as well as within and/or between agencies. Concerns about this re-distribution, or change, have not been effectively managed.

The FPA project team has worked very hard and has been committed and dedicated to complete a process and model within ambitious deadlines. The demand to meet these deadlines may have caused the focus to be on model development for Phase 1 without the appropriate investment in managing expectations or concerns about potential changes in distribution of funds and firefighting resources. We believe that, to be successful, there needs to be a common understanding and shared vision for implementing the desired changes. Currently, we don't believe there is acceptance, common understanding, or shared vision for the need for change within the affected agencies.

How the FPA process will be used in the budget formulation and allocation process has not yet been clearly defined. There are numerous questions about how strictly the FPA model will be used to redistribute funds and resources geographically across programs and agencies. While terms such as "informing" the budget process have been used, this still leaves fundamental questions unanswered. For example, one key question is how to address differences between what a science-based approach toward resource allocation shows compared to social and political expectations. Our experience indicates that social and political considerations are factors currently considered when making allocation decisions. How will these factors be considered in the FPA process? Although some of these factors may be captured in the weighting process, it is clear that many are not. Unless the FPA process can be clearly developed, accepted, and used by senior leadership, there is a high risk of 1) a model being developed that doesn't meet the overarching objectives that FPA was attempting to achieve, 2) model results that may be used and imposed in an inappropriate way, and 3) spending time and money on a product that will not be utilized.

There are also institutional barriers to change. One example is the inconsistent level of indirect support costs applied to the fire budget. The level of indirect support costs varies from 0% to 40% depending on the individual agency budget process. One agency funds indirect support costs out of a specific line item, while others assess each program a share of the support costs. The current version of FPA-PM allows each agency to input whatever indirect support cost they choose outside of the optimization process. This is a critical issue which needs to be resolved in order to fully implement FPA-PM.

While the FPA project teams made numerous attempts through briefings, training, and other forms of communication to share the objectives of the FPA process, it did not seem to result in a sufficient acknowledgement of the need for change, let alone the desire to make change. Fire managers and line officers did not have a clear understanding of how factors used in the model (e.g., WAM) incorporate and accomplish their land management and agency objectives, and how they reconcile with – or appropriately replace – the current measure of initial attack success. Another source of confusion was frequent changes in the message and direction covered in training and implementation documents. There was no clear, stable road map through the initial process.

This was further exacerbated by the incomplete nature of the modeling effort for Phase I, a lack of clear understanding of how model results would be used in the budgeting process, and concerns that results would be used pre-maturely, perhaps causing ill-informed decisions.

Although there are numerous examples of collaboration and sharing resources at the local level, until we can significantly improve the case for change and develop common understanding and commitment, we will continue to encounter substantial resistance. Most fire managers, and many of our partners, currently believe that their resources are barely sufficient to meet fire and land management objectives. If a new model suggests that their resources should be reallocated elsewhere, they will be reluctant to accept results from a model they do not trust that conflicts with their professional judgment. Fire managers need to be assured that the model is used in a way that appropriately factors in public safety expectations and land management objectives. This new process must also allow them to clearly explain how their resources and funding will meet the public expectations and agency needs.

Until the FPA process is clearly defined and fire managers and line officers are confident in the process and model that supports it, we will not have the widespread acceptance necessary for success.

Recommendations:

(4.1) Task the Interagency Oversight Group (IOG), described in action (1.0) above, to develop a clearly defined process for how FPA will be used for budget formulation and allocation.

(4.2) Increase the focus on the change management process significantly, by identifying and using an effective change management methodology that considers: awareness of need for change, desire to support the change, knowledge of how to change, ability to implement desired skills and behaviors, and reinforcement to sustain the change. This effort needs to identify and implement actions, including those required by management, to address the resistance to change, lack of buy-in, lack of confidence in new methodologies, impacts of the initial shortcomings from Phase I module roll-out including compressed timeframes, and lapses in communications and training.

Question 5: What is the role of agency/department leadership in the FPA process?

There needs to be more effective involvement by line-officers and senior executives in setting policy, influencing program direction, and implementing change management in the FPA process. Expectations of the FPA Steering Committee for a project of this magnitude and complexity have been unrealistic, recognizing that this has been a collateral duty assignment for these team members. Because fire represents such a large and integral component of each agency mission, it is important that non-fire managers be engaged in a more meaningful way.

There is a lack of understanding at all levels of the organization about why we are making fundamental changes to the way we develop fire budgets, the objectives and vision of FPA, and its importance to meeting the resource objectives of the agencies. We recognize that the FPA process has the potential to modify our management of natural resources. Integration with other resource programs will be a vital aspect of this change. Because of these factors, leadership from the top agency executives is critical for success.

Recommendations:

(5.1) Retain the FPA Steering Committee for day to day oversight of the FPA organization and development activities.

(5.2) Create new interagency common performance standards that provide for manager accountability, give incentives for changing behavior, and encourage them to work collaboratively in the FPU.

Question 6: Should the FPA Preparedness Module be used for budget formulation and allocation in its present state?

A review of the FPA-PM Charter shows that the PM module includes initial attack, extended attack, large fire costs, and wildland fire use (see Figure 1). A decision was made at some level to develop the PM module in two phases (1 and 2). This suggests that the FPA-PM module is not complete until both phases are finished. We sensed that there is strong interest in using interim FPA results to adjust budget formulation and budget allocation to improve cost effectiveness in fire management operations. For example, a review of the budget direction suggests that outputs from FPA Phase 1 will not be used to formulate fiscal year 2008 budgets, but could be used to inform decisions about moving money between FPU's.

We believe implementation of any change in the IA resource mix, placement, or budget based on FPA-PM Phase 1 outputs, until the entire Preparedness Module is complete, would be a misuse of FPA-PM. Solely using Phase 1 outputs to make allocation changes could result in suboptimal results, which could ultimately increase our total fire suppression costs. The impacts to FPA's results by including extended attack and/or large fire support costs could result in a significant shift in the results for a particular FPU.

If agencies rush to use or implement parts of FPA-PM for budget purposes before it is complete, there are great risks. Critics could easily refer to the science team report, the FPA-PM Charter, and other supporting documentation for FPA to curtail its further development. Further, imagine the consequences of an escaped fire being blamed on budget changes made as a result of an incomplete FPA model run.

Recommendations:

(6.1) Do not use FPA-PM Phase 1 outputs for budget development or allocation until Phase II has been completed and the IOG (see action #1 in the Conclusion) has concurred on its implementation.

(6.2) Managers should continue efforts at the FPU level to identify and implement local efficiencies. Incentives to further these efforts must be created.

Question 7: What lessons have we learned that can be applied to future efforts in building FPA?

The MRT acknowledges the dedication, commitment, and hard work of the FPA team members. They are to be commended for their effort. However, several lessons can be learned that should help improve communications and how the project is managed in the future.

To date, FPA has been driven largely within the fire community, and has not engaged a broad array of expertise from scientists, agency administrators, and managers. This has resulted in a lack of understanding, limited oversight, and buy-in at many levels of agency organizations.

The focus of communication has primarily been on completion of the model. Appropriate attention has not been placed on articulating the role of FPA, components of the FPA process and how they fit together, and how model outcomes will be utilized.

The mechanisms used to communicate have resulted in information overload and an inability to identify the most important information. The use of white papers, due to volume (over 45 papers), changing content, and lack of indexing has not been effective. It has resulted in inconsistent messages, where employees hear direction differently and at different times. This has been exacerbated by the sheer number of priority projects currently underway in the fire community (e.g.,NIMO, All Risk, Landfire, IFPM, etc.) The prioritization and links among these projects have not been clearly communicated.

Communication has been further confused because FPA terms and assumptions are different compared to existing fire terminology (e.g., initial attack success, WAM). A common understanding is needed to ensure the success of the FPA process. The existing FPA communication plan has recognized the need to standardize definitions, language and acronyms. However it does not appear that this action item has been completed and well distributed.

As a result of attempting to meet very compressed timeframes, sufficient systematic beta testing of the model did not occur before the model was deployed by all 135 + FPUs. This is an inefficient approach to model development that resulted in the investment of large amounts of time by all members of the FPUs, and significant frustrations dealing with numerous changes in the model and procedures.

Recommendations:

(7.1) Improve the existing blueprints and white papers documenting FPA. A one page blueprint should identify where we are in the process, where we are going, timeframe, etc. This needs to be a color diagram of the project with which everyone can identify. This diagram needs to show all phases of the project and the timeline. People need to understand where they fit in. Stakeholders need to see where they are involved. Keep it simple and easy to read.

(7.2) Complete FPA beta testing by using existing prototype FPUs to ensure model stability and usefulness before involving other FPUs. Ensure timeline for future efforts builds in adequate time and funding for sufficient model testing before deployment for broad use.

(7.3) Utilize more formal mechanisms for communicating significant procedural and policy changes (don’t rely solely on White Papers for internal communications). Consider having an all employee letter signed by all agency heads speaking to vision, objectives, strategy and next steps in the FPA process.

(7.4) Review and revise the existing FPA communications plan – incorporate findings identified above, and create more specific action items.

Conclusion

Our team believes that the vision and goals articulated in the report "Developing an Interagency, Landscape-scale Fire Planning Analysis and Budgeting Tool" remain sound, and Federal Wildland Fire Agencies should continue towards achieving the ideals articulated in this report. Existing legacy systems will not allow us to achieve the vision outlined in the Report. Therefore, we believe immediate actions must be taken to ensure our collective success in achieving the goal of an integrated budgeting system that looks across agency boundaries and incorporates land management objectives.

To ensure this success, we recommend actions listed in this report be implemented as soon as practable. We make these recommendation based on three key observations:

1. Understanding, acceptance, and support among various stakeholders are not what we believe they should be at this point in the development process in order for success. A strong indicator of this is the mixed expectations we discovered during the course of our review.

2. The Science Review Team's answers to questions posed by the FPA development team (see appendix) have raised important questions about the FPA model that should be resolved before continuing.

3. A significant amount of money has been spent so far ($16,000,000), and projected future investment is also significant. We believe it is incumbent upon management to ask if it is sound to continue as originally intended before further investment is committed, given the amount of concern that has been raised about FPA.

The following actions should be accomplished in an expeditious manner:

1. Establish an FPA Interagency Oversight Group (IOG), composed of: an agency scientist, a unit level agency manager, a senior agency administrator, an agency fire director, an agency budget director, and a NASF representative. This group will assist Wildland Fire Leadership Council (WFLC) in management oversight of FPA development. This oversight group would also charter the science panel mentioned in recommendation 2.0, and other ad hoc groups as needed. This group, comprised of a broader spectrum of agency management, would replace the intermediary role currently played by NFAEB.

2. Convene an ad hoc science panel that reports to the IOG, to answer questions like:
    - Is the modeling approach used in FPA appropriate?
    - Are there other approaches or types of models that might be significantly more effective and economical?
    - Is the optimization modeling approach used in FPA appropriate for the high risk wildland fire management environment?
    - How should FPA consider risk management?

- Does the current use of weighting factors allow for meaningful comparison across FPUs?

We understand there has been considerable disagreement among some scientists about FPA. Therefore, it is imperative that this panel be comprised of impartial members to insure an independent, non-biased review.

3. Complete a peer review of FPA-PM to validate the direction FPA development has taken. If the review suggests a change in direction, then a recommendation on how best to use work done to date should be provided.

4. The FPA development team should complete the planned analysis of Phase 1 FPU data submitted by the field on 2/15/2006. The results should be provided to the IOG and the science panel for their deliberations.

5. The FPA development team should complete an after-action review of the process used to develop FPA in order to prepare for any course corrections directed by the IOG or WFLC. The after-action review that is currently scheduled for April could be used as the forum to address this item.

6. Managers in each FPU should continue to look for local efficiencies.

Finally, regardless of the outcome of mid course correction strategies, we recommend FPA continue as a ***multiyear adaptive process*** that seeks to gain efficiency and effectiveness for interagency fire program delivery. After all, the challenge of modeling the interagency wildland fire management environment is incredibly complex and has never been done before. It will only be successful if we learn as we manage. Because fire management risks are significant and costs are high, interagency leadership has no choice but to continue developing an effective learning process that will help develop cost-effective budgets and effective policy for the public.

Appendix

Fire Program Analysis
Scientific Review Team Report

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Fire Program Analysis
Scientific Review Team Report

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Overview

The Scientific Review Team was convened to conduct a technical review of the Fire Program Analysis (FPA). The team was charged with performing a technical review of FPA and providing constructive feedback to enhance the model's functionality. Specifically, the team was to address high level technical and conceptual design considerations and not focus on the details of software design. Team members were chosen for their expertise in fire behavior and ecology, statistics, operations research, and economic modeling. Short biographies are included in Appendix I.

In initial discussions with the Steering Committee, it became obvious that the Science Review Team could not complete a comprehensive technical review in the short time allotted. With this in mind, the Steering Committee framed seven questions for the team to consider with the expectation that the team would answer and make recommendations on each question.

The team met on December 12-13, 2005, in Boise, Idaho. On the first day, members of the FPA Development Team and programmers from IBM gave the Science Review Team an overview of the major system components. The following day, the members of the Review Team discussed the questions and selected lead reviewers for each question based on their areas of expertise. Other team members were then assigned to assist each lead. The remainder of the day was spent interviewing selected development team members and IBM personnel. Following the meeting, team leads wrote responses to their questions with input from the other team members. The report was edited and compiled by the coordinator and then sent back to the members for their review and comment. The report represents a consensus of all team members.

The following are short summaries of the team's findings and recommendations:

> Question 1.Suggestions are given about sensitivity analysis for speeding up calculations, assessing variability, reducing model size, and documenting data quality.
>
> Question 2.How well the Initial Attack (IA) containment modeling approach used in FPA will perform remains an untested question that careful simulations might help address. The ability to accurately generate and use multiple random scenarios for both the optimization model and a simulator should be carefully tested.
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> Question 3.Wildland Fire Use (WFU) is handled as well as can be expected given the IA context of Phase I into which it was introduced. The benefits of WFU however, are not necessarily balanced with the potential losses or benefits of unwanted wildland fires since the final sizes and impacts of the latter are not estimated with the same methods as for WFU.
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> Question 4.There is a fundamental difference between the fire management policy implemented by the IA module of FPA, which maximizes weighted area managed (WAM), and current fire management policies of Federal agencies, which maximize containment of all ignitions before they become "large" wildfires. Because the IA module maximizes WAM, it does not include incentives inherent in the current fire

management policy that consistently produces IA success rates of 96-98%. As a result, the IA module's predictions of number of fires escaping initial attack can be much lower than observed. Increasing initial attack success rate predicted by the IA module can be achieved by changing the objective function from maximizing WAM to maximizing weighted number of fires contained, refining line construction and perimeter growth rates, and increasing the number of fire event scenarios in the optimization model.

Question 5.There are two major assumptions in the modeling of airtankers. First, the baseline upper bound on total cost is found by solving the initial attack model with airtanker bases filled to capacity. If fewer than the capacity number of airtankers are employed in the optimal solutions for the fire planning units, then funds previously used to pay for airtankers will be shifted to "budgeted" resources. The second assumption is that analysis of airtanker cost and effectiveness is done at the FPU level, independent of activity in adjacent FPUs. This may cause overestimation of WAM if a shared resource is simultaneously used in two or more FPUs. It may also overestimate the fixed cost of the shared resource.

Question 6.Unfortunately, there are no short-term options available for replacing the fire event scenario with something that represents the variability of combinations of fuels, weather, topography, and ignition histories. This variability, and the uncertainty that it contributes to, are the key challenges to fire suppression performance and must be represented in any fire planning system.

Question 7.Substantial documentation exists on the FPA web page but an increase of documentation in the scientific literature (both journals and agency publications) would add credibility and provide a framework for scientific peer review.

It is extremely important that the Steering Committee realize that this review addresses only the seven posed questions and cannot be considered a thorough peer review of FPA. It is the team's strongest recommendation that appropriate aspects of the FPA be submitted for peer review in refereed journals.

Question 1. What are approaches to sensitivity testing that might identify ways to simplify the model and produce comparable results?

Sensitivity Analyses

Sensitivity analyses can be extremely valuable for assessing a variety of issues:

- Speeding up calculations
- Annual variability
- Ability to follow recommendations
- Quality of input data
- Model acceptance
- Prelude to validation
- Other objective functions
- Characterization of variability

There are many overlaps concerning the above items and below the above items are examined in more detail followed by a suggestion as to how to proceed with the sensitivity analyses.

Speeding up calculations

As suggested in the original question, sensitivity analysis might lead to simplifications in the model which would result in much faster simulations but still give similar results.

A big limitation of the current model is its computational requirements, which prevent analysis of uncertainty about the number, location, and intensity of fires during the year. While the current model can be readily extended to include multiple fire event scenarios representing different possible fire seasons, computational limits prevent its solution in reasonable amounts of time. Therefore, if the current model can be simplified and produce comparable results with less computational requirements, then it might be possible to extend that simpler model to include multiple fire event scenarios and analyze the uncertainty about fire season. Here are two possible avenues to explore. (See also Questions 2 and 6).

Eliminate the time dimension

For each ignition, the model splits the 18-hour period of initial attack into eight intervals and determines the optimal interval for containment. If none of those intervals are optimal, then no resources are expended on initial attack and the fire is assigned its 18-hour burned area. To simplify the model, the IBM team formulated an equivalent model by expressing the time dimension as a continuous interval and representing the time-dependent parameters as piece-wise linear functions of time. Although this formulation had significantly fewer decision variables and less computational requirements, those requirements still prevented solution of multiple-scenario formulations in reasonable times.

Another idea is to eliminate the time dimension entirely. In this case, each ignition is characterized by a fixed amount of fire line that must be produced for containment, an area burned if the fire is contained, and an area burned if the fire is not contained. As before, 0-1 variables define whether or not each resource is deployed to each fire (except here the time dimension is dropped). Associated with each decision variable is a parameter for the length of fire line produced, which depends on the distance (time) the resource must travel to reach the fire, and its production rate. Associated with each variable is a cost of deployment. Each fire is contained if the sum of the fire line produced by the resources deployed exceeds the fire line requirement. Obviously, excluding the time dimension does not produce an equivalent model because it assumes average values of the parameters for fire size, fire line production, deployment cost, etc. Nevertheless, the model might produce similar results with significantly less computational requirements.

Formulate a standard response model

Another idea is to formulate a standard response model. In this model, each fire is characterized by location, rate of spread, and a set of potential responses. Each potential response specifies the number and type of resources that are required to reach the fire within maximum response times.

Associated with each potential response is a burned area and deployment cost. For example, one potential response is to dispatch two engines that can reach the fire within 30 minutes. This response will result in a relatively small burned area. An alternative response to the same fire would be to send no resources for initial attack, which results in a relatively large burned area. The model positions resources at bases and selects the standard response to each fire to maximize weighted acres managed subject to a total cost ceiling for the Fire Planning Unit (FPU). This model simplifies the problem by pre-defining a small number of potential responses to each fire. The deployment cost and burned area associated with each response is calculated outside the optimization model. Because there are fewer decision variables and fewer computations, the model should have fewer computational requirements. Standard response models have been developed and applied to fire protection in urban settings (e.g., Marianov and ReVelle 1991). It would be interesting to see if a standard response model can be formulated to provide comparable results to the existing initial attack model for wildland fires with significantly less computational requirements. Then, the standard response model could be expanded to include multiple fire event scenarios for the analysis of uncertainty about the fire season.

Annual variability

The model is based on averages over the 10 most current years of data but for any year that the model is in use, Mother Nature will provide a great deal of variability. The effect of this variability should be characterized for the main objective function Weighted Acres Managed (WAM) and any other secondary objective functions such as escaped fires.

One technique to do this is to use the "leave one out approach". This is very similar to the statistical jackknife procedure and *k*-fold cross-validation. If there are 11 years of data available for characterizing the model inputs, then making 11 separate runs of the model leaving out one of the years for each run will provide a measure of variability for the amount of WAM. If a small amount of variability in WAM is realized, then this would give others more comfort in the model. (An alternative – but not quite as satisfying – that would use only 6 runs of the model would be to remove 2 neighboring years at a time using a total of 12 years of data. Years 1 and 2 would be removed for the first run. Years 3 and 4 would be removed for the second run. And so on. Each run would still be with 10 years of data.)

Ability to follow recommendations

Besides the variability provided by Mother Nature, those implementing the suggested deployment of resources won't always be able to follow the recommendations exactly. Is the optimal solution highly dependent on exact adherence to following specific procedures? Variations from the optimal recommendations (with respect to at least a few variables most likely to deviate from the optimal solution) need to be examined. Here, too, one of the benefits of this process could be an increase in confidence in the model.

Quality of input data

The model output might be sensitive to the quality of some or all of the input data. Sensitivity analysis can suggest where data quality is adequate or inadequate. This type of sensitivity analysis is related to quality assurance in that for the variables in question it is the determination of the amount of variability in the input and that effect on the objective function rather than any attempt to "adjust" for that variability. This aspect of the sensitivity analysis would attempt to separate the effect of the natural variability of some of the input variables with the measurement errors associated with the input variables.

Model acceptance

Sensitivity analysis can help provide acceptance of the model for a variety of audiences. More specific examples are given throughout the items listed for Question 1. It is listed as a separate item because of its importance and pervasive nature.

Prelude to validation

A step beyond sensitivity analysis is "validation". The plans for validating portions of the model should be outlined and the results from sensitivity analysis can help suggest where validation efforts are needed (and not needed). Here, too, there are far more aspects of validation than can possibly be examined. The recommendation is to take the most controversial aspects of the model and design some (at least partial) validation procedures even if they cannot be currently implemented.

Here is a specific example. The initial attack model simplifies reality by assuming that fire line construction does not affect fire spread until the fire is contained, multiple fires on a single day occur simultaneously, resources cannot fight more than one fire a day, and existing dispatch rules are ignored. An important part of validation is determining whether or not these assumptions make any difference in system performance (e.g., WAM). One idea is to use a simulation model of initial attack, in which fire line construction affects fire spread rate, fires occur at different times of day, and resources can be dispatched to more than one fire a day, to determine WAM for a given resource configuration and see if the answer is similar to that produced by the FPA initial attack model. Using two models to address a given problem is a common approach to model comparison and evaluation.

Other objective functions

Sensitivity analysis can examine the effect of variation of input (and implementation) on other objective functions. For example, the single objective function chosen is WAM. But what of the levels (and variability) on other model outputs of concern such as escaped fires? Should we expect an increase or decrease in sedimentation rates if the optimal allocation of resources is followed to achieve optimal WAM?

One cannot optimize all objective functions simultaneously. But that does not mean that once an objective function is chosen (WAM for this model), all other objective functions can or should be ignored. Clearly the "weighted" part of the acronym WAM is an attempt to accommodate for other important objective functions but even that weighting cannot allow for optimization of all desirable objective functions. The recommendation is that one should describe the effect on other objective functions.

Characterizing variability

One of the benefits of sensitivity analyses is the formalization of the multiple sources of variability both spatial and temporal. All of the above items just described will help characterize the variability associated with the model and not just focus on the mean values. There is a concern that the model output appears to be focused solely on the expected WAM with little mention of the variability associated either with a particular year of use or the variability associated with input data used to create the model.

Overall recommendations for the sensitivity analyses

How can the above recommendations be accomplished? First, one needs to determine the major reasons for performing sensitivity analyses. One reason is to provide credibility for the model – and it is credibility not within the development team as those folks have thought long and hard about what should and should not go into the model and they are convinced of its value. It is for the various audiences that might be critical of the model or those that need a bit more back-up when they defend the model.

One of the audiences that could certainly be critical or be a great supporter would be the scientific community. Performing sensitivity analyses for that audience would go a long way towards achieving acceptance. (There are additional recommendations associated with this audience for Question 7.) Equally, if not more important is credibility with the management community. If FPA is to be successful, it must be seen as credible by its users.

If certain sensitivity analyses would be desirable but cannot (currently) be performed, then, at a minimum, write up the rationale for not doing so and provide a description of what needs to happen to be able to proceed (again, for credibility). This would give someone else (with the appropriate resources) the information needed to complete the task. There is no reason why the development team needs to (or even should) perform all of the sensitivity analyses.

Question 2. Will the optimization application of the economic model provide adequate strategic cost effective planning and budgeting for the fire season, at various budget levels at the FPU and National levels?

At the FPU Level

The FPU model is formulated to maximize weighted acres managed subject to a budget constraint for a single fire event scenario. The fire event scenario is a list of fires occurring in a season. Each fire is characterized by day, location, and spread rate. The fire scenario is selected as the median from a sample of 99 randomly generated scenarios, which are ranked according to the sum of the fire spread rates.

Fire event scenarios may vary a lot in terms of number of fires, location of fires, and number of days with multiple fires. To account for this variability, the existing initial attack model can be modified to maximize expected WAM subject to a budget constraint given a set of possible fire event scenarios weighted by their probability of occurrence. The solution to this problem, in terms of the optimal type and location of suppression resources and expected weighted acres managed, might be different than the solution obtained from the model with a single median fire event scenario. One reason the results might differ is that the number of days with multiple fires in the median scenario might be small relative to the number of days with multiple fires in the other possible scenarios. Because more escapes are likely on days with multiple fires, the solution from the model with the median fire event scenario might overestimate weighted acres managed compared with a model that accounts for the variability in fire events.

In the short run, computational limits prevent the solution of a model with multiple fire scenarios. For the present, the analysis team should attempt to evaluate and qualify the results obtained from a model with a single scenario. One test of an optimal resource configuration obtained from the model with a single scenario is to compute WAM for many of the other possible fire event scenarios. This estimates a distribution of WAM that represents the variability in outcomes of a particular resource configuration. The expected value of this distribution can then be used as a measure of performance of the resource configuration obtained with the deterministic model and the median scenario. There may be other resource configurations for the same budget that provide higher expected WAM; however, those must be found using an optimization model with multiple scenarios, which is not available yet. In the mean time, optimal resource configurations obtained from the model with a single fire event scenario should be tagged with the qualification that they don't necessarily maximize expected WAM given the variability in fire event scenarios.

In the long run, the large number of event scenarios possible for some planning units may preclude probability-weighted modeling that includes most scenarios. Nonetheless, experiments documented in the draft manuscript included with this report (Bevers, M. 2006. Optimizing seasonal firefighting resource allocations with random consequences: A stochastic integer and chance-constrained programming estimation approach. Canadian Journal of Forest Research. [in review]) suggest that including even a small number of randomly drawn scenarios in an FPU model might substantially improve the quality of solutions. Implementing this over the next year most likely means finding ways to further reduce the size of current single-scenario models. Steps that might be considered are eliminating the within-day time intervals or using standard response formulations (see Question 1), and leaving out fires and days when any initial attack organization likely to be selected will almost certainly contain all fires (see Question 6).

At the National Level

Results of the FPU models are aggregated into a single optimization problem. Each FPU computes and forwards to the National model maximum WAM for five different budget levels. From these data, the National model selects a single budget level for each FPU to maximize the sum of WAM across all FPUs subject to a National level budget constraint. Currently, the values of maximum WAM that are used in the National model are associated with optimal resource configurations obtained from the FPU model with a single fire event scenario. These values of WAM do not account for the variability in fire scenarios. To account for this variability, the expected WAM should be computed for each optimal resource configuration computed with the single-scenario model at the FPU level. Expected WAM of a resource configuration can be computed by stochastic simulation: compute WAM for each of a large number of randomly determined fire event scenarios and compute average WAM. Then, expected WAM and budget level for each resource configuration at the FPU level should be forwarded to the National model. With this information, the National model would choose a budget level for each FPU to maximize the sum of expected WAM across all FPUs subject to a National budget constraint.

An interesting and easy extension of this approach is to compute both the mean and variance of WAM for each resource configuration obtained from the single-scenario model at the FPU level. When this information is forwarded to the National level, models can be formulated to explore the risk-return tradeoffs at different budget levels. For example, one could choose a budget level for each FPU to maximize the sum of expected WAM subject to a National budget constraint and a safety rule that requires National WAM to exceed a target a specified percent (e.g., 95%) of the time. Holding the budget constant and varying the target allows determination of the tradeoffs between risk (target level for WAM) and return (expected WAM). The higher the target WAM that must be exceeded with high probability, the lower the expected WAM. Examples of this type of risk-return analysis in forest management are given by Hof et al. (1992) and Reeves and Haight (2000).

An unexplored issue associated with the National model is the sensitivity of its results to differences in weighting systems across the FPUs. The weighting system assumes that areas with wildland-urban interface are assigned a weight of one, and other areas are weighted in relation to WUI. If FPUs define and value WUI differently, then comparison of WAM across FPUs may not be valid. For example, one FPU could assume that WUI values are really high so that weights in other areas are relatively low. Conversely, another FPU with the same amount of WUI could assume that WUI values are moderate so that weights in other areas are relatively high. The weights employed in an FPU may affect the slope of the curve showing WAM versus budget, which in turn, will affect the allocation of resources across FPUs at the national level.

General Comments

How well the Initial Attack (IA) containment modeling approach used in FPA will perform remains an untested question that careful simulations might help address. Indeed, many of our comments have suggested the use of a simulator. The ability to accurately generate random scenarios for both the optimization model and a simulator should also be carefully tested. For example, if fire histories indicate the presence of trends, moving averages, autoregressive relationships, or spatial correlations, that might suggest using more complex random fire scenario generation schemes (see also Question 6).

How well maximizing WAM conforms with fire suppression policies and various land management objectives is not entirely clear. The FPA development team indicated that the model is not currently able to account for some land management objectives. Model results will be most useful when model objectives are consistent with actual performance measures.

The initial attack module is designed to take a fairly comprehensive and detailed approach to fire organization planning that has resulted in large optimization models. Whether a more incremental approach, perhaps using simulation optimization or other methods, would be either more appropriate for decision making or more easily integrated with Phase 2 modules remains to be seen.

For a variety of reasons, deviations from current budgets are being constrained for planning FY08. Similar constraints should perhaps be considered for organizational deviations.

Question 3. Are the benefits of fire use adequately balanced in the model with the benefits of suppressing unwanted fire?

General Comment

Wildland Fire Use (WFU) is handled as well as can be expected given the IA context of Phase I into which it was introduced. The benefits of WFU however, are not necessarily balanced with the potential losses or benefits of unwanted wildland fires since the final sizes and impacts of the latter are not estimated with the same methods as for WFU.

Influence of specific assumptions

Our review suggested the following assumptions in FPA have a large influence on the way that suppression and fire use incidents are managed in the system:

- Final fire sizes for fires that remain uncontained during the designated initial attack period of 18 hours are set to the elliptical fire size achieved at the 18 hour IA limit. In other words, there is no attempt to estimate the final size of the wildfire or its impacts (positive or negative weights) beyond 18 hours. This has wide-ranging impact on the absence of penalties for IA failure (see Question 4 below).
- By contrast, a procedure is implemented for estimating final fire size for wildland fire use incidents. Benefits to the WAM are accrued from the entire final burned area which could be much larger area than for wildfires that escape IA.
- The user has the option of assigning a different schedule of weights (benefits & losses) to WFU incidents than for IA fires, even those that burn under identical weather and fuel conditions where impacts would be ecologically and physically the same. In fact, the standard procedure appears to always assign negative weights to wildfires (those not managed as WFU).
- WFU incidents that are designated as too complex, large, or of long duration are dropped completely from the program. No benefits or losses or resource-use costs are assigned.
- The implementation of wildland fire use (WFU) is somewhat out of place within the initial attack paradigm of FPA Phase I because it really involves elements of the Large Fire and Fuels modules of forthcoming Phase II. Wildland fire use benefits are acquired by limits on IA response (saving money) but mostly through positive impacts on fuels, ecological values, and future fires from the areas that burn well beyond the ignition location. If all WFU incidents remained local to the ignition location (i.e. did not spread) very little benefit would be achieved. By contrast, the paradigm of IA incidents for FPA (as well as many previous fire planning systems) is that all behavior is estimated from the ignition location and short time-frame (i.e. assumes spread for only local fuels and topography and for short-term weather conditions). Thus, different procedures are required to accommodate fire use (mostly longer-term and larger area) than suppression fires (short-term and smaller area).

Question 4. Preliminary results show that in some cases the number of fires escaping with initial attack seems unreasonably high. Are the fire spread rates in the model reasonable relative to the containment effort? If IA success rates are unrealistically low when modeled against current budget levels, what options might we explore within the context of the existing model to make the initial attack success rates more realistic?

There is a fundamental difference between the fire management policy implemented by FPA through the WAM objective compared to the fire management policies practiced by all agencies in most places in the US today. Specifically, the objective of the current IA optimization is to maximize WAM – that is, use suppression to produce the greatest savings of values otherwise impacted by burning. Regardless of whether this policy is desirable or practical, it stands in stark contrast to the *de facto* IA policy that rewards efforts to extinguish all ignitions before they become “large” wildfires. The *de facto* fire management policy encourages containment of every fire, largely because of the huge potential impacts of a large wildfire on values remote from the ignition location and the costs, difficulty, and uncertainty of managing large fires. The IA module of FPA does not include management costs or final sizes of fires uncontained by initial attack. As a result, it does not include the incentives inherent in the *de facto* fire management policy that consistently produce IA success rates of 96-98%.

Improvements to the initial attack success rates can be made through refining line construction and perimeter growth rates, changing the objective function from maximizing weighted acres managed to maximizing weighted number of fires contained, and increasing the number of fire event scenarios in the optimization model.

Line Construction and Perimeter Growth Rates

One reason the number of fires escaping seems unreasonably large might be that fire growth rates are too large relative to line construction rates. A review of these factors reveals that the fire growth rates are calculated from the standard fire behavior prediction system and line production comes from the rates published in the fireline handbook. Fire behavior values are calculated for the afternoon fuel moisture conditions and assumed constant throughout the 18-hour period as are line production rates. Both of these are likely to overestimate the true values because actual fires and line production vary depending on fuels, weather, and topography at the point and time of ignition.

There are several reasons why the fire perimeter growth estimates in FPA might be too large relative to fire line production rates. Real fires burn patchy fuels. Fire perimeter growth in a patchy landscape with less flammable fuels, rock outcrops, and bodies of water would have smaller fires than a homogeneous landscape. Further, a patchy landscape has various types of natural firebreaks so that crews need not construct fire line around 100% of the fire's perimeter to contain it. To account for landscape heterogeneity, the initial attack model used by the Ontario Ministry of Natural Resources (LEOPARDS) assumes that fires grow at 50% of the peak rate predicted for homogeneous fuels in afternoon fuel moisture conditions (McAlpine and Hirsch 1999). Further, LEOPARDS assumes that fire containment occurs when fire line reaches 40% of the fire perimeter (McAlpine and Hirsch 1999).

Another reason why fire perimeter growth estimates in FPA might be too large is the assumption that fire line construction and fire perimeter growth are independent. This assumption ignores the potential impact that suppression tactics have on fire perimeter growth rate. For example, air tanker drops early in the life of a fire produce fire line and reduce fire perimeter growth rate so that fewer ground resources are needed for containment compared to a situation where air tanker drops produce fire line and do not affect perimeter growth. Fried and Fried (1996) built a simulation model of fire perimeter and area to analyze the effect of suppression tactics on perimeter growth and containment time. They compared the predictions of a model in which fire-fighting tactics affect fire growth rates with those of a model in which fire line construction and fire perimeter growth rate are independent. The latter model resulted in fire sizes and containment times that were larger than those predicted by the model in which fire line construction affected perimeter growth rate. Sometimes fire sizes and containment times were larger by as much as an order of magnitude.

Given these reasons to suspect that fire growth estimates in FPA are too large relative to fire line construction, the analysis team should explore the impact of reducing fire perimeter and area growth rates in the existing model. This can be done by reducing fire perimeters and areas over the period to the maximum time allowed for containment to reflect the possibility that fire perimeter growth is slowed by initial attack. Parameters for fire area subsequent to the maximum time allowed should not be changed because the model assumes those fires are not attacked. Reducing fire perimeters reduces the length of fire line and cost required for containment. As a result, more fires can be attacked and contained for a given budget.

While subjectively reducing fire growth rates will increase containment rates, there are possible drawbacks. Different adjustments would be required for each FPU depending on fuels, weather, and crew types and thus diminish the comparability among FPUs for suppression organizations Reducing fire growth rates may be grounds for comparison with the "calibration" process like that used in NFMAS because both would adjust fire behavior values until some criteria were met. Fire growth adjustments might cause unintended consequences to the WAM calculations (no way to know this at present). Finally, adjustments might cause problems for later phases of FPA (i.e. Phase II concerning large fire and fuels). Where containment rates are unrealistic, some modification of Phase I will be required before Phase II can be developed, because escaped fires are the starting point for those to be modeled and managed under Phase II.

Although it is possible that the relative values of the fire growth and line production rates contribute to biased estimates of fire containment, it is unlikely that these alone explain the consistently low IA success that has been reported throughout many FPUs in the country. Each FPU and FMU has different weather and fuels which would produce a different set of fire behaviors and consequent IA success since the line production rates are fixed nationally but the weather and fuels aren't. In other words, containment is low in diverse areas of the country where fire behavior and line construction aren't in common.

Objective Function

Another reason the number of fires escaping seems unreasonably high is the model objective, which maximizes weighted acres managed not number of escapes. With limited resources, the model will attempt to attack fires that grow large (by the end of 18 hours if not attacked) in fire management units with the highest weights. When there are only a few potentially large fires in highly weighted fire management units (FMUs) and many relatively small fires in low-weighted FMUs, and the budget prevents containing all fires, the proportion of the total number of fires that are contained may be small if resources are primarily used to attack fires in the highly weighted FMUs. In addition, some fires grow very slowly and are very small after 18 hours. Because those fires make an insignificant contribution to the objective function, there is no incentive to suppress them. An interesting artifact is that the number of escapes could increase as the budget increases. This might happen if, at low budget levels, resources are not sufficient to contain the small number of large fires in highly-weighted FMUs and instead are positioned to contain the large number of small fires in low-weighted FMUs. As the budget increases, resources are re-positioned to attack the fires in highly-weighted FMUs while ignoring the fires in the low-weighted FMUs thereby increasing the overall number of escapes.

To determine how the model objective affects the number of fires escaping initial attack, the analysis team should change the objective function to maximize weighted number of fires contained while leaving the structure and parameters of the model unchanged. In Formulation 1 described in the paper "Strategic planning of preparedness budgets for wild-fire management activities during initial response," the objective function (Eq. 1) could be modified by removing (or setting equal to 1) the parameter A_{it} (total area burned by fire i until time t), changing the index on the summation from T_i^0 to T_i (so that only fires that are contained within the maximum time period for initial response are counted), and removing the term $W_{(0)}$ and the minus sign (which is missing from Eq. 1). Then, solving the model with the same set of budget constraints, the analysis team can determine if this new management objective significantly changes the number of fires contained, weighted acres managed, and resource positioning. If changing the objective does not significantly increase the number of fires contained, then fire perimeter growth rates of attacked fires are probably too high. If changing the objective function increases the number of contained fires to levels observed in the field, the analysis group is faced with a dilemma about which objective is more appropriate: maximizing weighted acres managed or maximizing weighted number of contained fires. It would be interesting to determine the tradeoffs between these two objectives by solving a two-objective model using the weighting method of multi-objective programming. In particular, are there locations where resources should be stationed regardless of the weights on the two objectives?

Fire Event Scenarios

The current model uses a single fire event scenario that represents the median-level fire season. To provide a mixture of mild and severe fire seasons in proportion to those made possible by the climate of the area, the number of fire event scenarios used in the optimization should be increased. This may increase the number of IA successes because small fires under moderate conditions are more common than extreme events.

Question 5. Are modeling assumptions for resources (e.g., airtankers) shared between FPUs reasonable?

Modeling Assumptions

The modeling team used locations of 59 airtanker bases in the United States: 12 in the east, 39 in the west, and 8 in Alaska. Each base is owned by a state or federal agency and has 1-4 loading pits. To model the use of airtankers in a fire planning unit (FPU), the planner constructs a list of airtanker bases with access to each fire management unit (FMU). A base has access to an FMU if any part of the FMU is within a 100-mile radius of the base. Assuming a maximum of one airtanker per loading pit, the planner defines resource capacity at each base by specifying an airtanker type for each pit and the periods of the fire season when the resource is available. The fixed and variable cost parameters for each airtanker are defined nationally. The fixed cost is $450,000, which is the national average cost per plane based on contract information. Variable cost includes cost of deployment to a fire and cost of retardant. Cost of deployment depends on distance between the base and the FMU where the fire occurs and nationally-determined travel rates and costs per hour. Binary decision variables are defined for whether or not each airtanker is used for the season and on each fire that occurs in an FMU within 100 miles of the base.

The objective of the initial attack model is to maximize weighted acres managed (WAM) in an FPU subject to an upper bound on total cost. The total cost equation includes fixed and variable costs of resources that enter into the preparedness budget (budgeted resources) and costs of non-budgeted resources such as airtankers. The cost of an airtanker (fixed plus variable cost) is included in the total cost equation only if the airtanker is deployed to at least one fire in the model solution. If the airtanker is not deployed to any fire, the model assumes that the airtanker was not stationed at the base and the fixed cost of the aircraft is not included in the total cost equation.

Budget Range Optimal solutions of the initial attack model are found for five different upper bounds on total cost. The baseline upper bound is found by determining the optimal deployment of existing FPU resources, including non-budgeted resources like airtankers, assuming that those resources are fixed at the current locations. The total cost (sum of fixed and variable costs) of the optimal solution is the baseline upper bound. The other four upper bounds are ± 2.5% and ± 5% of the baseline. The Budget Range Optimal solutions are found with these total cost constraints and without any requirements on the number and location of budgeted and non-budgeted resources, including airtankers.

In addition to total cost, a preparedness budget is determined for each of the five optimal solutions. The preparedness budget is the sum of the fixed costs of all the budgeted resources positioned in the FPU in the optimal solution. Because airtankers are a non-budgeted resource, their fixed cost is not included in the preparedness budget. Total cost, the preparedness budget, and WAM associated with each of the five optimal solutions are submitted to the national optimization model, which determines the preparedness budget for each FPU to maximize the sum of WAM across all FPUs subject to an upper bound total cost at the national level, which includes fixed and variable costs of budgeted and non-budgeted resources like airtankers.

Implications

There are two major assumptions in the modeling of airtankers. First, the baseline upper bound on total cost is found by solving the initial attack model with airtanker bases filled to capacity (e.g., a base with four pits has four airtankers present). To analyze the implication of this assumption, let C_p be the sum of fixed and variable costs of suppression resources in the preparedness budget, C_a be the sum of fixed and variable costs of non-budgeted resources (i.e., airtankers), and TC be total cost ceiling, which includes fixed and variable costs of budgeted and non-budgeted resources. To find a Budget Range Optimal solution, the problem is to maximize WAM subject to the budget constraint $C_p + C_a < TC$ with no constraints on the number and location of existing resources. If no airtankers are positioned in the optimal solution, then $C_p = TC$. In this case, the funds used for fixed and variable costs of airtankers in the determination of the baseline upper bound of total cost are now utilized for budgeted resources. If this case happens in all the FPUs, then all of the funds for airtankers are shifted for use by budgeted resources, which is unlikely to happen. The development team should be careful to constrain the Budget Range Optimal solutions to represent realistic outcomes.

The second assumption is that analysis of airtanker cost and effectiveness is done at the FPU level, independent of activity in adjacent FPUs. This has two implications. First, when an airtanker base serves more than one FPU, optimal solutions of the initial attack model for adjacent FPUs may call for the same airtanker to be simultaneously deployed if fires ignite on the same day in both FPUs. If the airtanker can serve only one of the FPUs, then the optimal solution for the other FPU is infeasible and will overestimate WAM for the given budget. The second implication is that the fixed cost of stationing a given airtanker may be paid by two or more FPUs if that airtanker is present in the optimal solutions for those FPUs. Because the fixed cost of airtankers is included in each FPU budget constraint, the total fixed cost of the shared airtanker across those FPUs will be more than necessary. For example, suppose an airtanker in Durango CO has access to four FPUs and is included in the optimal resource configurations for all four FPUs. Then, the fixed cost of that airtanker, $450,000, will be counted four times, once for each FPU, for a total of $1.8 million, which is $1.35 million more than the actual fixed cost of the airtanker. This is $1.35 million that could have been used for budgeted resources across those FPUs. A simple, alternative approach would be to divide the fixed cost of the airtanker, $450,000, equally among the FPUs that it potentially serves when solving the optimization models for the FPUs. In this example, the fixed cost of the single airtanker at Durango, which potentially serves four FPUs, would be $112,500 for each FPU analysis.

Question 6. Does the Phase I fire event scenario provide a reasonable target for modeling fire season resources and budget?

The Current Fire Event Scenario

The current fire event scenario is selected as the median scenario (by rank) from a sample of 99 randomly generated scenarios. Each scenario is ranked by summing the fire spread rates for all fires in the entire season. This has the advantage of reflecting the total line production rates required to contain all fires, but does not distinguish scenarios where simultaneous fires cause competition among scarce suppression resources (which is in fact what contributes to most escapes). Thus, scenarios with the same rank may present very different challenges to a given suppression organization. Briefly, each scenario is originally generated according to a random sampling procedure used to obtain a list of fires by date, including for each fire the fuel type, topography (slope, aspect and elevation), and weather (windspeed and live and dead fuel moistures). The base data required to generate this list is provided by the FPA planner for each FMU and includes local data for the past 10-years on historic weather and ignitions by date, as well as spatial or non-spatial proportions of fuels and topography in each FMU. Thus, each fire scenario is likely to be different but each date in the season will be within the range of historic observations.

Fire Scenario Generator

In contrast to the current use of a single fire scenario, **the fire scenario generator was designed** for producing many fire seasons that would represent a large sample of the variation in potential seasons with which a suppression organization could be challenged. Fire weather presents the single greatest source of variation in suppression activity (successes and failures). The responses of fire behavior characteristics to weather variation and, in turn, the suppression resources to the fire behavior characteristics, is extremely non-linear. Therefore, no average season can be developed *a priori* to produce the average outcome. Instead, the expected outcome or performance of a suppression organization must be summarized as the expectation from a large sample of individual outcomes. The current procedure is inadequate to represent this variation and its effects upon suppression performance, but the use of a single scenario was required to conform to the computing limits of the IA optimization. **Given the impact that variable weather has on the year-to-year performance of a particular suppression organization, the question arises: should an IA optimization be performed at the level of an individual fire season (as is currently implemented in FPA) or among different suppression organizations**

subjected to a large sample of fire seasons? The performance of a suppression organization will vary widely according to the workload of the particular season which suggests that the overall basis for quantifying performance would need to cover a wide range of possible seasons. This does not mean that the organization is being designed for mild seasons (fires occurring in those seasons present trivial workload and small negative impacts but perhaps offer important positive impacts as well through WFU). It simply reflects the proportional influence of mild seasons among the statistical possibilities.

Accounting for the variability in weather in the current optimization framework is challenging because the specific suppression organizations produced by the optimization will be different among different fire scenarios (*i.e*. it is hard to derive a single organization from multiple runs). There are several possible approaches that might improve the optimization solution:

- Use multiple fire seasons to estimate maximum WAM for which a single optimized suppression organization has been planned. This point is covered in greater detail in Bevers (2006), which is included in the appendix of this report. Estimation has the benefit of representing multiple possible fire years, but limits on computing memory and time would likely restrict the number of fire seasons to a fairly small number (e.g. 10) rather than the 100s.
- As suggested in the answer to Question 2, select only those fire days in each season where suppression is challenging (e.g. multiple fire days or extreme weather, when success is not guaranteed). Computationally, this offers the advantage of having fewer fire days that require less memory and shorter solution time. The drawbacks to this approach are numerous, however:

    - Requires arbitrary decisions to select which fire days are included,
    - Assumes that the entire suppression organization can be understood from only the performance under the tasking conditions.
    - May overemphasize the impact of assumptions of unrealistically perfect dispatch logic used by the optimization because the scenario only includes fire days where critical tradeoff decisions are required (and uses perfect knowledge to make those decisions).
    - Still requires a large sample of fire years to accommodate the combinatorial possibilities of variable weather X simultaneous ignitions X fuels.

- Substitute a new dispatch logic for the current optimization which would then determine the performance of suppression organizations over many seasons (see also Question 1). This would allow a high-level optimization to be performed at the "organization" level where the performance was derived from the outcome of a large sample of seasons (using any measure or measures, like WAM, escaped fire percentage etc.). The benefits to this would be:

    - Resource performance could be assessed over a realistically large sample of possible seasons and ignitions,
    - Rapid computing time for individual suppression organizations.
    - Scalable suppression organizations across budget levels (because organizations are selected by the planner).
    - More realistic dispatch logic.

- The downside to this involves:
  - Reengineering of the IA portion of FPA
  - Developing an optimization, perhaps using heuristics, to improve the suppression organization performance among seasons and perhaps budget levels as well.

Conclusion

Unfortunately, there are no short-term options available for replacing the fire event scenario with something that represents the variability of combinations of fuels, weather, topography, and ignition histories. This variability, and the uncertainty that it contributes to, are the key challenges to fire suppression performance and must be represented in any fire planning system.

Question 7. Is there adequate documentation on the system?

Substantial documentation exists on the FPA web page (http://www.fpa.nifc.gov) consisting of:

- Quarterly Status Reports
- Newsletters (E Newsletter and TechNews)
- Maps of Fire Planning Units
- Implementation Timelines
- Interagency Memos and Attachments
- Draft Charters
- Software documentation (Preparedness Module (PM) and Personal Computer Historic Analysis (PCHA))
- White Papers

In addition, there is the F&AM (Forest Service Fire and Aviation Management) Information Systems Application Helpdesk to provide assistance. Further documentation currently resides in internal Lotus Notes databases.

These documents are informative and well written for the target audiences which appear to consist of fire management officials (in each of several agencies), the US public, and Congress. The one audience not targeted is that of the research community. The reasons for this observation are as follows:

- Few papers describing this unique inter-agency process occur in the scientific literature. One of the few is Rideout and Botti (2000).
- Many of the technical documents list no scientific references and most of the remaining have very few (typically just one or two references and only occasionally from the scientific literature).

- There does not appear to be a well-defined peer review process using outside reviewers.

We infer the need or desire to address the scientific community from the request for this very review (consisting of scientists from the U.S. Geological Survey and the Forest Service) and from the interagency report "Developing an Interagency, Landscape-scale Fire Planning Analysis and Budget Tool":

> "…OMB requested all five agencies to develop a common program analysis system that is … scientifically-based, peer reviewed …."

To bring in a larger contingent of the scientific community the following approaches are recommended:

- Papers describing the basis for the project need to be placed on a publication schedule and submitted for journal review. Two such papers that are of immediate interest are (1) "Weight System (EOWEP) for FPA-PM" by Douglas B. Rideout and Pamela Sue Ziesler, and (2) "FPA-PM Modeling Assumptions" (with authors not currently specified in the available working draft).
- Consider placing several of the white papers into General Technical Reports (GTR's) published by one of the Forest Service Research Stations. This would include a peer review.
- Substantial documentation also exists on the FPA Development Team and IBM Team internal web pages, including detailed documentation of model formulations, approximations, etc. used in the Preparedness Module. Some of this material would be of particular interest to the scientific modeling community. Making it more available might well stimulate outside studies that ultimately result in improvements to FPA. Scientists would likely have similar interest in the working details of PCHA, but that documentation was much more limited at the time of this review.
- Produce a written description of the plans for sensitivity analysis and any validation analysis and arrange for a scientific peer review.
- Develop a formal peer review policy or adopt an existing policy. Policies for consideration could be found through contacts at each of the Forest Service Research Stations and the USDA and DOI peer review guidelines based on the Data Quality Act found at the following two sites:

  http://www.ocio.usda.gov/qi_guide/scientific_research.html.

  http://doi.gov/ocio/guidelines/515Guides.pdf

- Create an additional web page in the FPA Library web pages for scientific citations and publications based on the analyses. These do not need to be just those research papers developed in-house.

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Appendix I. Scientific Review Team Biographical Sketches

Jim Baldwin is the Station Statistician with the Forest Service, stationed at the Pacific Southwest Research Station in Albany, California. In 1977, he obtained a PhD. in Applied Statistics from the University of California, Riverside. He has been a statistician for the PSW Research Station for over 25 years. His professional interest is in statistical consulting for research on fire, snow, water, wildlife, plants, fish, soil, timber, bugs, and recreation.

Michael Bevers is a Research Forester with the Forest Service at the Rocky Mountain Research Station in Fort Collins, Colorado. He obtained his PhD. Forest Science from Colorado State University in 1995. His research interests include applications of optimization and simulation modeling techniques to improve management of natural resource systems. In the past, his studies focused on formulating and solving spatial optimization models, and he is currently studying risk management.

Mark A. Finney is a Research Scientist with at the Forest Service, Rocky Mountain Research Station. He has been stationed at the Missoula Fire Sciences Laboratory in Missoula, Montana, for the past 12 years. Before that he spent 2 years on the research staff of Sequoia National Park in California. He holds a Ph.D. in Wildland Fire Science from University of California at Berkeley. His research interests are fire growth modeling, fuel management and spatial fuel treatment optimization.

Robert G. Haight is a Research Forester with the Forest Service at the North Central Research Station, St. Paul, Minnesota. He holds a Ph.D. in forest economics from Oregon State University. His research interests include conservation of wildlife and forest resources, modeling resource management problems, and using simulation and optimization methods to identify the strengths and weaknesses of alternative management strategies. Currently, his research focuses on protecting open space in metropolitan areas and funding fuel treatment and fire suppression programs.

Jan W. van Wagtendonk is a Research Forester with the U.S. Geological survey at the Western Ecological Research Center. He is stationed at the Yosemite Field Station in El Portal, California. He obtained his PhD. In Wildland Resource Science from the University of California at Berkeley. He has been at Yosemite since 1972, first with the National Park Service and now with USGS. His areas of research have included prescriptions for burning in wildland ecosystems, recreational impacts in wilderness, and the application of geographic information systems to resources management. His work currently focuses on the role of fire in Sierra Nevada ecosystems.

Appendix II. Optimizing Seasonal Fire Fighting Resource Allocations

The attached draft article by Mike Bevers is a good example of the methods that could be used as an alternative to the large number of event scenarios needed for some planning units using probability-weighted modeling that includes most scenarios. Experiments documented in the article suggest that including even a small number of randomly drawn scenarios in an FPU model might substantially improve the quality of solutions

Bevers, M. 2006. Optimizing seasonal firefighting resource allocations with random consequences: A stochastic integer and chance-constrained programming estimation approach. Canadian Journal of Forest Research. (In review)