

Developing a Decision Support System to Optimize Spatial and Temporal Fuel Treatments at a Landscape Scale

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Abstract

There is a recognized need to apply and maintain fuel treatments to reduce catastrophic wildland fires in the United States. Forest managers must establish priorities for where, when, and how to apply hazardous fuel reduction treatments, yet they are faced with limited budgets, narrow prescription-burning days, air quality issues, and effects on other critical forest resources. A number of models and decision support systems have been developed to address different aspects of fuel treatments on a landscape, but no one model adequately handles the strategic scheduling of fuel treatments that simultaneously considers 1) the spatial and temporal changes of fuel treatment effects on a landscape, and 2) the economics of fuel treatments as well as other operational constraints. In order to fill this critical gap, a decision-support system, called OptFuels, is in development that builds linkages between the existing fire behavior, vegetation simulation, and land management planning models. This system is designed to optimize spatial and temporal location of fuel treatments in the way that landscape-level fuel management effects are maximized and maintained over time while satisfying given budget and operational constraints. Upon completion of the system, OptFuels is expected to facilitate analyzing effective spatial and temporal fuel management strategies and provide valuable information to land managers who are searching for the most cost effective way of applying fuel treatments in their forests.

Introduction

There is a recognized need to apply and maintain fuel treatments to reduce catastrophic wildland fires in the United States. The Healthy Forests Restoration Act of 2003 mandates actions to identify and inventory priority areas. Treating all of the 81 million hectares of federal land in the US considered at risk from fire (Schmidt et al. 2002) would be costly and impractical. Forest managers faced with limited budgets, burning windows, air quality issues, and effects on other critical forest resources must establish priorities for where, when, and how to apply new and maintenance fuel treatments. Science-based yet field applicable guidelines to strategically maintain fuel treatments on landscapes should be incorporated into treatment design to reduce catastrophic fire and restore ecosystem health over time.

A number of models and tools have been developed and extensively validated for addressing the effects and effectiveness of fuel treatments from different perspectives and geographic scales. For example, FARSITE (Finney 1998) and FlamMap (Finney 2006) are able to compute fire behavior characteristics at a landscape scale. However, neither temporal effects of treatments nor maintenance scheduling are included in either of these models. FVS-FFE (Reinhardt and Crookston 2003) has the ability to model stand-level fuel and vegetation dynamics, but it does not simulate the spread of fires between stands. As an economic optimization tool, MAGIS (Multiple-resource Analysis and Geographic Information System; Zuuring et al. 1995, Chung et al. 2005) has the ability to optimize forest treatments spatially and temporally in the presence of multiple objectives and constraints, but no fire spread logic exists in the system.

The objective of this ongoing study is to integrate existing fire behavior, vegetation simulation, and land management planning tools into one decision support system that supports long-term fuel management decisions. The system, called OptFuels, builds on the existing land management optimization tool (MAGIS), while incorporating FFE-FVS and FlamMap to analyze spatial and temporal effects of treatment activities. This system is designed to optimize spatial and temporal location of fuel treatments in the way that landscape-level fuel management effects are maximized and maintained over time while satisfying given budget and operational constraints. The release version of OptFuels will be available in 2010. This paper introduces the system design and development methods.

System Development Methods

We used the existing MAGIS framework with proper modifications in the development of OptFuels. The existing MAGIS system has the capacity to set up the vegetative model, incorporate stand and treatment unit GIS data, set up problem parameters (e.g., management objectives and resource constraints), build the matrix of costs and effects of potential treatments, optimize resource schedules and display solution information (Zuuring et al. 1995, Chung et al. 2005). We combined MAGIS with the FFE-FVS to simulate fuel dynamics and stand-level treatment effects over time and FlamMap, a raster-based fire behavior model, to evaluate landscape-level effects of combined fuel treatments in each time period (Figure 1). For this integration, we have developed data transfer interfaces between models and modified the current MAGIS heuristic solver to evaluate spatial and temporal fuel treatment effects and schedule long-term fuel management activities.

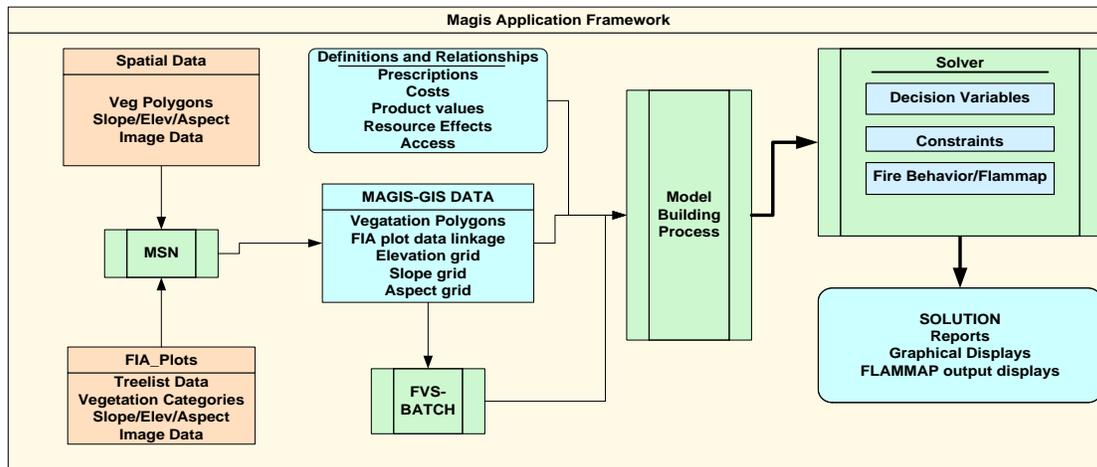


Figure 1. Data transfer interfaces among models

Interface between MAGIS and FFE-FVS

Using the current MAGIS user-interface, stands can be grouped depending on their attributes, such as forest type, region, ownership, slope, current fire hazard, and others. Users can develop different silvicultural prescriptions (fuel treatments) that can be applied to each group of stands. A data transfer interface between MAGIS and FFE-FVS has been developed to 1) identify all the treatment-timing combinations available for each stand, 2) convert silvicultural prescriptions into the FVS readable format, and 3) run FFE-FVS in a batch mode. Using FFE-FVS requires tree list data for individual stands. Using the k-Nearest Neighbor (kNN) imputation process using the Random Forest method as described by Crookston and Finley (2008) can be one way to associate USFS Forest Inventory and Analysis (FIA) stand inventory data with every polygon in the landscape of interest and provide FVS-ready tree lists for each polygon. FFE-FVS are then run for each relevant treatment and timing option on each polygon and the results are stored in a relational database.

MAGIS and FlamMap

In OptFuels, we measure the effectiveness of a fuel treatment in terms of its contribution to the reduction of fire spread rates across a landscape under a specific set of weather conditions. A set of candidate fuel treatment units developed by the MAGIS heuristic solver (described in the following section) collectively form a spatial pattern with diverse fuels and topographic conditions. The effectiveness of the spatial pattern is then measured by the estimated minimum fire arrival time at each pixel on the landscape. With this procedure, a fuel treatment unit, which highly contributes to the reduction of fire travel time across the landscape (e.g. treatment units along the minimum fire travel routes) will receive a higher probability for being selected in the final treatment schedule, while those which contribute little to the landscape-level effects will likely be excluded from the final solution due to other resource constraints. FlamMap (<http://fire.org/>) is used to compute fire behavior values (e.g. flame length) and minimum travel time (MTT) for each pixel for an entire landscape using data layers consisting of fuels, topography, and weather conditions. An automatic data transfer interface has been developed in the

heuristic solver to run FlamMap from MAGIS that 1) reads fuel characteristics developed by FFE-FVS for each stand for each time period based on a given treatment schedule, 2) mosaic the stand-level fuel characteristics to compose raster-based fuel maps over a landscape for each time period, and 3) transfer fuel maps to FlamMap and run the program with the MTT algorithm option in a batch mode. Fire behavior characteristics developed by FlamMap are then delivered back to MAGIS by the interface and used in evaluating the selected fuel treatment schedule.

Heuristic Solver for OptFuels

Scheduling spatial and temporal fuel treatments involves a large amount of data and an enormous number of solution alternatives, and thus becomes a large combinatorial optimization problem. The current MAGIS heuristic optimizer (Chung et al. 2005) uses the Simulated Annealing (SA) heuristic (Kirkpatrick et al. 1983) to optimize resource management schedules while considering the economics (cost and benefit) of management activities, resource constraints, and operational feasibility. SA is a Monte Carlo search method that uses a local search in which a subset of solutions is explored by moving from one solution to a neighboring solution. In forestry, SA has been widely used to solve large spatial harvest scheduling problems (Öhman and Eriksson 1998, Boyland et al. 2004).

For OptFuels, we have modified the current SA algorithm in MAGIS so that the optimizer automatically 1) develops a variety of fuel management schedules, 2) evaluates each alternative schedule in terms of minimum expected loss values across a landscape, associated costs and revenues, and operational feasibility of treatments, and 3) finally selects the best spatial and temporal arrangement of fuel treatments that produces maximum treatment effects over time while meeting given resource and operational constraints. Specifically, the OptFuels heuristic solver is designed to generate and evaluate alternative fuel management schedules using the following steps.

- Step 1: Start with an initial solution that does not include any treatment activities (no action) across a landscape of interest during the entire planning periods (up to 5 time periods).
- Step 2: Modify the previous solution by randomly selecting a certain number of management units (polygons) and altering the previously assigned treatment-timing combinations to create a new solution (for example, changing from no action during the planning horizon to mechanical thinning in the first period).
- Step 3: Evaluate the solution by 1) running FlamMap and the MTT algorithm suggested by Finney (2002) to compute fire arrival time and flame length at each pixel, and then 2) calculating expected loss values from the landscape using user-defined probability of burn periods and flame length categories.
- Step 4: Accept or reject the new solution based on the SA solution acceptance rules.
- Step 5: Repeat Steps 2 through 4 until the SA stopping criterion is met.

In this procedure, we assume ignition is placed in user-defined locations and the environmental conditions such as wind speed and direction and spatial arrangement of fuel moistures are constant. The solutions can be also evaluated in terms of management costs, benefits from output products (e.g., timber), and road accessibility. Among

alternative solutions (fuel management schedules) evaluated, the solution that maintains the minimum expected loss value from the entire landscape (maximum treatment effects) over time and meets budget and operational constraints is selected.

Concluding Remarks

Development of the data transfer interfaces among the MAGIS, FlamMap, FVS-FFE models and the heuristic solver for OptFuels has been completed. Extensive testing of the system and applications development are currently in progress. Major hurdles we have encountered while applying the system to a large landscape include 1) the lack of polygon-level forest inventory data and spatial information, and 2) a large amount of computation time required by the solver due to the large scale and complexity of the scheduling problem. To substantially reduce computation time, we have been investigating parallel programming techniques and applying them to the heuristic solver. Upon completion of the system, OptFuels is expected to facilitate analyzing effective spatial and temporal fuel management strategies and provide valuable information to land managers who are searching for the most cost effective way of applying fuel treatments in their forests.

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