

Incorporating Landscape Fuel Treatment Modeling into the Forest Vegetation Simulator

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Abstract—A simulation system was developed to explore how fuel treatments placed in random and optimal spatial patterns affect the growth and behavior of large fires when implemented at different rates over the course of five decades. The system consists of several command line programs linked together: (1) FVS with the Parallel Processor (PPE) and Fire and Fuels (FFE) extensions that pauses the simulation during each cycle and transfers data to and from other system components; (2) a component to create the spatial landscape file with fuel model logic to select fuel models not available in FFE; and (3) a command line version of FlamMap utilizing the Minimum Travel Time fire growth method and Treatment Optimization Model to identify treatments, simulate wildfires, and evaluate the performance of the fuel treatments. Simulations were performed for three study areas: Sanders County in western Montana, the Stanislaus National Forest in California, and the Blue Mountains in eastern Oregon utilizing the Inland Empire, Western Sierra, and Blue Mountain FVS variants. Several limitations of FVS were identified during the project. Understory vegetation important for fuel modeling is not simulated in FVS, and the cap of 10,000 stands in PPE limited the size of the analysis areas. This simulation system required a large time commitment for data development, multiprocessor computer hardware to perform the simulations, and a range of technical expertise that is more specialized than land management agencies are currently staffed to handle. The system was successful in meeting the project's requirements. The research nature of this simulation system suggests it is probably not practical to run in most places for operational planning uses.

Introduction

Local or stand level changes in fire behavior resulting from fuel treatments are well documented (Agee and Skinner 2005; Cram and others 2006; Graham 2003; Graham and others 2004; Pollet and Omi 2002; Raymond and Peterson 2005;). Designing fuel treatments for landscapes (essentially a collection of stands composed of a variety of fuels and topography) creates additional challenges (Finney and others 2007), especially if there are constraints to the proportion of the landscape that can be treated. Finney (2007) has reported an algorithm to apply a mathematically derived treatment pattern to realistic complex landscapes. Additionally the effects and scheduling of treatments through time further complicates the issues. Testing these concepts with real fires on real landscapes is not feasible. So we developed computer simulations for modeling fires and fuel treatments at the landscape level through a period of time that would allow forest dynamics to modify treatments and dynamically schedule retreating stands as necessary.

Modeling forest fuel changes over time within a stand requires first modeling the dynamics of vegetation growth and death as well as the derivation of dead and live fuel components from the vegetation. The Fire and Fuels Extension (FFE) (Reinhardt and Crookston 2003) to the Forest Vegetation Simulator (FVS) (Wyckoff and others 1982) allows the effects on surface and aerial fuels for stand level treatments to be modeled over time. This extension explicitly represents:

- Dead fuel production from live vegetation components (litterfall, branchwood)
- Deterioration of dead fuels
- Dynamics of live fuel components (regeneration, canopy fuels).

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Here we report on the methods, tools, limitations, and assumptions of using FFE to simulate stand level fuel changes and fuel treatments and the interactions with landscape level fire behavior over five decades. We used FVS with FFE and Parallel Processor Extension (PPE) (Crookston and Stage 1991) to simulate forest stand dynamics, and linked with external methods to select and schedule treatments and simulate wildfires. The results illustrate that the rate of fuel treatment (percentage of land area treated per decade) competes against the rates of fuel recovery to determine how fuel treatments contribute to multi-decade cumulative impacts on fire behavior. Using fuel treatment prescriptions that involve thinning and prescribed burning, fuel treatment arrangements that are optimal in disrupting the growth of large fires require at least 1 to 2 percent of the landscape to be treated each year. Randomly arranged units with the same treatment prescriptions require about twice that rate to produce the same fire growth reduction. The results also show that the topological fuel treatment optimization tends to balance maintenance of previously treated units with treatment of new units. Complete results of the study are presented in Finney and others (2007).

Methods and Assumptions

The overall system flow diagram is shown in figure 1. This system consisted of FVS with a modified version of PPE which controlled the system by calling various other components as command line programs. Some of these command line programs are also available as features in version 3 of FlamMap (Finney 2006) while others were specifically developed for this simulation system. In general, data were transferred between components with files written to the computer's hard drive. The components shown in figure 1 are explained in detail below.

Data Preparation and Study Sites

Simulations were done at three study sites using the FVS variants described in table 1. While the study was designed to investigate landscape level fire behavior, the methods dictated a need for stand level detail. Relatively small, homogeneous polygons were used as stands to eliminate the need to divide polygons with treatments. Nearest neighbor techniques, such as Crookston and others (2002) which was used in the Blue Mountains, were used to assign forest inventory FVS tree lists to individual forested stands. Non-

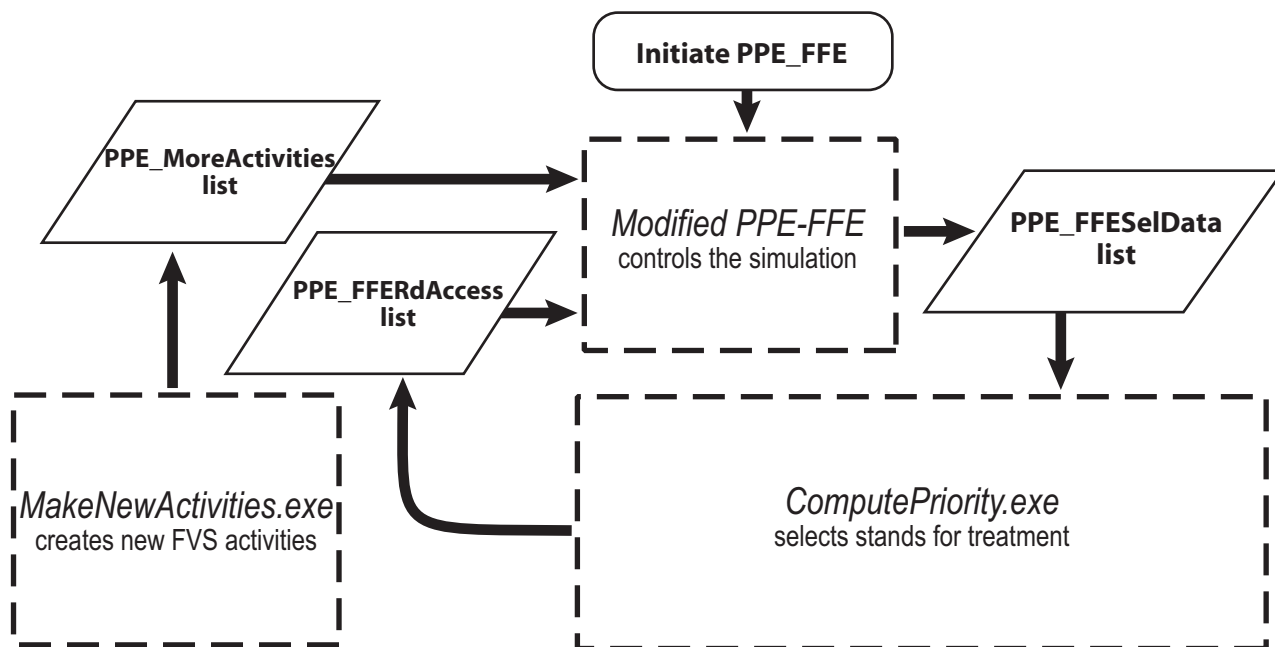


Figure 1—General flow of simulation system. Dashed boxes are the major components, parallelograms are data files used to transfer data between components.

Table 1—Study sites.

Site	Area	Number of FVS polygons	FVS variant
Blue Mountains, WA	54,600 ha	5,752	Blue Mountain. (BM)
Sanders County, MT	51,700 ha	9,699	Inland Empire (IE)
Stanislaus NF, CA	40,500 ha	7,754	Western Sierra (WS)

burnable (rock, water), grass, and shrub polygons were not assigned tree lists and were assumed to be static surface fuel models. A rasterized polygon/stand theme (StandID grid) was developed as an index for stand parameters when developing the landscape (LCP) files (Stratton 2006) from FVS outputs.

Modifying the Parallel Processor Extension

PPE (Crookston and Stage 1991) extends FVS to allow a list of stands in a landscape to be processed one cycle at a time. PPE can model dynamic interactions between adjacent stands, and place landscape-level constraints and goals on management activities. However, PPE has very limited ability to relate stands topologically, and FFE functionality was not available within PPE.

For this study PPE was modified (PPE-FFE) as follows (fig. 2):

1. FFE was added;
2. PPE changed to pause after implementing trial treatments for every stand and
 - a. Output a table of stand and fuel conditions with and without treatment (PPE_FFEStdData in figs. 1, 2, and 3),
 - b. Call a generic program (user developed) named “ComputePriority.exe” which selects which stands to treat,
 - c. Wait for ComputePriority.exe to complete and produce a list of stands selected for treatment (PPE_FFEStdAccess in figs. 1, 2, and 3);
3. When ComputePriority.exe terminates, PPE implements the stand-level treatments;
4. PPE changed to call an optional generic program (user developed) named “MakeNewActivities.exe” which accepts any new FVS activities before finishing the cycle (for example, wildfires).

For ComputePriority.exe to evaluate trial treatments, prescriptions must be identified for every stand where the potential for treatment exists. In other words, a treatment must be specified for every stand that could possibly receive a treatment. We used a series of If/Then statements to develop a FVS keyword file (an example is found in appendix A) to deal with a wide variety of possible stand conditions that would affect the choice of treatment prescription. While treatments were designed to modify surface and aerial fuels, they had to be silviculturally feasible.

FFE functions were modified as follows:

The CANCELC keyword with the minimum tree height parameter set to 0.6 m (2 ft) was used for all variants, defaults were used for the other CANCELC fields;

The default fuel pool initialization was used for the Montana study site, while initialization values were developed for the Stanislaus N.F. and Blue Mountains study sites using the FUELINIT keyword.

No FVS growth/mortality multipliers or insect and disease extensions were invoked for these simulations. The modifications made for this study have since been incorporated into the production versions of these programs.

ComputePriority.exe

ComputePriority.exe is a command line executable that must be developed by the user. The program must use this name so that PPE-FFE can interact with it. The only requirements for ComputePriority.exe are to pass a list of stands to treat to PPE-FFE and terminate after each trial cycle so flow control returns to PPE-FFE and finishes the current FVS cycle (fig. 3). In our system, ComputePriority.exe first reads a text file that contains arguments for other programs required to prioritize treatments and manipulate files as described below.

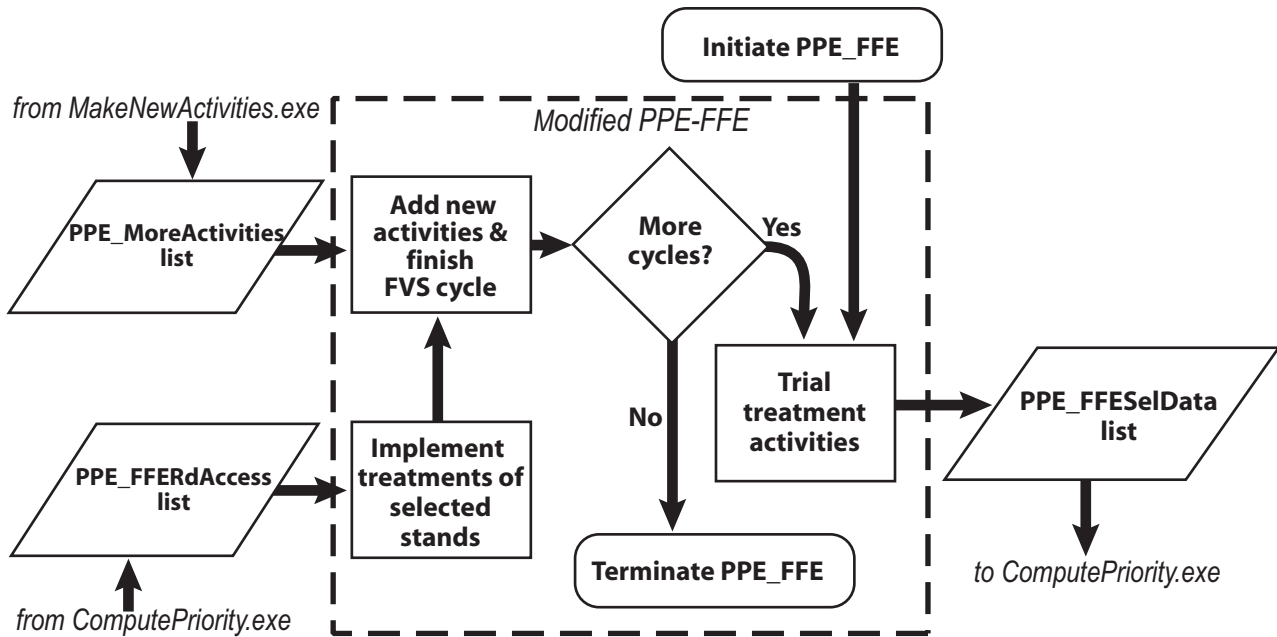


Figure 2—Details of modified PPE-FFE component. Solid boxes are processes within the major component, diamonds are branch points.

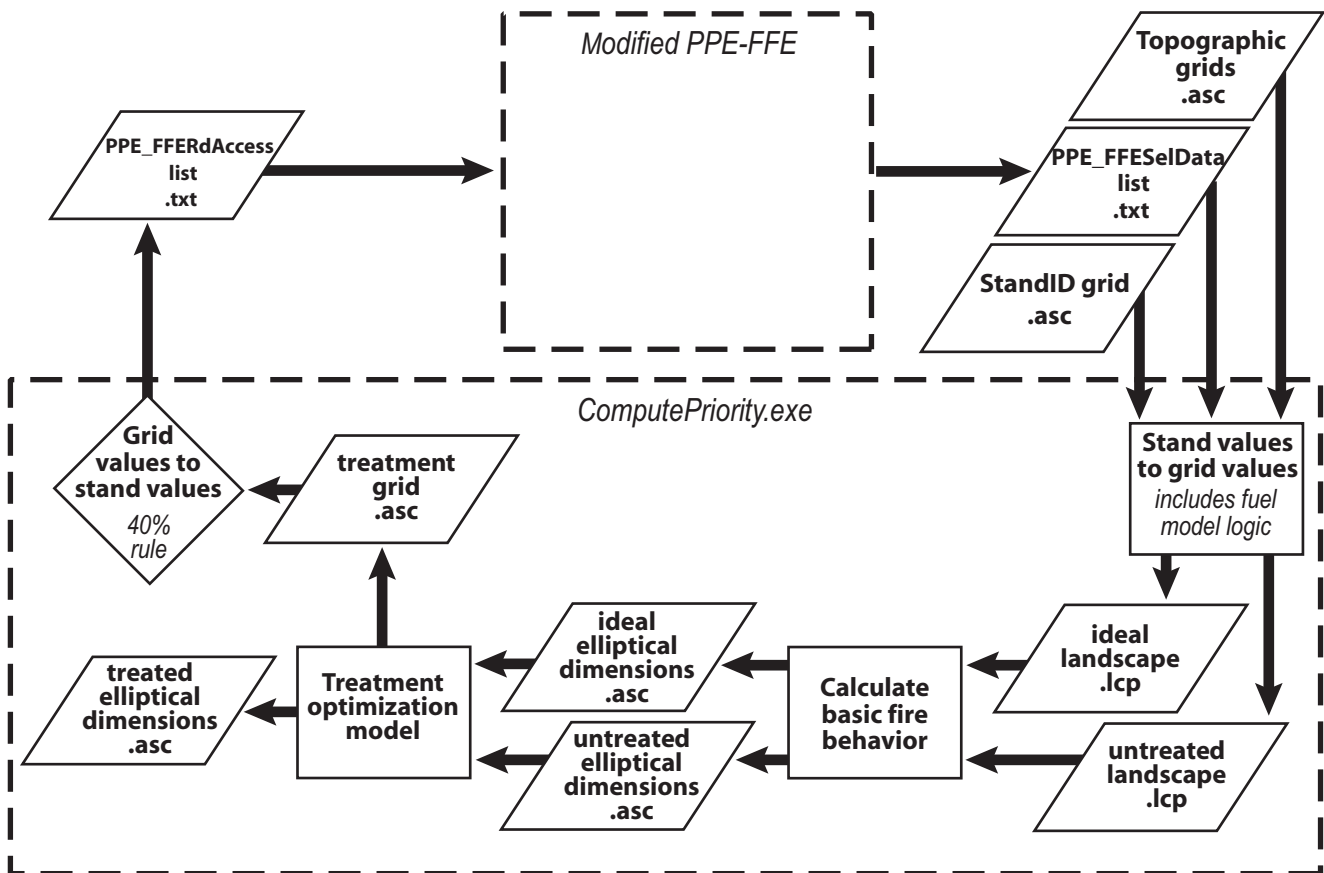


Figure 3—Details of the ComputePriority.exe component and its relation to PPE-FFE.

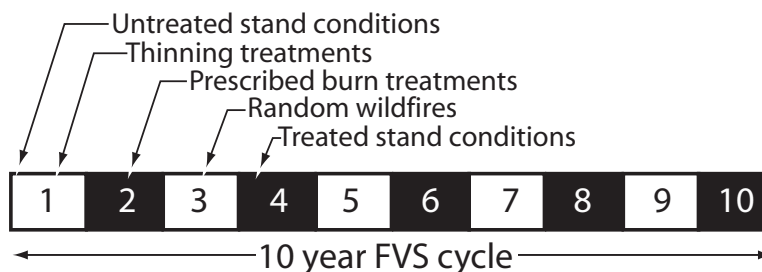


Figure 4—Timeline of PPE-FFE activities within one FVS cycle.

Convert Stands to Spatial Grids—FVS stand level output is converted to a raster LCP file using the program `fvs2lcp.exe` (fig. 3). Topographic features remain static through the simulation and user supplied slope, aspect, and elevation grids are read into `fvs2lcp.exe` to be included in the final LCP files. For each FVS cycle two LCP files are created, an untreated LCP file and an ideal LCP file, in which every stand was treated according to the FVS prescription. Both LCP files reflect treatments and forest dynamics from previous cycles. The ideal LCP file reflected the results of the FVS trial treatments at year 4 of the FVS 10 year cycle. This allowed for all activities to be completed and enough simulation time to pass so that short-term consequences of activities (for example, thinning causing temporary increases in fine fuel loading) would not unduly influence results. The untreated LCP used year 1 stand conditions with changes only due to FVS growth and mortality functions from the previous cycle (fig. 4).

Stand values from PPE-FFE for both treated and untreated conditions are passed to `fvs2lcp.exe` via a text file, `PPE-FFESelData.txt` (table 2). This file contains a table of stand-polygon values for canopy cover, stand height, canopy bulk density, and canopy base height that `fvs2lcp.exe` assigns to raster cells by cross referencing the polygon index identification with a raster representation of the polygon locations (StandID grid) containing the index values. A single fuel model was selected for the stand as described below and assigned to the landscape.

Our program deviated from the FFE surface fuel model logic because the fuel models assigned to stands by FFE were found to be inadequate for the treatment optimization. The original 13 Fire Behavior Prediction System fuel models (Anderson 1982) used in FFE do not adequately describe natural variability in surface fuels across large landscapes, or realistically describe a treatment's effect on live and dead surface fuels. (Scott and Burgan 2005)

Table 2—Variables from `PPE_FFESelData.txt`.

Stand value	FVS event monitor name	Purpose
Stand ID	n/a	Link to StandID grid
Year	n/a	Used in fuel model logic
SelCode	SELECTED	Trial treatment or untreated values
CBH	CRBASEHT	Directly applied to LCP
CBD	CRBULKDN	Directly applied to LCP
Canopy cover	ACANCOV	Directly applied to LCP
Stand height	ATOPHT	Directly applied to LCP
1hrLoad	FUELLOAD(1,1)+FUELLOAD(7,7)	Used in fuel model logic
10hrLoad	FUELLOAD(2,2)	Used in fuel model logic
100hrLoad	FUELLOAD(3,3)	Used in fuel model logic
1000hrLoad	FUELLOAD(4,6)	Used in fuel model logic
Habitat type	HABTYP	Used in fuel model logic (IE variant only)
Forest type	FORTYP	Used in fuel model logic
RTPA	RTPA	Used in fuel model logic
Fire flag	FIRE	Used in fuel model logic
Last treatment	FIREYEAR	Used in fuel model logic

The Scott and Burgan (2005) fuel models realistically place more weight on live fuels, both herbaceous (grasses, herbs) and woody (shrubs). Since FVS does not provide growth models for non-tree vegetation, surrogates for live woody fuels were used. Basic live fuel parameters, including live woody loading and fuel bed depth, were developed using habitat type as the surrogate for the IE variant, elevation and aspect for the WS variant, and forest type for the BM variant. These live fuel parameters were reduced in stands where canopy covers exceeded 50 percent and following fuel treatment. After treatment, the live fuel parameters followed a straight line recovery to pretreatment values 20 years after treatment. An example of the fuel model logic for the IE variant is shown in appendix B.

Fire Behavior—Fire behavior was calculated with a command line version of FlamMap for each LCP file cell under the target fuel moisture and wind conditions. Fire behavior was calculated for both LCP files in order to contrast fire behavior produced in each stand with and without treatment. Fire behavior output is stored as ASCII grid files for further use in treatment selection and wildfire simulation (Finney 2002). The fire behavior is represented as elliptical dimensions of fires in each cell that capture the orientation and shapes of fires needed for computing fire growth.

Treatment Optimization Model—The treatment optimization model (TOM) identifies optimal treatment locations as described in Finney (2007) given the constraints of maximum treatment linear dimension and the total proportion of the landscape desired for treating. Extreme target weather conditions were used so that potential crown fire activity was considered when identifying treatment locations. The treatment optimization outputs an ASCII grid file of the treated cells. Because of the similar fire behavior of all cells in a stand and the optimization method, the treated cells tend to clump into logical treatment units (fig. 5). The treatments were not a fixed size, only the user supplied maximum linear dimension constrained their size.

Convert Treatment Grid to Stands—Further processing by ComputePriority.exe converts the treatment grid into a list of treated stands for PPE-FFE to implement. The treatment ASCII grid is compared to the StandID grid and the stand is considered treated if more than a specified percentage of the cells in a stand are indicated as treated in the treatment output grid. After trial and error, the threshold value of 40 percent was found to produce a polygon map that closely approximated the gridded representation of the treatment units (for example, if 40 percent or more of the cells in a polygon were selected for treatment, the entire polygon was identified for treatment). These results are passed to PPE-FFE in the file PPE_FFERdAccess.txt, a list of all stands with a flag specifying which stands were selected for treatment (figs. 1, 2, and 3).

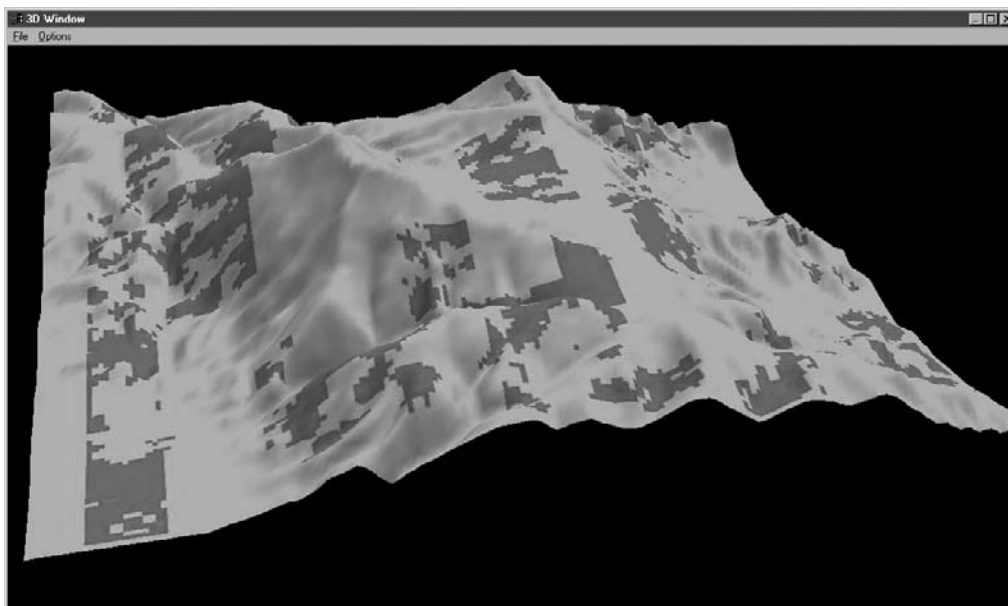


Figure 5—3-D display of treated cells identified by the treatment optimization model.

MakeNewActivities.exe

Once the stands are selected for treatment, PPE-FFE simulates the scheduled activities, models the consequential stand growth, fire and fuel dynamics, and fire effects. However, before it starts this loop over stands, it calls another external generic program called *MakeNewActivities.exe* (fig. 6). Like *ComputePriority.exe*, *MakeNewActivities.exe* is a user-defined executable with a static name for PPE-FFE to interact with. From the FFE-FVS point of view, using an external program to simulate wildfire behavior is the functional equivalent of making new activities and entering them into the activity schedules for the appropriate stands.

Simulating Random Wildfires—For our simulation system we used *MakeNewActivities.exe* to model random wildfires on the treated landscape. *MakeNewActivities.exe* then creates SIMFIRE and FLAMADJ keywords for burned stands so PPE-FFE could model stand level fire effects. The treated landscape is created by overlaying the ideal elliptical dimension values on the untreated elliptical dimension grids where stands were selected for treatment. Since both the ideal and untreated elliptical dimension values were generated once with *FlamMap*, these simulated wildfires burn under the same extreme wind and fuel moisture conditions that the treatments were designed to be effective with.

Random wildfires are simulated using a command line version of the Minimum Travel Time fire growth model found in version 3 of *FlamMap* (Finney 2006). The number of wildfire simulations is calculated from a user-supplied annual fire probability from the *script.txt* file. Random ignition locations are placed on the treated landscape for each year in the FVS cycle. A fire duration value, also from *script.txt*, is used with the treated landscape elliptical dimension grids to establish a fire perimeter for each ignition. The 40 percent rule described previously was used to select which stand polygons were burned in the simulated wildfires (for example, a stand was indicated as “burned” if 40 percent or more of the cells were within the wildfire area). All burned stands are identified in a

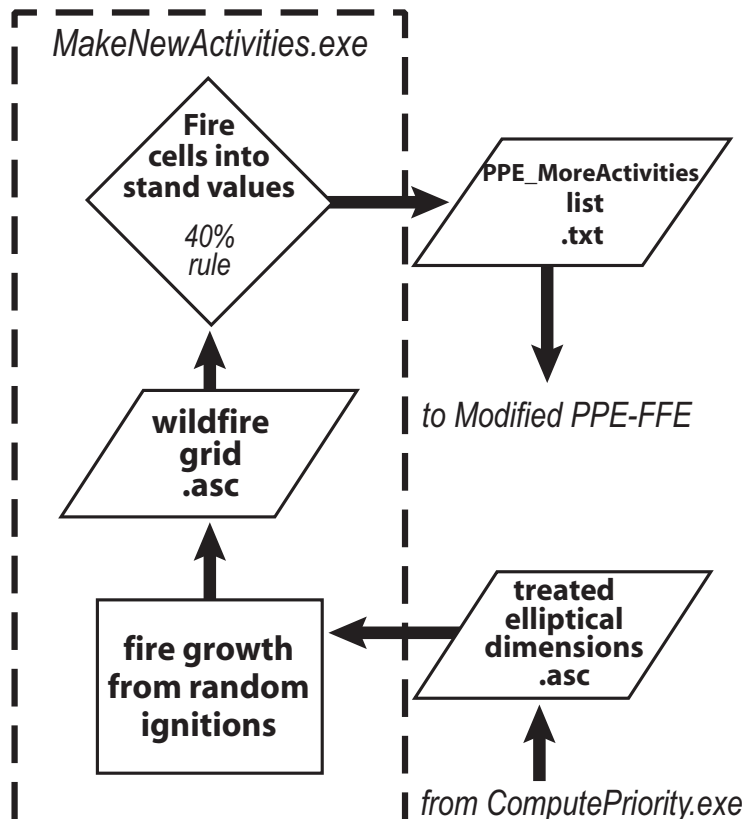


Figure 6—Details of the *MakeNewActivities.exe* component and its relation to PPE-FFE.

table written to an output file PPE_MoreActivities.txt; two FVS keywords are used to indicate the fire behavior that occurred. The SIMFIRE keyword was for year 3 of the cycle, after treatments have been completed in PPE-FFE (fig. 4). Even though the post treatment conditions contained in the file PPE_FFESelData.txt are for year 4 of the cycle, these stand conditions do not include the random wildfire effects since the treated LCP file is created before the random wildfires are scheduled. Parameters for FLAMADJ keyword (flame length, percent crowning, and scorch height) are also calculated for each stand burned by wildfires.

Other Processes

Several other applications were used after the simulation to evaluate response variables for the simulated treatments. One of those applications calculated what we called the endtime value. The endtime value is the average fire arrival time for the leeward row of cells in the landscape. In effect this measured the time it took for a simulated fire to burn the entire landscape from a line ignition along the windward landscape border. Dividing the treated landscape endtime value by the untreated landscape endtime value provide a relative average spread rate, which was used to compare results.

Results

Our simulation system was successful in meeting the goals of the project, we utilized an spatially explicit method (TOM) to select stands for treatment over multiple FVS cycles. We used a 16-processor shared memory computer to meet the needs of the multi-threaded treatment optimization and wildfire models. Simulations spanning five FVS cycles, 10 years each, required between six hours and several days depending on maximum treatment size and number of cells in the landscapes. Except during development, we excluded the random wildfire simulations from MakeNewActivities.exe because it added too much variability to the results of the treatment effects, which was the primary objective of the study. Effectiveness of the treatments varied by study site and several examples of the Montana study site results are given below. Full results of the project are documented in Finney and others (2007).

Figure 7 shows the effects of treatment size compared to randomly treated stands on the relative average spread rate. The amount of treatment between cycles and treatment sizes was constant. The topological placement of treatments by the treatment optimization algorithm out performed random treatments, especially in the earlier cycles of the simulations. For a given total amount of treated area, the size of the treatments had minimal influence on the relative average spread rate.

As shown in figure 8, the optimal rate of treatment was approximately 20 percent per decade; however, even lower treatment rates were also effective at reducing the relative average spread rate. Treatment rates of 30 percent or more showed small improvements in the early cycles, but matched the 20 percent rate in cycles 3 through 5. Effect of treatment for all the treatment rates was greatest the first decade and leveled out after the second decade.

Discussion

The landscape files describing the fuel conditions are important to acquiring meaningful results. Since the treatment optimization process was used to identify a relatively small proportion of the landscape for treatment, the accuracy of the current fuel conditions and the validity of the treatment effects on fire behavior are paramount to simulating a realistic treatment scenario. This points out the need for quality up-to-date information relevant to the issues for making science based decisions. We found the significance of live fuels in the Scott and Burgan (2005) fuel models and lack of understory vegetation modeling in FVS problematic. We developed simplistic surrogates for shrub cover (appendix B), but did not attempt a systemic evaluation of these surrogates.

In figure 4 it is apparent that FVS activities scheduled in PPE-FFE always occur in a specific year of the cycle. For example, thinnings are always scheduled for year 1 and wildfires for year 3. This is not very realistic as one would expect some random wildfires to occur prior to treatments and logistical considerations usually dictate management

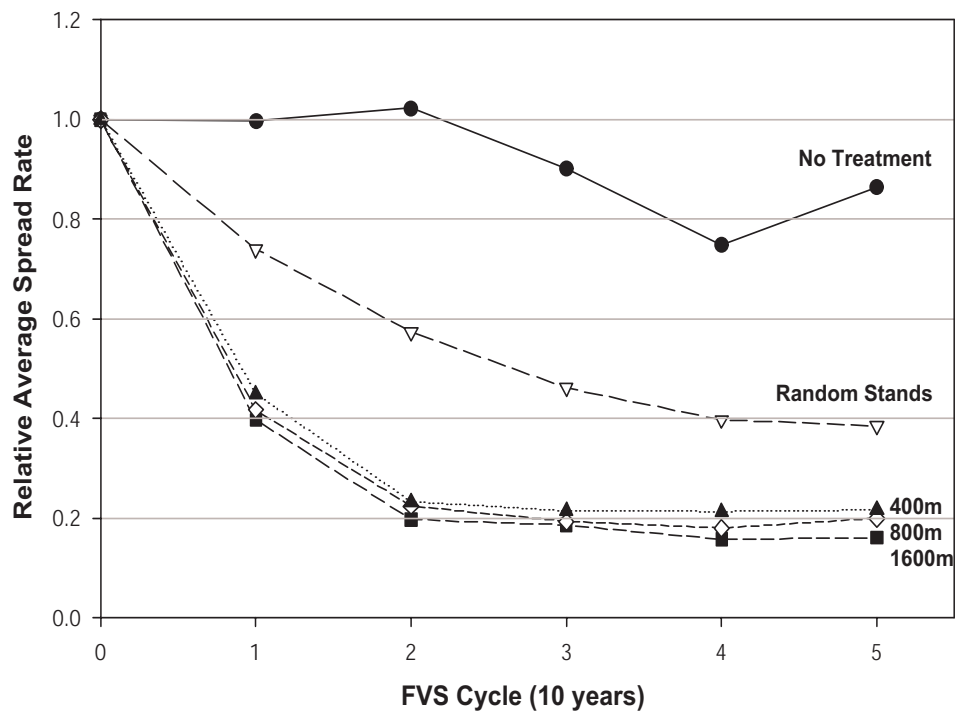


Figure 7—Relative average spread rate across the Prospect Ck. landscape, Sanders Co., MT for five 10-year FVS cycles. All scenarios treated 20 percent of the landscape per cycle. Treatment patterns developed with the treatment optimization methods preformed better than treating random stands, especially in the earlier cycles. Treatment unit size had little effect on the average fire spread rate.

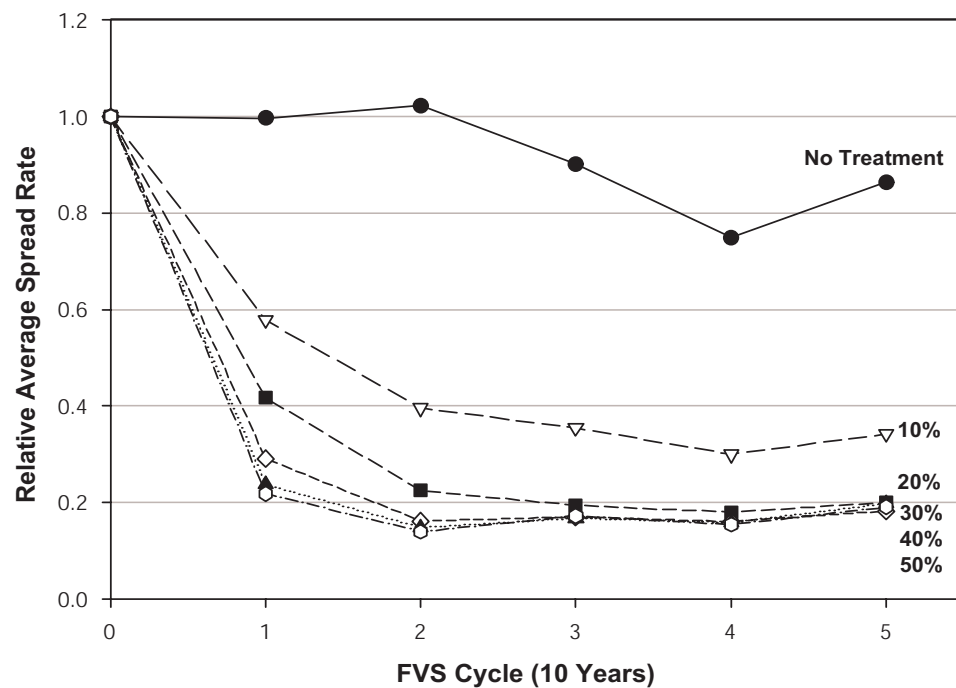


Figure 8—Relative average spread rate across the Prospect Ck. landscape, Sanders Co., MT for five 10-year FVS cycles. All scenarios used a maximum treatment dimension of 800 m. Treatments implemented at a rate of 20 percent per cycle produced overall reductions in average fire spread rate similar to higher treatment rates.

activities be completed over several years. This issue could be minimized by shortening the FVS cycles, exploring more realistic methods of scheduling FVS activities, or both.

Treatment optimization techniques required significant computational capacity when used for these large (50,000 ha) areas. However advances in computer capacity during the life of the project suggested that smaller (25,000 ha) landscapes could be simulated on common multiprocessor desktop computers.

We achieved our results while limiting simulation landscapes to 10,000 stands, the current limit of PPE. While this limit could be increased, FVS is not multi-threaded to take advantage of multiple processors and PPE-FFE portions of the simulation would occupy a larger proportion of the simulation time. On our 16-processor computer, 15 of the processors were idle while PPE-FFE was executing, which was approximately 30 percent of the total simulation time. Recent advances in multi-processor computers would easily allow fast mid-scale simulations or large simulations with 100,000 or more stands if PPE-FFE were multi-threaded. Multi-threading would also allow more detailed simulations with a large number of small stands since the treatment optimization technique selects treatments at the individual raster cell level.

In theory, larger landscapes could be simulated with our existing system by utilizing larger stands, larger LCP grid cells, and larger maximum treatment dimensions since all of these control computational requirements. However, some modifications to the system (the 40 percent rule, for example), larger treatment units, and coarser results should be expected.

Once a landscape was calibrated, prescriptions developed, and otherwise debugged, subsequent runs were easily created by editing the script.txt file for user defined inputs such as maximum treatment size or treatment rate.

The endtime value, and thus relative spread rate, proved an effective measure of landscape fire behavior. As shown in Finney and others (2007), burn probability and fire size distribution would also be equally effective measures. Burn probability, fire sizes, and fire spread rate reflect very similar trends because slower spreading fires are smaller after a fixed period of time, which translates to a smaller probability of burning any part of the landscape within a given time period.

While successful in a research setting, the level of expertise and data availability may limit this type of simulation in operational or project level planning. This project required large efforts in acquiring, preparing, and organizing the data for these simulations. Imputing FVS tree lists into thousands of different stands was adequate for our proof of concept study, but is likely not suitable for planning projects where the accuracy of the individual stand vegetation is important. The suite of expertise required to develop and operate the system is also beyond the capability of most management teams. A variety of ecologists, computer programmers, fire behavior specialists, and geo-spatial analysts were needed to develop and operate the system and evaluate the results. In addition, fire behavior and FVS skills were required to develop and debug the complex interactions between system components and customize prescriptions and fuel logic for individual study sites.

Acknowledgments

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Appendix A: Sample FVS Prescription

Keyword file for western Montana study site showing the prescription logic used for all stands with tree lists.
Code explanation:

```

SizCls (size class)
  1—sawtimber
  2—poletimber
  3—seedling/sapling
ForTyp (forest type)
  201—Douglas-fir
  221—ponderosa pine
  241—western white pine
  281—lodgepole pine
  321—western larch

IF      0
Selected EQ Yes AND Year GE 2005 AND SizCls EQ 3
Then
ThinBTA      0      640.   0.9500   0.    6.    0.    999.
IF      0
Selected EQ Yes AND Year GE 2005 AND SizCls EQ 3 AND FuelLoad(1,3) GE 2.5
Then
Fmin
PileBurn      0      1      80      5      90      1
End
IF      0
Selected EQ Yes AND Year GE 2005 AND SizCls EQ 2 AND (ForTyp EQ 201 OR ForTyp EQ 221)
Then
ThinBBA      0      130.   1.0000   0.    999.    0.    999.
Fmin
SimFire      1      12.00      2      70.0
End
IF      0
Selected EQ Yes AND Year GE 2005 AND SizCls EQ 2 AND ForTyp GT 221
Then
ThinBBA      0      150.   0.90      0.    999.    0.    999.
Fmin
PileBurn      1      1      70      5      90      3
End
IF      0
Selected EQ Yes AND Year GE 2002 AND SizCls EQ 1 AND (ForTyp EQ 201 OR ForTyp EQ 221 &
OR ForTyp EQ 241 OR ForTyp EQ 321)
Then
ThinBBA      0      140.   0.9000   0.    999.    0.    999.
Fmin
SimFire      1      12.00      2      70.0
End
IF      0
Selected EQ Yes AND Year GE 2002 AND SizCls EQ 1 AND ForTyp EQ 281
Then
ThinBBA      0      0.    0.9000   0.    20.    0.    999.
Fmin
SimFire      1      12.00      2      70.0
End
IF      0
Selected EQ Yes AND Year GE 2002 AND SizCls EQ 1 AND (ForTyp GE 250 AND &
NOT (ForTyp EQ 281 OR ForTyp EQ 321))
Then
ThinBBA      0      150.   .95000   0.    999.    0.    999.
Fmin
PileBurn      1      1      80      5      90      1
End

```

Appendix B: Sample Fuel Model Logic

Logic Used to Select Fuel Models for the Western Montana Study Site.

Variables used for this logic were from the text file PPE-FFESelData.txt described in table 2. Some of both the original 13 (Anderson 1982) and Scott and Burgan (2005) fuel models were used in this method.

First, live woody fuel loading and fuel bed depth were determined from the shrub constancy and average coverage for the stand habitat type (Cooper and others 1991; Pfister and others 1977).

Shrub type	Live woody load, Mg/ha (T/ac)	Fuel bed depth, m (ft)
Tall shrubs	6.6 (3.0)	0.9 (3.0)
Medium shrubs	4.4 (2.0)	0.6 (2.0)
Low shrubs	2.2 (1.0)	0.3 (1.0)
No significant shrubs	0.0 (0.0)	0.1 (0.4)

If more than 40.5 trees/ha (100 trees/acre) were cut (RTPA) and no fuel treatment was accomplished, assign a slash fuel model (11, 12, 13, SB1, SB2, SB3, or SB4) by comparing 1hrLoad, 10hrLoad, and 100hrLoad.

Else—modify live woody fuel loading and fuel bed depth for recent treatments and high canopy cover with one of the following rules:

- If the last treatment is less than 20 years old, reduce live woody fuel loading and fuel bed depth by the ratio (Year–Last Treatment)/20.
- If canopy cover is greater than 70 percent, multiply live woody fuel loading and fuel bed depth by 0.333.
- If canopy cover is between 50 percent and 70 percent, multiply live woody fuel loading and fuel bed depth by 0.666.

If canopy cover is less than 30 percent, assign fuel model as follows:

1. If live woody fuel loading is greater than 0.0 and fuel bed depth is greater than 0.6 m (2.0 ft), assign fuel model GS2.
2. If live woody fuel loading is greater than 0.0 and fuel bed depth is less than or equal to 0.6 m (2.0 ft), assign fuel model GS1.
3. If live woody fuel loading is 0.0, assign fuel model GR1.

Else—If forest type is Ponderosa Pine, assign fuel model as follows:

1. If canopy cover is less than or equal to 50 percent, assign fuel model 2.
 2. If canopy cover is greater than 50 percent and 1hrLoad is greater than 9.62 Mg/ha (4.36 T/ac), assign fuel model TL8.
 3. If canopy cover is less than or equal to 50 percent and 1hrLoad is less than or equal to 9.62 Mg/ha (4.36 T/ac), assign fuel model 9.
- Else—assign a fuel model (5, 8, 10, GS1, GS2, SR1, SR2, SR5, TU1, TU5, TL1, TL3, TL4, TL5, or TL7) by comparing 1hrLoad, 10hrLoad, 100hrLoad, live woody fuel loading, and fuel bed depth.