Decision Support Models

for Economically Efficient Integrated Forest Management

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ABSTRACT

Forest managers are challenged to fulfill conflicting social, biological, and commodity production objectives. To wisely use available, scarce resources for management activities, it is not enough to consider short term costs and effects of management (fuel reduction, planting, or other forest treatments). Long term tactical, spatial and temporal planning is needed to reduce risk, meet other objectives, and minimize cost.

Researchers at the U.S. Forest Service's Rocky Mountain Research Station, the University of Montana, and the U.S. Forest Service Inventory and Monitoring Institute have worked to develop MAGIS (Multi-Resource Analysis and Geographic Information System), a powerful modeling software package for planners and decision-makers in natural resources management. Any number of scenarios may be specified by modelers (research staff or resource managers) and results compared. Menus, dialogues, and custom, interactive maps (based on ArcGIS ArcObjects) enable the creation of resource planning models and the specification and display of scenario results.

INTRODUCTION

Forest managers are increasingly in need of GIS-based planning tools for developing projects that are both economically efficient and environmentally beneficial. Integrated management, from the strategic level down to operational planning, across multiple objectives and over the long-term, is more cost effective than independent planning at various stages (Aspinall and Pearson 2000, Bellamy and others 1999, Hahn and others 2001, Jakeman and Letcher 2003). Projects that incorporate biomass utilization in particular need to be planned with strategic or tactical consideration of the transportation problem. Software is available to determine optimal rotation times and maximize economic benefit both at the strategic level (Gustafson 1999) and the tactical level (Mowrer 1997), but which do not consider access costs. Conversely, operational-level planning software is available for supply-chain or traffic flow problems, but which assumes the user already knows which units are to be harvested (Chung and Sessions 2002). If the problems are considered together, a more complete picture of the problem emerges; an in-depth analysis of scheduling alternatives that will improve efficiency and minimized adverse environmental effects, leaving managers less vulnerable to criticism about data and information used to develop projects. With increased pressure on public land managers to provide economic and ecological justification for harvest projects, the use of analytical tools has become critical for efficient planning. Planning tools need to be flexible, fast, easy-to-use, and address the relevant economic issues for efficient planning.

The only efficient, organized way of meeting these needs is to utilize Geographic Information System (GIS) technology. A Spatial Decision Support System (SDSS) planning tool is needed that combines GIS with modified versions of existing predictive models and optimization methods.

Researchers at the US Forest Service's Rocky Mountain Research Station, located at the Missoula Forestry Sciences Lab (RMRS), The University of Montana - Missoula (UM), and the US Forest Service Inventory and Monitoring Institute (IMI), Fort Collins, Colorado, have developed landscape-scale software to aid natural resource managers in making these and similar complex management decisions. We present here a software application: MAGIS (Multi-Resource Analysis and Geographic Information System), which was developed to address this need.

Current MAGIS development, research, and application is focused in the problem area of fire management in conjunction with ongoing multiple resource management objectives. Twentieth century forest management practices of fire exclusion have caused a build-up of forest fuels that, combined with current weather patterns, threaten the ecological health of America's forests. The remedy for the buildup of forest fuels may seem straightforward. However, while forest managers are knowledgeable in methods to reduce fire risk, doing this effectively while working within budget, planning transportation, and also adhering to wider principles of ecological multiple-use forest management and public interests is much less so.

In meeting these objectives it must be decided where to reduce fuels. Is it possible to determine locations which would most effectively lessen the risk of stand-replacing fire? Are treatments in those locations consistent with other objectives? Can costs be offset by incidental biomass or other appropriate utilization?

Figure 1. Example of dense understory with ladder fuels in a forest stand. This build-up of fuels increases risk of severe wildfire under dry weather conditions. Forest Service photo taken at the Sawmill Creek Research Natural Area in the Bitterroot National Forest, Montana.

Decision support for resource management

Long term tactical, spatial planning via MAGIS aids forest managers to reduce risk, meet other objectives, and minimize operational cost for decades to come. This does not in any way imply that short term costs and effects of management actions (fuel reduction, planting, or other forest treatments) are ignored. Short term costs and effects are included in the overall analysis and resulting management schedule. Objectives may include reducing fire and other risks, providing habitat for terrestrial and aquatic organisms, producing commodity outputs such as forage, sawlogs, and biomass, monitoring changes on the land over time, cumulative effects of actions taken over time and space, bio-diversity, endangered species, maintenance of old growth and mosaic structures over landscapes and providing recreational access and use.

The general purpose of MAGIS is to schedule land management and related road access activities. Specific capabilities include

- Inclusion of multiple issues in an encompassing resource model for a management planning area.
- Consideration of road access simultaneously with vegetation treatments.
- A user interface to guide managers through model specifications, scenario design, and display of scenario results.
- Models include assisted mathematical representation of relationships among spatial features and management criteria.
- Choose linear programming, multiple integer programming, or heuristic optimization solver.
- Optimization of user-specified objectives in sequence in multiple alternative scenarios.

- Computing treatment effects, feasibility, economics, and trade-offs for each scenario.
- Spatially-explicit treatment schedules over time.

In the problem area of fuel management, the modeling objective may be stated thus: Treat fuels to change the intensity and behavior of wildfire AND restore ecosystems (to historic fire regimes). This includes deciding where and how to apply treatments based on management priorities.

Optimization addresses the timing and sequence of treatments, and road management (optional) to provide adequate access to treatment locations while minimizing the costs of doing so.

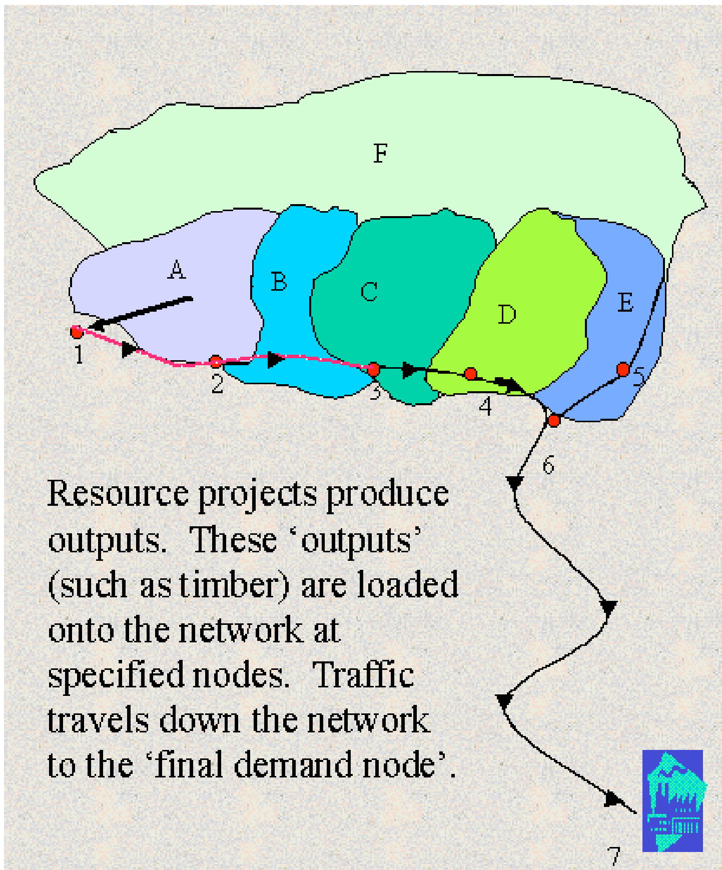

Figure 2. MAGIS models define potential resource projects for treatment units. In situations where treatments produce forest products as outputs, optimization will also include transportation considerations.

A MAGIS solution consists of a schedule of treatments and road projects in time and space and the various results of those treatments (costs, revenues, timber volume and other non-timber outputs, which may include risk (fire, insect), hydrologic response components, wildlife habitat, vegetation states, traffic volume). Upon completion of the optimization process, feasible solutions may be displayed in tabular as well as visual form.

Advantages of optimization are far-reaching in their impact. These include

- The ability to analyze large problems not easily solvable by mere map interpretation.
- Determine the most prudent use of public money while also saving money.
- Economics or resource use and protection is a factor in deriving a solution for any alternative scenario: the solvers seek the most economically efficient solutions.
- Ecosystem benefits are balanced with economic benefits.

Important, too, is the aspect of integrated resource management. These improve the likely success of any resource management planning and implementation.

- Ecosystem perspective.
- Other resource issues and management objectives.
- Economic and operational feasibility improves success.
- Social feasibility.

Software Design and Construction

A custom SDSS would ideally empower managers by guiding them through the modeling process, handle mundane and technical processing tasks behind the scenes, and allow managers to analyze and visualize large sets of spatial and non-spatial data, and play "what if" games to determine the effects of various alternative forest management actions without actually carrying them out on the ground. Complex information is more readily interpreted when presented in graphic form.

MAGIS provides all of this and also allows managers a great deal of control in defining models and scenarios. The user interface includes a menu system, dialogues, table views, and custom interactive maps to guide the user and streamline tasks required to operate MAGIS. The GIS interfaces and processes facilitate MAGIS processing, and improve the accuracy of data values, model specifications, and visual interpretation of solutions. Figures 3a and 3b show two of the custom interactive GIS interfaces.

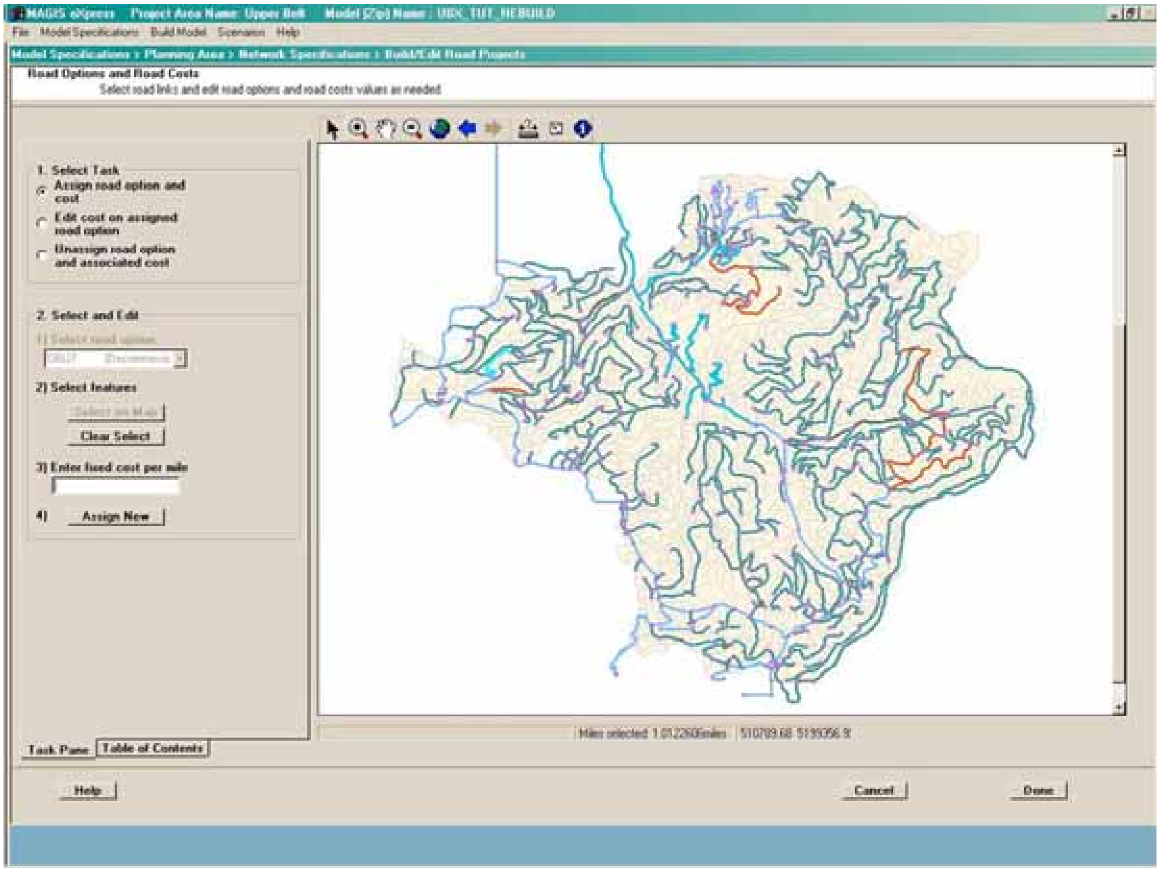

Figure 3a. The task pane at left manages the interface. Users may assign new potential road management actions, edit the cost per mile, or unassign potential actions. In this image, one road segment is selected in the upper left for the obliterate (code “OBLIT”) management action.

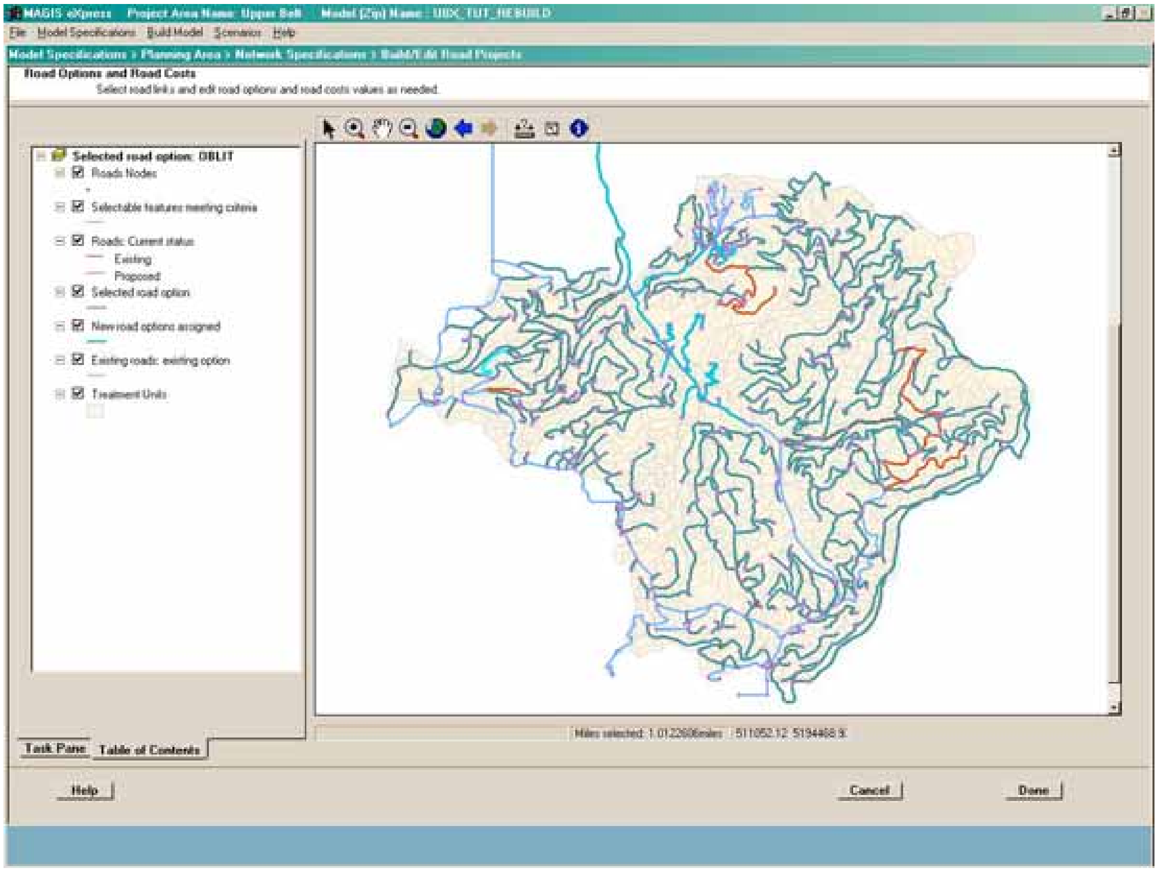

Figure 3b. The Table of contents provides visual feedback of the tasks being selected with respect to road options and costs.

MAGIS provides dialogues, optimization solvers and custom interactive maps via one common menu system. MAGIS executes under ArcGIS 8.3 or 9.0 in either Microsoft WINDOWS 2000 or WINDOWS XP operating systems. File management, dialogues, maps, and processes are controlled by a system of programs written in the Microsoft Visual FOXPRO database software development language.

The interactive maps designs have been implemented via ESRI ArcGIS ArcObjects as Microsoft Visual Basic standalone ActiveX user controls or ArcMap VBA projects. The standalone ActiveX controls are embedded in and managed by Microsoft Visual FoxPro forms launched by the MAGIS VFP framework.

Two versions of MAGIS have been developed, MAGIS Pro and MAGIS eXpress . For MAGIS Pro, MPSIII, a commercial mathematical LP package (Ketron Management Science, Inc. 1992) must be installed. This consists of several modules but only MIPIII, a mixed integer programming solver, C-WHIZ, a linear programming optimizer, and a runtime version of DATAFORM, a special database management system, are required. To use MAGIS eXpress, no additional software is required since a heuristic solver is included. In this paper, MAGIS will generally refer to both forms of the software.

Using MAGIS

Defining a model. Data that define any resource planning problem are (1) entered via a series of interactive input forms and (2) imported from geospatial databases. Through a comprehensive setup procedure, a planning model is formulated, and a LP matrix is generated for input to the solver.

Managers are in control at every step: specifying a planning framework, defining planning area models, building potential planning scenarios, and displaying scenario results. Planning decisions are based entirely on local situations, including natural and other resources, existing policies, and public concerns.

Planning framework. The planning framework is consists of definitions of the building blocks or components used by one or more planning-area models: activity-costs, products and prices, non-product outputs (sedimentation for example), definition of zones and attributes which are used to build cost and output relationships, management regime definitions and rules for assignation to individual treatment units as options, road management option definitions, and the vegetation pathways. Cost/price changes can be assigned to the inputs and outputs of road network and land management units by time unit.

Vegetation pathways can be thought of as the sequence of a starting vegetation state per time period, an activity, and the resulting state. Trajectories from state to state are determined by habitat-type group, and length of time in a given state. Selection of management actions can change the projected state in particular ways. For example, a selective harvest treatment could reduce both the density and dominant species components of the vegetation state, placing the stand in a different pathway.

Management objectives are formulated as mathematical relations, referred to as ‘effects functions.’ Effects functions are specified as one of five main types (four for eXpress): Outputs(includes timber products), acreage and length control (not in express), cost, and net revenue. Examples include: acres in a specific successional stage; acres having unique stand characteristics (such as density, height or diameter categories); the number of miles of open road; acres in forage production or cover; and timber harvest volumes by product. An effects function can be defined to apply to the entire planning area or portions thereof, delineated by zones such as drainages or wildlife management areas. Similarly, the time periods for which the effects function is calculated is determined by user selection.

Effects functions quantify relationships between model components (decision variables, traffic, outputs) and control the selection of decision variables to meet a scenario’s specifications (see “Build a Management Scenario” below). For example, if total net present value is used as the objective function to be maximized, MAGIS will search for the solution that generates the largest value for that function. However, this value could be constrained by limiting the amount of timber harvested, or limiting the number of miles of new road, or by leaving a minimum number of acres untouched by harvesting for example. Any of those constraints can be expressed as an effects function. Not all effects functions totals calculated by the solver meet the specified limits in the function definitions; the essential concept is that none violate them.

Project Area model specifications. For a particular planning area, the required geospatial databases include land management (treatment) units, stands (not in eXpress) and transportation network links. Each land management unit and road link is assigned one or more potential management options, in one or more time periods. These management options comprise the totality of ‘decision variables’ from which the solver may choose a schedule of land management unit treatments and road projects. The example GIS interface shown in Figures 3a and 3b is one of the interfaces provided to facilitate entering project area specifications.

Build a management scenario. Once the model components and relationships between them are defined, one or more alternative management scenarios are defined. They involve specification of the following: solution controls (including objective function), management constraints, and decision variables.

Solution controls refer to the solver/analysis type and the objective to be maximized or minimized. The user then sets management constraints (upper or lower limits) as needed on any of the remaining defined effects functions. For example, a constraint could be set for a specific number of acres in the entire area to be in a particular size class. This could be used to control the amount of old growth or new growth, as the user requires. In MAGIS eXpress, only two objective functions can be selected from: Net Cost (minimization) and PNV (maximization). There are also some limits on effects functions available in eXpress.

Preselecting decision variables and setting spatial constraints provide two more avenues of control on the solution.

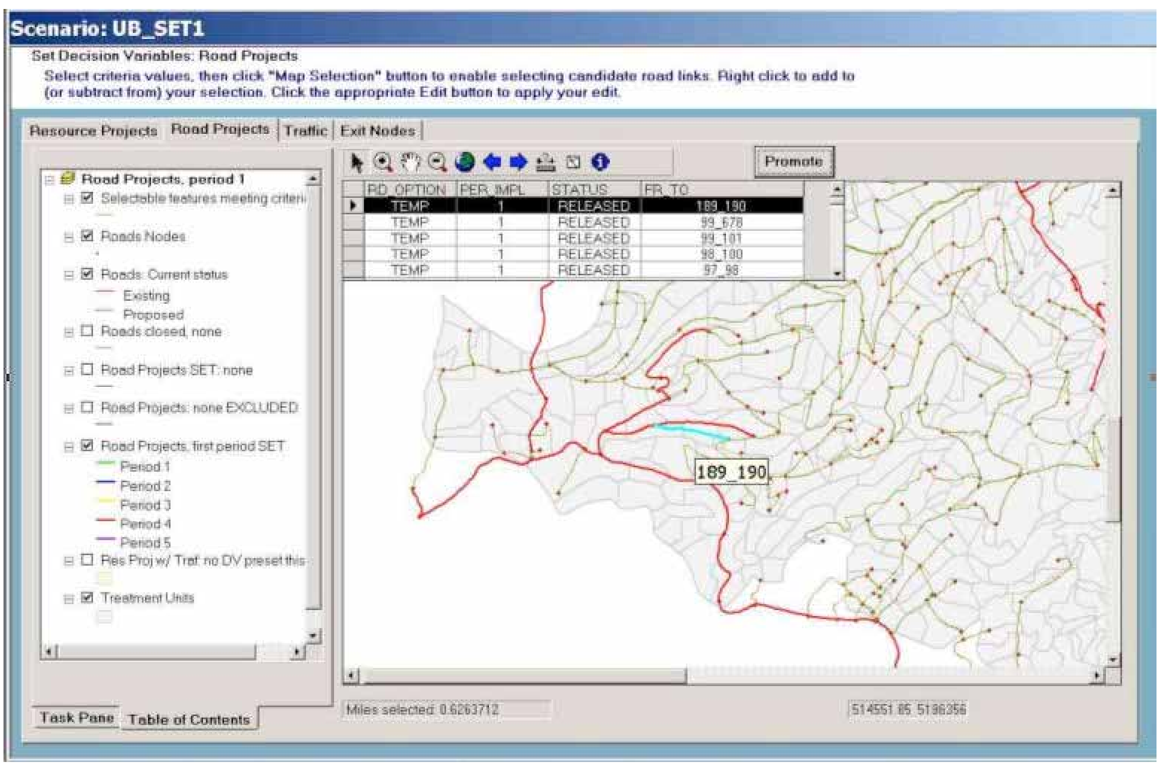

Figure 4. This custom GIS interface facilitates preselecting decision variables (resource projects, road projects, traffic closures/non closures, and traffic end point constraints). The user first defines a broad selection by attribute by selecting from the

dropdown lists. The inset table depicts decision variable records for features in that initial selection. The user then selects a subset of treatment unit or road records or features to preselect decision variables for those features. A user can toggle between the task pane and map Table of Contents.

During the solution processing, MAGIS selects vegetation treatment projects and road projects, calculates the resultant traffic routing and volume, projects vegetation changes through time based on succession and the selected activities, and calculates the values of all defined effects functions.

An alternative is to select some or all of the treatment unit and road management options (preselection of decision variables) for one scenario solution and then use the solver in simulation mode to calculate the output values.

Interpret results. There are two modes by which to view solutions results: tabular reports or GIS display maps. The maps display effects functions values for each treatment unit, vegetation states for each period, and schedules for management regimes and road management actions. The latter include specific activities and traffic amounts for each time period. Customized displays include: query tool for management regimes, custom legend dialogue to categorize management regimes, and mouseover displays in status bars.

Two examples of maps which display a scenario's predicted outcomes are shown below (Figures 5 and 6). The 'Display Solutions' custom interface allows the user to select which maps to display. Schedules of forest treatments selected by the optimization solver are summarized visually and may be also queried via mouse over displays in status bars or by a custom identification tool. The examples below are for one management alternative modeled for the Upper Belt area in Montana.

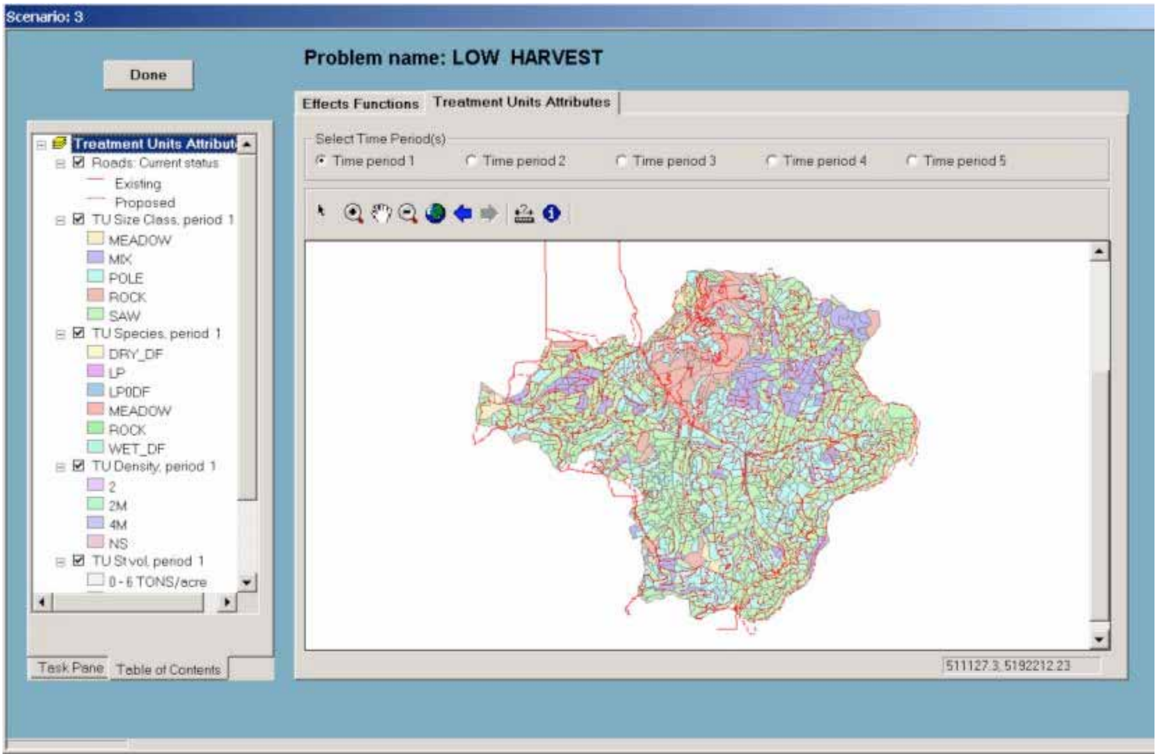

Figure 5. Treatment unit size class in time period 1 for the Upper Belt study area. The user can easily toggle among time periods.

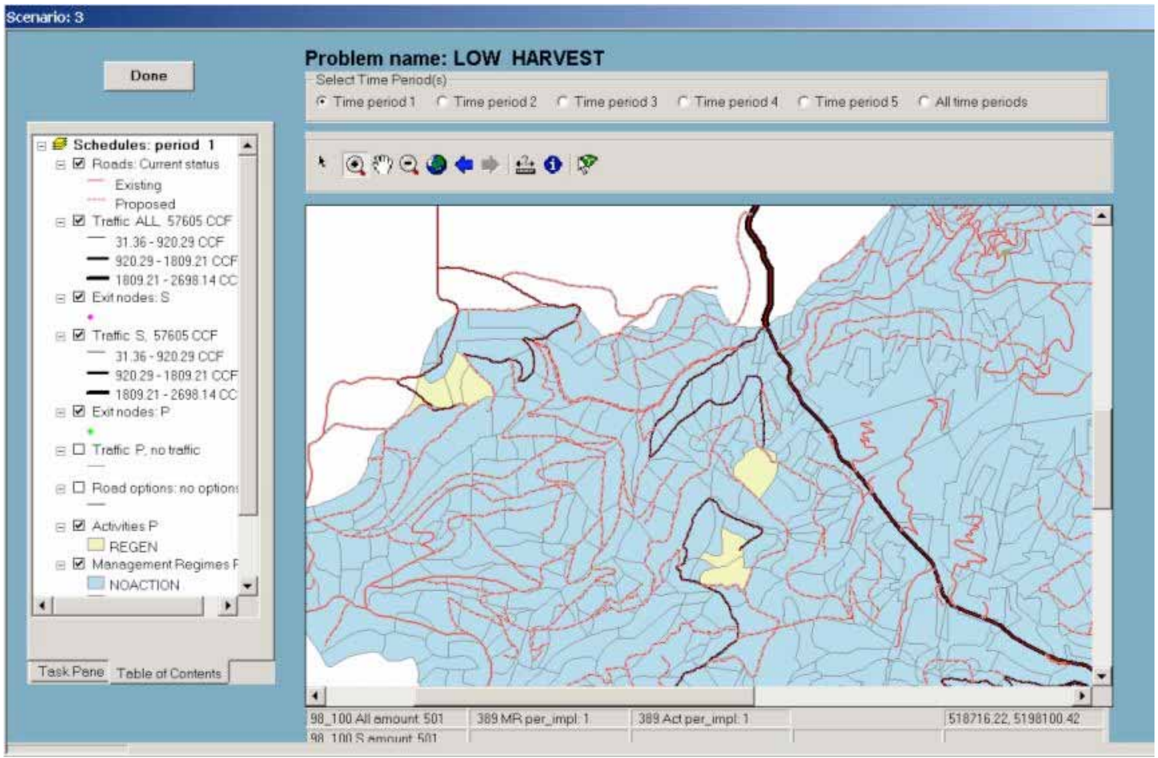

Figure 6. The activities, regimes, and traffic outcomes generated by the solver for period one. Notice that graduated symbols are used to depict traffic volume. Values for individual treatment unit and road segment features are displayed in the status bar panes as the mouse cursor is moved over a treatment unit or road segment.

Costs for road options and traffic flow are specific to each road segment. Each treatment unit with management options has 'connections' to the road network (loading nodes, see Figure 2). As units are selected for harvest, traffic from the harvest is loaded onto the network. If the loading node is on a 'proposed' road, or a road that requires reconstruction before it can carry traffic, the road management options for those construction or reconstruction options are selected as well. The model selects the least cost route to the 'exit' or final demand node, and keeps track of the total amount of traffic (of each type) by road segment and by time period (see Figure 6 above).

Figure 7. The Sawmill Creek Research Natural Area forest stand after the dense understory was removed. Treatments included thinning and selective burning. Forest Service photo.

INTEGRATING MODELING SYSTEMS

Advantages of using MAGIS for fuel treatment analysis accrue when complimentary modeling systems are used together. Some categories of natural resource management models, with examples, are:

- Fire behavior: FARSITE, FLAMMAP, MTT, TOM
- Landscape vegetation disturbance: SIMPPLLE
- Scheduling: MAGIS
- Resource models: WATSED, WEPP

MAGIS may be used alone or in conjunction with other modeling systems as listed here with planning area project examples.

- MAGIS alone :
    - WUI (static)
    - Vegetation objectives (dynamic)
        - Bitterroot NF, Belt Creek (Helena NF)
    - FRCC modeling (dynamic)
        - Bitterroot NF
- MAGIS plus SIMPPLLE (simulation)
    - Angeles NF
    - Bitterroot NF
    - Gila NF
    - Yosemite NP
    - Fishlake NF and BLM
    - Kenai Peninsula in Alaska

  - Planning area in South Platte Watershed – Colorado Front Range Partnership
  - Beaverhead-DeerlodgeNF
- MAGIS plus MTT/TOM (fire behavior simulation) and SIMPPLLE
  - Bitterroot NF – Bitterroot Ecosystem Management Research Project
  - Planning area in South Platte Watershed – Colorado Front Range Partnership
  - Beaverhead-DeerlodgeNF

In using MAGIS alone, the criteria for prioritizing sites for fuel reduction treatments may be based on proximity to urban areas (Wildland Urban Interface or WUI), vegetation conditions over time, or FRCC (Fire Regime Condition Class), http://www.frcc.gov. After MAGIS has been used to schedule treatments, users may make further use of the resulting geospatial databases in their own resource evaluation methodology.

The figure below depicts how the above mentioned complimentary models may be combined with MAGIS. For example, a vegetation disturbance factor could be simulated by SIMPPLLE to identify priority treatment locations and to assess the effectiveness a treatment strategy developed via MAGIS.

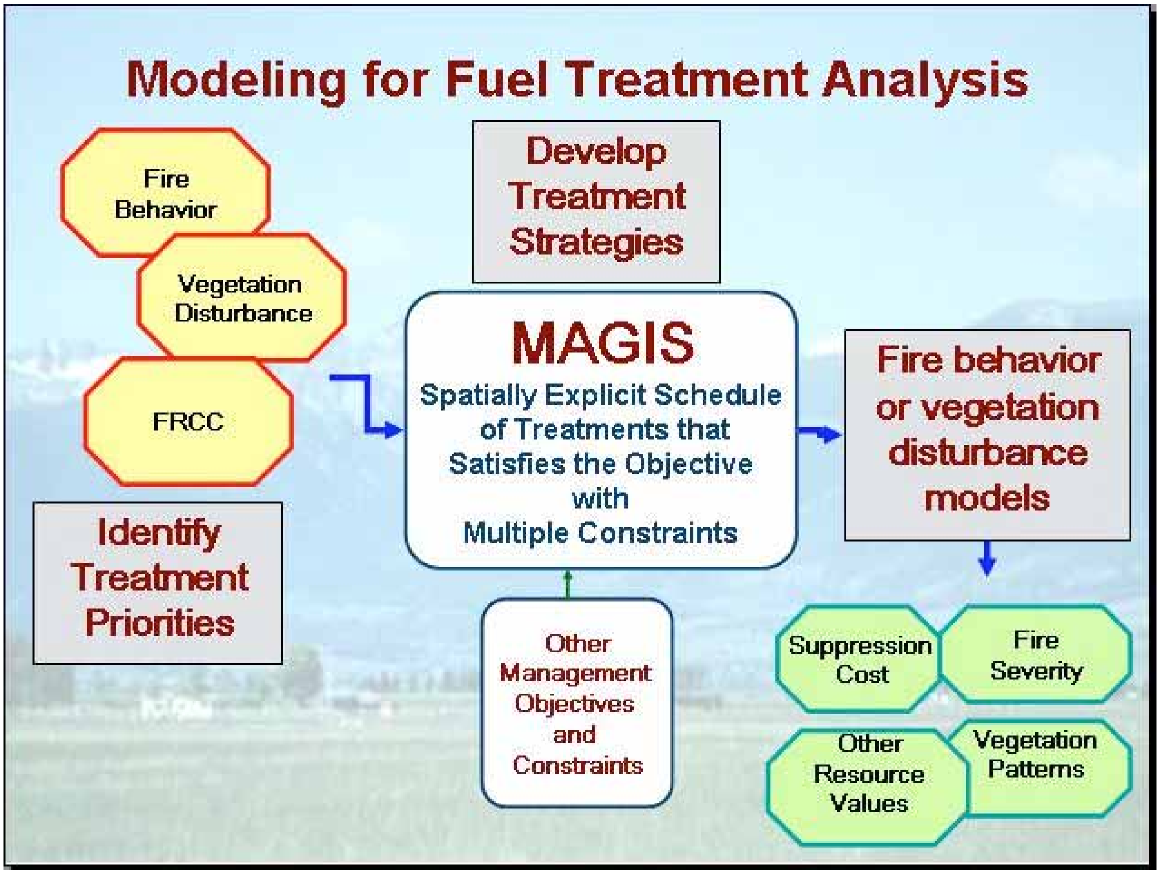

Figure 8. Priority locations for fuel reduction treatments may be derived by one or more of fire behavior models, vegetation disturbance models, or FRCC indices. This information, plus other management objectives and constraints are analyzed by MAGIS to recommend optimal fuel treatment strategies for one or more scenarios. The recommended strategy or strategies may then be evaluated by a number of measures derived from fire behavior or vegetation disturbance models.

SIMPPLLE (Simulating Patterns and Processes at Landscape LEvels) has been used in conjunction with MAGIS for a series of fuel treatment analysis projects. SIMPPLLE provides stochastic simulation of natural processes from which natural disturbance risk indices are derived. Combining simulation and optimization yields spatial treatment alternatives that account for disturbance processes that influence current and future vegetation (Jones and Chew 1999, Chew and others 2003, Jones and others 2004). SIMPPLLE is used first to simulate a management alternative that includes fire suppression as the only management activity. The resulting generated “risk index” value for each treatment unit is incorporated into MAGIS and combined with resource and operational objectives and constraints to develop an alternative spatial treatment schedule. Next, the location and timing of treatments in an alternative are input into SIMPPLLE and stochastic simulations are run to predict the location of frequency of processes given that treatment schedule. The results of these simulations are compared with the results of the “no action” simulations to measure the effectiveness of the fuel treatment scenario. Completed modeling projects utilizing this approach include:

Kenai Peninsula. A section of the Kenai Peninsula in Alaska was modeled for restoration of bark beetle killed white spruce. Treatments included prescribed burning in a wildlife refuge, logging dead white spruce in the general forest and logging with replanting in the wildland urban interface. Scenarios involved hazard reduction, hazard reduction with maximum treatment, and hazard reduction with improving wildlife habitat.

Yosemite National Park. Yosemite National Park was modeled for the effects of fuel treatments on fire frequency. Treatment scenarios included treating by mechanical removal in a wildland urban interface area and by prescribed burning in the western portion of the park. These scenarios were adapted from alternatives in the Draft Yosemite Fire Management Plan.

Gila National Forest. The Reserve District of the Gila National Forest was modeled for the management concerns of catastrophic fire risk in the wildland urban interface and habitat protection for two sensitive species, Mexican spotted owl and Northern goshawk. Modeling scenarios were designed for treatments with emphasis on wildlife, emphasis on treatments in the WUI, or with a commercial timber emphasis.

Angeles National Forest. Angeles National Forest was modeled to reduce the risk of fire in chaparral. Treatments included mechanical and prescribed burning. Spatial priorities were set up based on housing density. Scenarios included treating with or without spatial priorities, in or not in wilderness areas, and for different amounts of total acres treated (Jones and others, 2004). Figures 10 – 14 depict this case study and results.

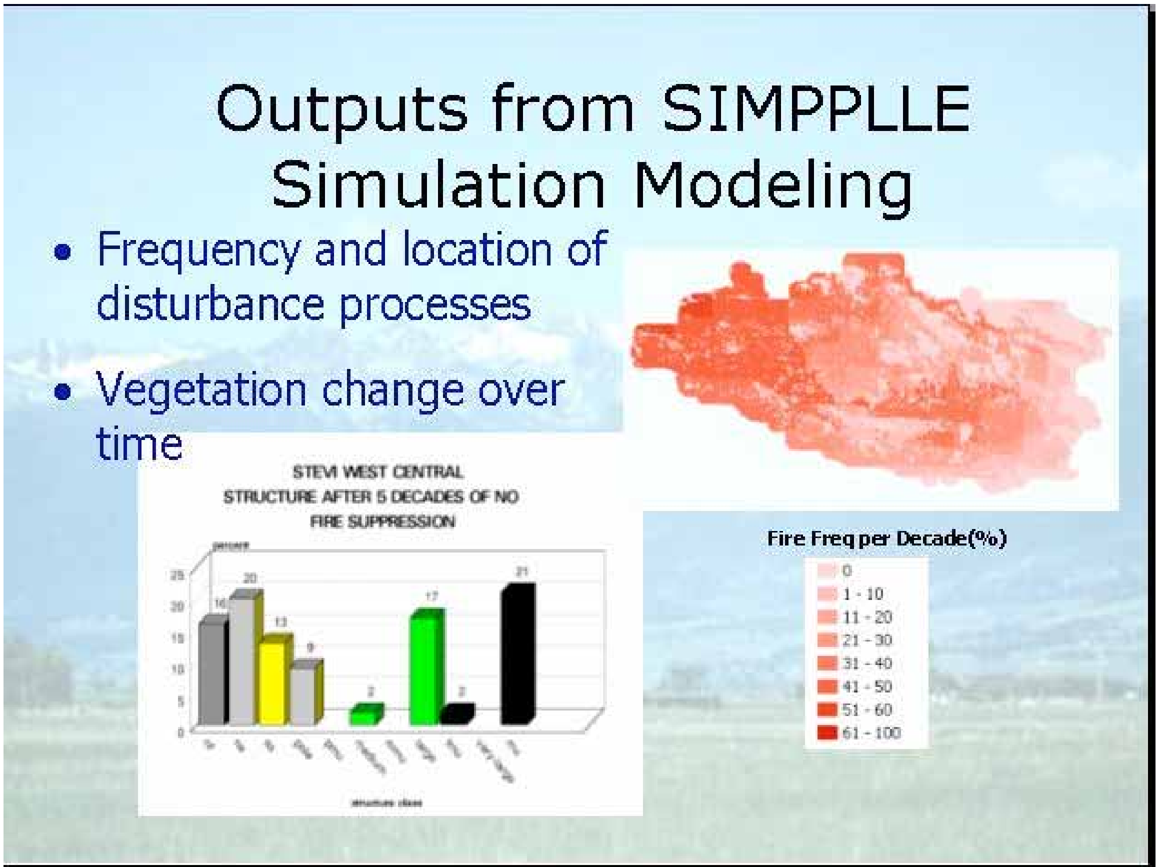

Figure 10. Several of the important outputs produced from stochastic SIMPPLLE simulations.

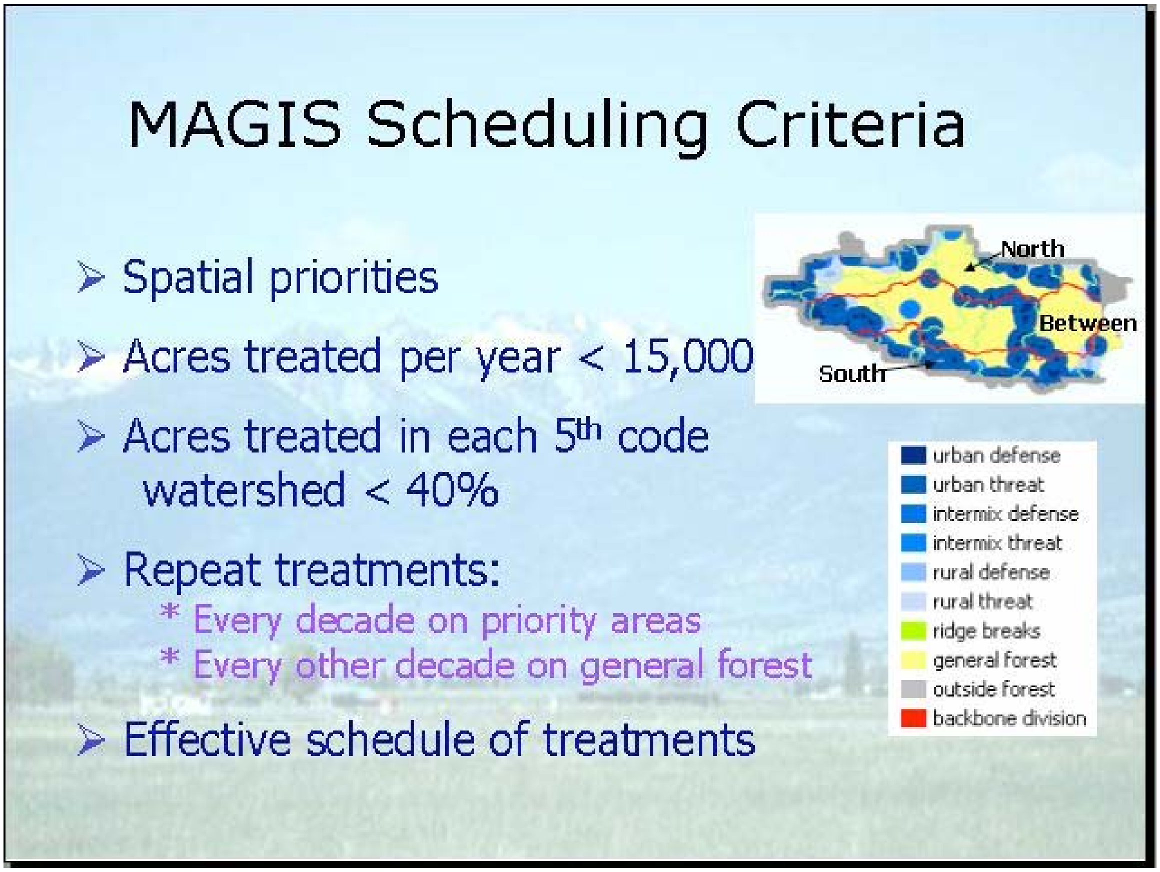

Figure 11. Management objectives and constraints were specified by Angeles National Forest wildland fire managers.

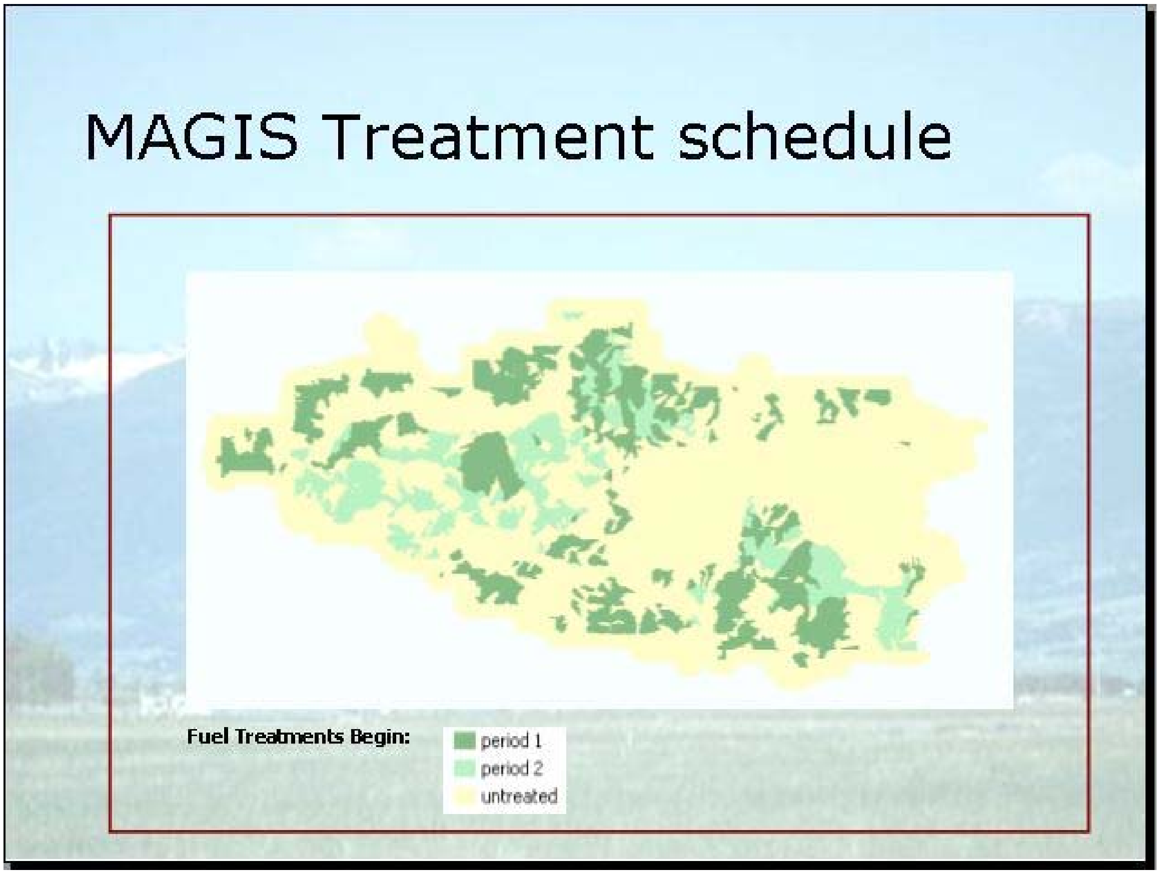

Figure 12. A simplified display of treatments, showing the location and time periods for fuel reduction treatments, as recommended by the optimization solver.

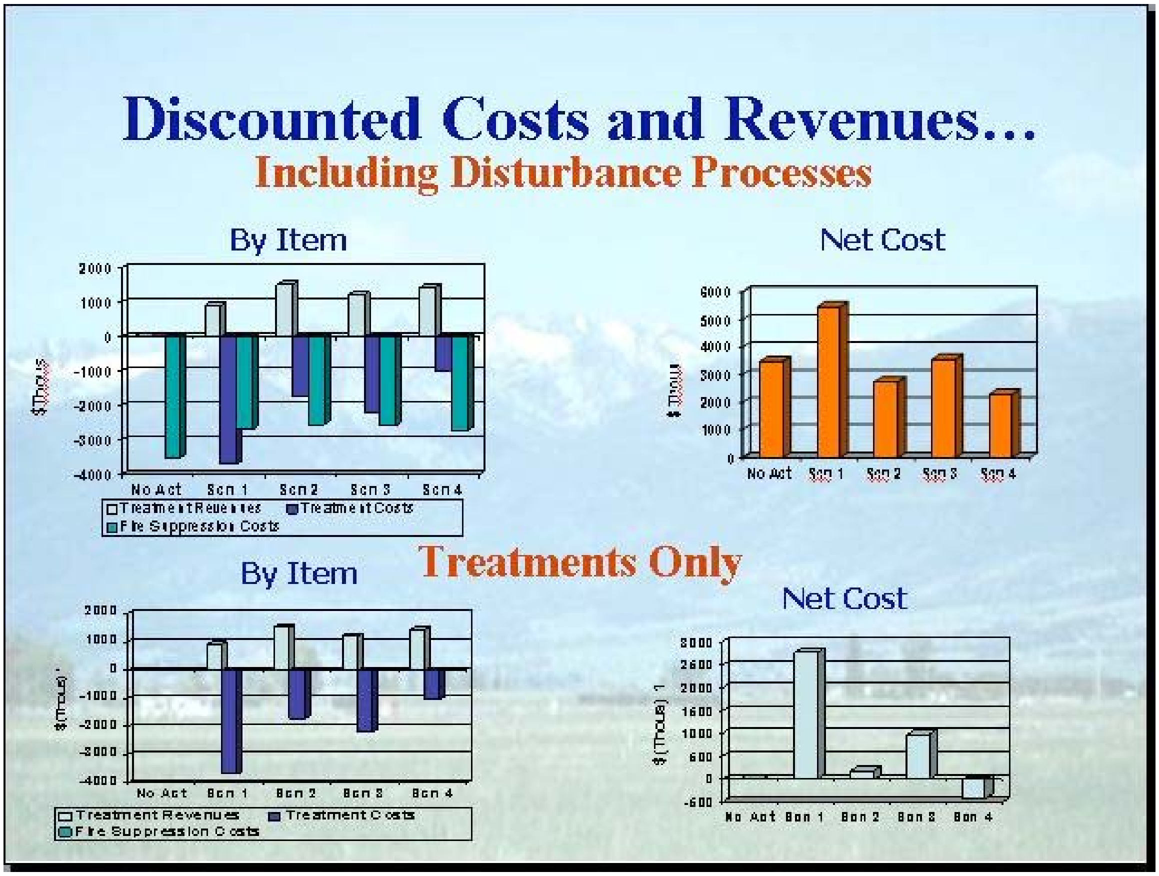

Figure 13. These charts reveal the importance of including potential fire disturbance in economic analysis of fuel treatments. Net costs for the “no action” scenario are zero when only treatment costs are considered (ie. fire suppression costs are not considered). However, scenarios 2 and 4 have lower predicted net costs than “no action” when fire suppression costs are considered.

Extended analysis by inclusion of fire behavior models. A collaborative planning effort for the Bitterroot National Forest currently underway is extending the integration of modeling systems to evaluate and compare additional models for use with MAGIS and SIMPPLLE. These may be suitable to identify priority treatment sites and evaluate fuel reduction treatment schedules generated via MAGIS.

Briefly, MTT (Minimum Travel Time) a potential fire behavior model used in FLAMMAP determines the least-time path of large fire movement across a landscape. This path is simulated based on a hypothetical fire start point and wind direction, along with geospatial data inputs (fuel model, crown bulk density, height to lowest limb, and terrain). The minimum travel time paths represent the areas to be prioritized by MAGIS for fuel treatments designed to change and slow down fire spread and intensity. Through the use of TOM (Treatment Optimization Model) an effective placement of treatments can be developed, followed by the use of MAGIS to test the feasibility (within the other constraints) of the treatment schedule. After a MAGIS schedule of treatments is selected, MTT could again be run to test the effects of the treatments on the minimum travel time paths.

SIMPPLLE predicts vegetation conditions during each time period based on the combination of vegetative pathways and stochastically derived disturbance processes. SIMPPLLE can be used in conjunction with MAGIS to predict the combined effects of proposed treatments and disturbance processes on vegetation patterns. Figure 14 depicts the adopted extended integrated modeling system to develop and assess fuel treatments.

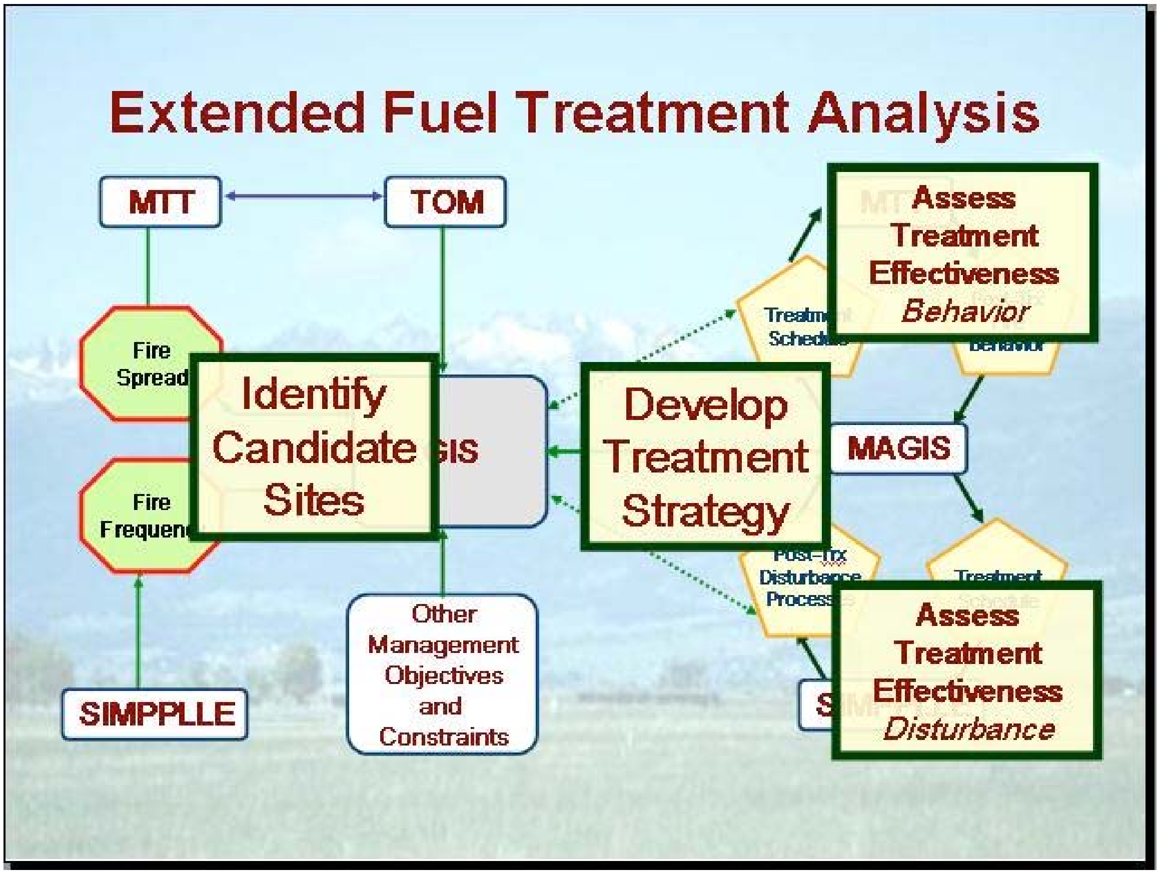

Figure 14. This flow diagram is a special case of the scheme depicted in Figure 8. Fire behavior and vegetation disturbance models are combined with MAGIS.

A range of benefits are associated with this combined MAGIS modeling approach:

- Combined simulation and optimization gives optimal solution that accounts for disturbance process influence on current and future vegetation.
- Fire behavior modeling creates confidence that fuels treatments are in effective locations by increasing precision of the results of fuel reduction treatments.
- Analyze trade-offs between fuel treatments & wildland fire.
- Hydrology management and sediment reduction.
- Wildlife habitat management.

- Include economic efficiency (budget, target acres) with ecosystem ‘efficiency’ –where will fuel treatments do the most good, PLUS other resource effects, PLUS roads.
- Encourages cooperation among resource specialists in project planning.

As an example of the extended fuel treatment analysis depicted in Figure 14 an area of the South Platte River along the Colorado Front Range was modeled, in cooperation with the Pike National Forest, to reduce the risk of fire. Conflicting with the reduction of forest fuels, a number of values must be protected during the planning for the optimization of fuel-treatments. The management concerns were:

- Minimizing sediment production and delivery to the stream network
- Managing habitat for threatened and endangered species such as the Mexican spotted owl, Pawnee montane skipper butterfly, and Preble’s meadow jumping mouse
- Reducing wildfire risk to the wildland urban interface
- Managing for forest health, such as insects and disease
- Planning for and facilitation of efficient biomass utilization
- Mitigating the effects of smoke from prescribed fire
- Minimizing road density
- Minimizing operations costs
- Minimizing sedimentation as the watershed is a part of the Denver water source

CONCLUSION

MAGIS models for scheduling vegetation treatments in view of multiple objectives and constraints as well as road access. State of the art GIS interfaces streamline data entry, problem specification, and display of results. The capabilities and architecture of MAGIS are such that it may be used alone or in combination with other models or methods for predicting fire behavior for developing integrated plans for fuel treatments and ecosystem restoration.

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