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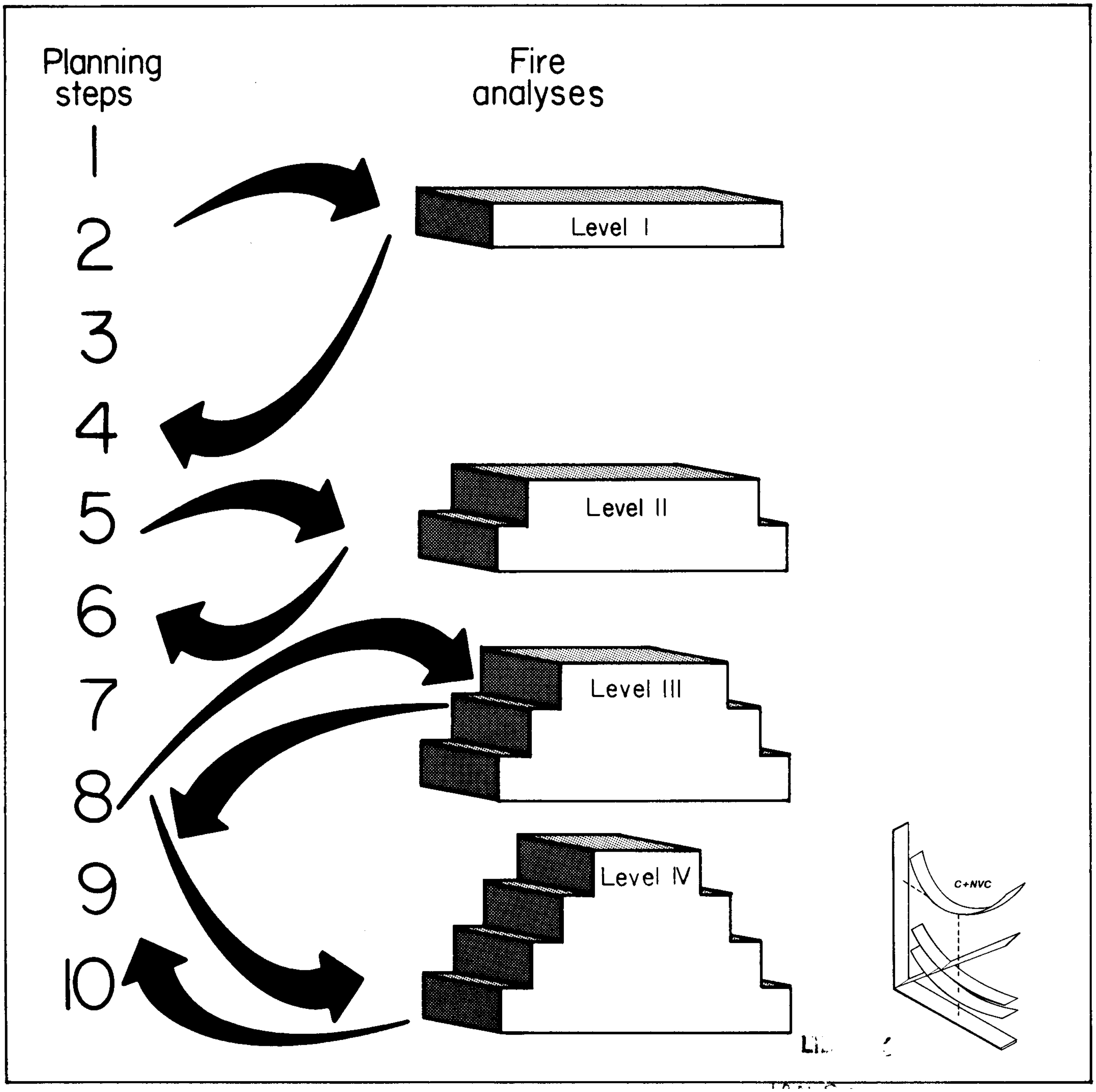
Integrating Fire Management Analysis into Land Management Planning

Thomas J. Mills



Author:

THOMAS J. MILLS, a forest economist, is in charge of the Station's unit studying fire management planning and economics, with headquarters at the Forest Fire Laboratory, Riverside, Calif. He earned degrees at Michigan State University (B.S. in forestry, 1968; and M.S., 1969, and Ph.D., 1972, in forest economics).

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The analysis of alternative fire management programs should be integrated into the land and resource management planning process, but a single fire management analysis model cannot meet all planning needs. Therefore, a set of simulation models that are analytically separate from integrated land management planning models are required. The design of four levels of fire management analysis that contribute to the planning process has been developed. The interactions among these four levels and between the fire management analysis and the planning process are designed for consistency and analysis efficiency. These analytical models emphasize economic efficiency and risk consequences of fire management program options.

Retrieval Terms: economic efficiency, risk, probability modeling, fire suppression.

Cover: To screen fire management options, a ten-step process progressing through four levels of analysis has been designed.

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Analysis of alternative long term natural resource programs pose challenges to both planners and managers. One dimension of the challenge is the diversity of both management actions and resource outputs affected by those actions. Management actions that vary from timber harvesting to road building, and from cover type conversion to fire suppression, for example, affect both market priced outputs, such as timber and range yields, and nonmarket priced outputs, such as water, wildlife, and visual quality. Each of these management actions and outputs have unique aspects that require special analysis, but each must also be addressed in an integrated resource analysis to avoid achieving a high level of one output at the expense of excessive reductions of another output, i.e., to avoid suboptimization.

Another dimension of the challenge is the wide range of temporal and spatial detail, i.e., levels of analysis resolution, that must be considered in long term planning. For example, the initial screening among numerous long term management programs can be completed at a relatively low time and space resolution. It may be sufficient at that stage to evaluate programs for generic "types" of management areas, rather than site-specific areas. Eventually, however, the planning must address a few site-specific management actions in greater detail for real time decisions.

If these challenges are met with a set of interrelated and complementary analytical tools, it will be possible to develop information efficiently for complex resource management decisions. If, on the other hand, the analytical models are not sufficiently interrelated and do not adequately address the question of time and space consideration, the information produced from the separate models is likely to be inconsistent and costly. A common error is the application of highly site-specific models at early stages in the screening among program alternatives. Being highly site-specific is extraneous at that point in the overall evaluation framework.

This report describes a framework for simulation models that integrate fire management analysis into the land planning process. Similar frameworks are appropriate for other functional programs, such as timber and recreation. Examples are drawn from Forest Service, U.S. Department of Agriculture situations, but the same general concepts apply to any organization with wildland fire management responsibilities.

FIRE MANAGEMENT

Major changes in the land management planning process on National Forest lands were formalized in the National Forest Management Act of 1976 and subsequent regulations for its implementation (U.S. Dep. Agric., Forest Serv. 1979a). The Act requires that the planning process fully integrates the various resource components of the management program, and that the criteria for designing and selecting alternatives be explicit.

The revised National Forest fire management policy contains related changes--the fire management program must be cost effective and consistent with land management objectives (U.S. Dep. Agric., Forest Serv. 1978). Minimization of fire program cost plus the net value change (C + NVC) in resource outputs has been specified as the cost effectiveness criterion (U.S. Dep. Agric., Forest Serv. 1981a).

Four "levels" of fire management analysis, each one designed to address different questions at appropriate levels of time and space analysis detail, have been described to help implement these policy changes (U.S. Dep. Agric., Forest Serv. 1979b). Analytical models for portions of the four-level framework are described in a handbook (U.S. Dep. Agric., Forest Serv. 1982). The process in the handbook contains major improvements over earlier procedures and is a step forward in the evolution of complete and analytically efficient procedures. A more complete and consistent framework for full fire management program analyses is needed, however.

Although economic efficiency analysis of fire control programs is emphasized here, other fire program activities, such as prescribed burning, and other effects not easily placed within an economic analysis are also important. The ecological effects of fire, such as those documented by Davis and others (1980), Kilgore (1979), and Parsons and DeBenedetti (1979), are also important long term factors that should be considered in the fire program analysis. Those ecological factors might more appropriately be addressed during deliberations of the interdisciplinary planning team. Gorte and Gorte (1979) reviewed the economic efficiency dimension of fire management program evaluations, and Martell (1982) reviewed operations research application to fire management decisionmaking.

INTEGRATED PLANNING PROCESS

In the past, the management plan for a Forest Service administration unit was sometimes a simple summation of the separate plans prepared for each resource function. This practice often led to suboptimal programs and direct conflicts between functional activities. Fire control before 1978 is an example. The fire planning criterion (U. S. Dep. Agric., Forest Serv. 1972) was to control all fires before they reached a size of 10 acres, and the policy was to take action to achieve control by 10 a.m. of the second day if initital [sic] attack on the first day was unsuccessful. This policy sometimes led to aggressive fire suppression which was in direct conflict with resource objectives-especially in low intensity fires.

The National Forest land management planning process (U.S. Dep. Agric., Forest Serv. 1979a) was designed to resolve this type of conflict. The planning process is an interdisciplinary and fully integrated approach to decisionmaking. Issues and concerns are addressed by an intentionally broad array of management alternatives. The alternatives are evaluated against several explicit planning criteria in a process open to public scrutiny. The selected alternative is then converted into an annual operating plan and its implementation is monitored to ensure consistency with the planning criteria and objectives.

A fully integrated evaluation of management alternatives, though a desirable goal, is difficult to achieve analytically. For example, only one of the many potential fire management program options, from a wide array of technically feasible options, can be incorporated into the management alternative during functionally integrated analysis. The included fire program must be consistent with both the objective of the alternative and the planning criteria. If a less-than-optimal fire program is included and its cost is a major share of the total management cost, the management alternative may be rejected-not because it is not the best one, but because it is not configured in its optimal form.

One solution to this problem is to develop the fire management program options for each integrated management alternative in a model that is analytically separable from an integrated analysis model (U.S. Dep. Agric., Forest Serv. 1981b). The costs and resource effects of the selected fire option would be included in the integrated analysis model along with similar estimates from other resource programs. Because the fire management analysis model would be narrower in scope than the integrated analysis model, a more thorough screening of fire program options could be accomplished at a lower cost than under alternative approaches. This approach does *not* advocate a return to single-resource planning. Rather it simply recognizes the analytical complexity of the fire system and the practical limits of the integrated analysis model.

Definitions

For the purposes of this report, the following terms and their definitions are used: A *management objective* is a land and resource condition, and a multiresource output stream, which a management program is designed to achieve. A *management alternative* is a multifunctional land and resource management program of actions formulated to accomplish the management objective. A *management prescription* is a specific management action taken on a particular parcel of land; the sum of various prescriptions describes the management alternative. *Integrated analysis,* as opposed to fire management analysis, Man evaluation of multiresource or multifunctional programs. The *fire program mix* is the composition of inputs, such as initial attack forces versus acres of fuel treatment, purchased with the budget specified by the program level. The *fire program option* is a particular combination of dollar program level and program mix. The *management area* is the land unit to which a particular fire program option is applied.

Premises

Three premises underlie the design of this fire management analysis framework.

Premise 1: Fire management programs do not simply *support* resource management activities; they *contribute* directly to the accomplishment of resource management objectives by affecting resource output levels and program costs. They should, therefore, be considered as options for addressing the issues and concerns at the same time as other resource management opportunities.

Premise 2: Evaluation of fire management program options is so complex that separate analytical models are needed even if some suboptimization results. The suboptimization is probably far less than the cost of the errant decisions which result from an insufficient screening of fire program options within the main body of integrated planning models.

Premise 3: A single analytical model cannot efficiently perform at all the required levels of time and space detail. A universal fire program analysis model is infeasible, or at least very inefficient. The fire management analysis must also be clearly linked to and guided by the preliminary decisions generated within the main body of integrated planning.

Levels of Analysis

Four levels of fire management analysis are proposed to accomplish the screening of fire program options. These levels and their objectives vary somewhat from those described elsewhere, (U.S. Dep. Agric., Forest Serv. 1979b), particularly in the use of acreage-burn standards or pars.

Level I

Level I fire management analysis provides a prescreen of fire program options that contribute most toward the accomplishment of the tentative management alternative (*fig. 1*). Since both fire management program level and program mix affects program performance, discrete fire program options which address both the level and mix should be evaluated. The low resolution Level I analysis deals with the time and space dimensions of the analysis in a relatively shallow, but broad manner.

Three types of input information are required: (a) a list of tentatively stated management alternatives as derived from the issues, concerns, and opportunities identified in Step 1 of the integrated planning process, expressed in terms of an intended time stream of resource outputs; (b) the planning criteria (Step 2); and (c) a description of a representative management area to which each tentative management alternative applies, including parameters that influence fire program performance and effects, such as resource values, terrain, fire occurrence, and vegetation type (Step 3).

The revised National Forest fire management policy (U.S. Dep. Agric., Forest Serv. 1981a) stresses the importance of economic efficiency as a planning criterion. This importance had been underscored earlier by the U.S. Office of Management and Budget and the U.S. Senate (1978) in their inquiries about the Forest Service's fire programs (U.S. Dep. Agric., Forest Serv. 1977). The minimization of the sum of the program cost plus the fire-induced net value change in resource outputs and improvements is an appropriate economic efficiency criterion for fire programs (Gorte and Gorte 1979, Mills 1979, Simard 1976). Quantitative effects of fire on resource outputs is another criterion even though some effects are already included in the C + NVC calculation. Risk consequences is another important criterion in Level I analysis.

Several pieces of output information are produced from Level I for each tentative management alternative and fire program option evaluated on the representative management area. One output is the expected C + NVC. The expected value is a probability weighted average. Another output is the expected net change in the output of resources. The net change is the output levels without fires minus the output level that would occur with the fires simulated to occur under the fire program option being evaluated. A third output is the risk consequences as measured by the shape of the cummulative probability distributions about C + NVC and resource output change. The last output is the expected value number of fires or acres burned or both by fire size and fire intensity classes which is the basis for a planning criterion in Level III.

Selection of a fire program is determined by the relative weights or constraint levels or both applied to the planning criteria. If the decisionmaker does not specify the relative weights in advance, the minimum expected value C + NVC should be used as a default criterion since it does the most complete job of incorporating program costs, resource outputs and values, and the stochastic nature of the fire management program.

The fire program cost and resource effect coefficients thus derived are incorporated into the integrated analysis of the management situation (Step 4). The integrated alternatives are

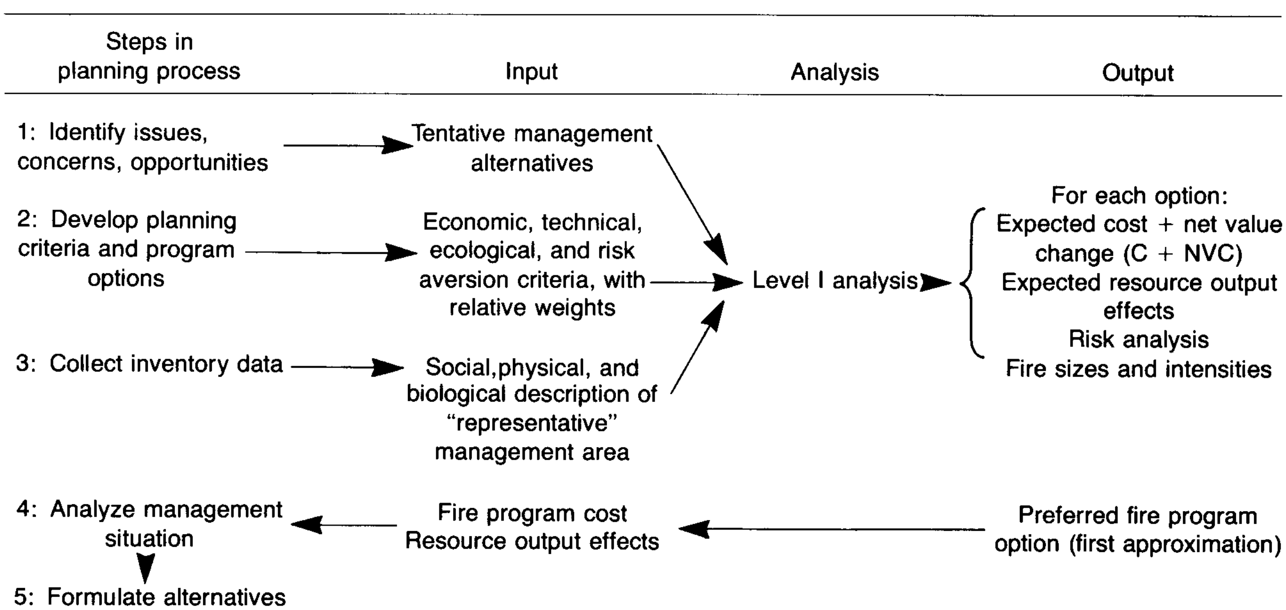

Figure 1--In Level I of the fire management analysis, a broad range of fire program options is prescreened to determine which one contributes the most to the tentative land management alternative.

then formulated (Step 5) with the benefit of this fire program prescreening.

The Fire Economics Evaluation System (FEES) now being developed by the Forest Service will meet the design requirements for Level I (Bratten 1982, Mills and Bratten 1982). The system will evaluate widely different fire management programs applied to management areas that are described in situation-specific, but not site-specific, terms. This design is built on the premise that there are classes of management areas that exhibit essentially the same fire program performance for this first level screening.

Level II

Guided by the formulated alternatives (Step 5) and the fire program selected in Level I, the Level II model performs a more detailed analysis on a more narrowly defined range of fire program options, thus refining the Level I fire program selection (*fig. 2*). The refined cost and resource output change coefficients are incorporated into each integrated alternative (Step 6). The planning process then moves through the evaluation of management alternatives (Step 7) and the selection of one alternative (Step 8).

Analysis at this level is characterized by increased specificity of site and time dimensions of the analysis and concentration on a narrower range of program options. This narrowing of analysis scope is a major source of analysis efficiency. Without a Level I analysis, the Level II analysis would probably be applied to a far too narrow range of program options because the cost of evaluating each program option is greater.

Input information required in Level II is similar to that in Level I: a description of planning criteria, a site-specific description of the management area, and the formulated management alternatives in terms of intended resource outputs. Risk is analyzed by a probabilistic model in Level I, so Level II can be restricted to expected value results. Additional criteria include site-specific fire constraints. For example, fires in an area containing cultural resources may be restricted to an average of no more than 10 acres.

Four categories of output are developed from the Level II analysis: (a) the expected value C + N VC; (b) the fire-induced expected value resource output change; (c) whether the fire constraint is satisfied; and (d) the expected number of fires, by fire size and fire intensity. The opportunity cost of the fire constraints must be evaluated carefully, at least by showing the foregone C + NVC.

The Level II results for fire program costs, resource output effects, and number of fires by size and intensity should be similar to those estimates from the Level I analysis for the same fire program option. If they are not consistent, the analysis and/or data resolution in Level I may have been too gross, or the tentative management alternatives in Level I could be much different than the formulated management alternatives analyzed in Level II. If the Level I-11 difference is small, Level II will do just what it is designed to do, refine the Level I estimates. If the difference is substantial, it may be more efficient to repeat the Level I prescreening for the formu-

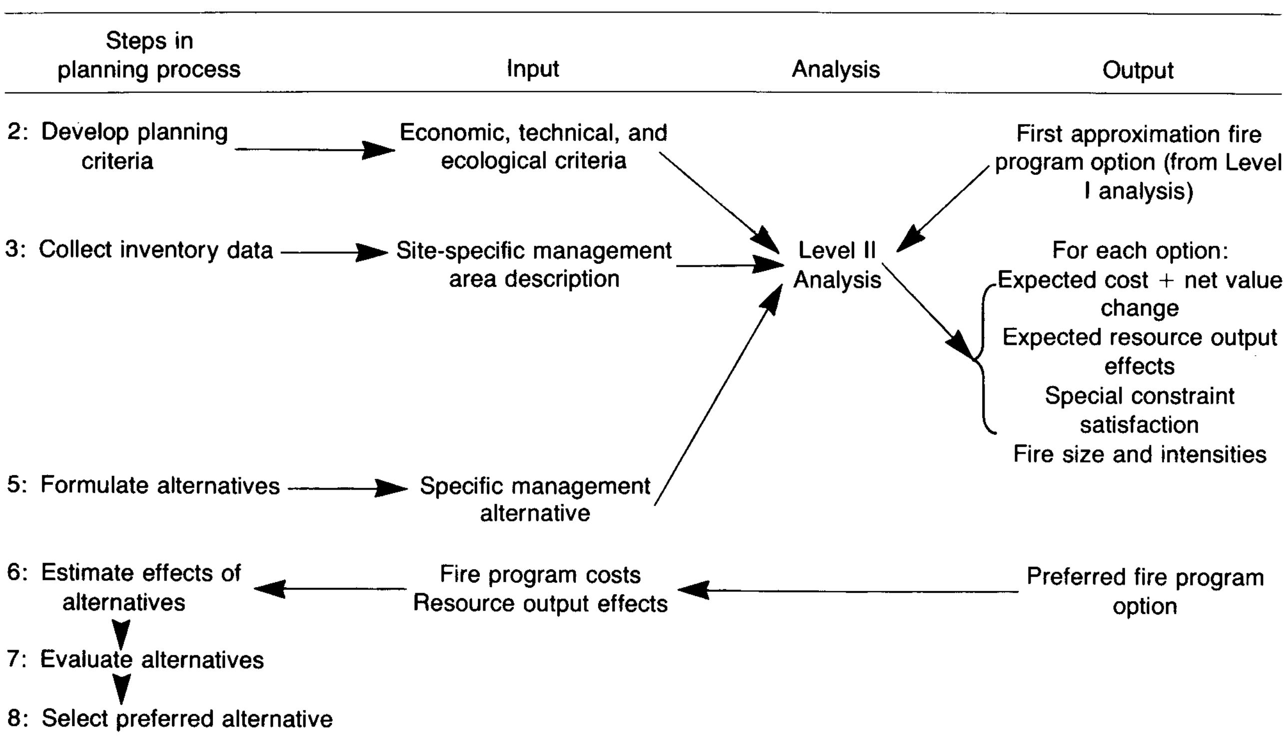

Figure 2--In Level II of the fire management analysis, the first approximation of preferred option derived in Level I is refined.

lated alternatives than to apply the Level II analysis on a large number of options.

The Forest Service's (1982) Fire Management Analysis and Planning Handbook (FSH 5109.19) describes an operational system that provides most of the analysis capability required by this Level II design. The analysis detail is properly greater than in the Level I analysis but it still falls short of the site-specificity needed in later analyses. The Handbook evaluates fire program performance at "representative" fire locations, for example, rather than at all possible fire locations. The representative location structure permits consideration of the fire site constraints, but avoids the analysis cost of greater specification than is needed at this point.

Level III

The Level III fire management analysis transforms the fire program option embodied within the selected management alternative (Step 9) into an annual, operational or implementation plan for the fire management program (*fig. 3*).

Four categories of Level III input are required. One is a description of the management area, but a more site- and time-specific description than in Level I and Level II. Level III data, for example, may include a travel-time network whereas access in Level I may be represented through historical distributions of initial attack arrival times (Mees 1983). The second input is the management direction implied in the selected management alternative. The management direction in Level III is represented by a par or standard for acres burned by fire size and fire intensity derived from Level II output. The use of pars leads to a reduction in Level III analysis complexity since the fire effects and resource values estimates required for the C + NVC evaluation are not needed. The pars may be augmented by the special fire constraints, the third input. Since the pars were guided in Level II by economic efficiency, resource output, and risk criteria, those criteria can be replaced in Level III with a cost minimization criterion. The fourth input is the Level II fire program option contained in the preferred alternative. This limits the range of program options evaluated in Level III considerably.

The development and use of pars advocated here is different than what has been proposed elsewhere (U.S. Dept. Agric., Forest Service 1979b). Attempts to develop pars directly from the integrated planning process had serious shortcomings since it is difficult to transform the resource outputs of each management alternative directly into pars. Too much weight was given to the historical acreage burned. That effort attempted to establish pars as absolute acre-burn ceilings, levels above which intolerable losses occur. An "intolerable loss" from fire is not meaningful, if intolerable implies infinite disbenefit. Furthermore, no place to judge the reasonableness of the cost of achieving the pars was provided for. The use of pars proposed here overcomes these difficulties because the pars are developed in Levels I and II before they are used as a selection criterion in Level III. The pars are, therefore, developed after a full consideration of all planning criteria.

Three categories of output are derived for each fire program option evaluated in Level III: (a) an estimate of acres burned by fire size and fire intensity class for comparison with the pars; (b) an evaluation of whether the special constraints are met; and (c) an estimate of the fire program cost.

A major component of the Level III fire plan is an annual budget request. The decisionmaker may question what would result from a budget increase or reduction. If consistency has been achieved, the fire program options evaluated in Level III are a subset of those evaluated at Levels II or I at a less site- and time-specific level of resolution. Estimates of the economic efficiency, resource output, and risk impacts from budget changes can, therefore, be drawn from the results of Levels I or II or both. That information does not have to be included directly in the Level III model.

The FOCUS simulation model (Bratten and others 1981) operates at the resolution appropriate for Level III analysis.

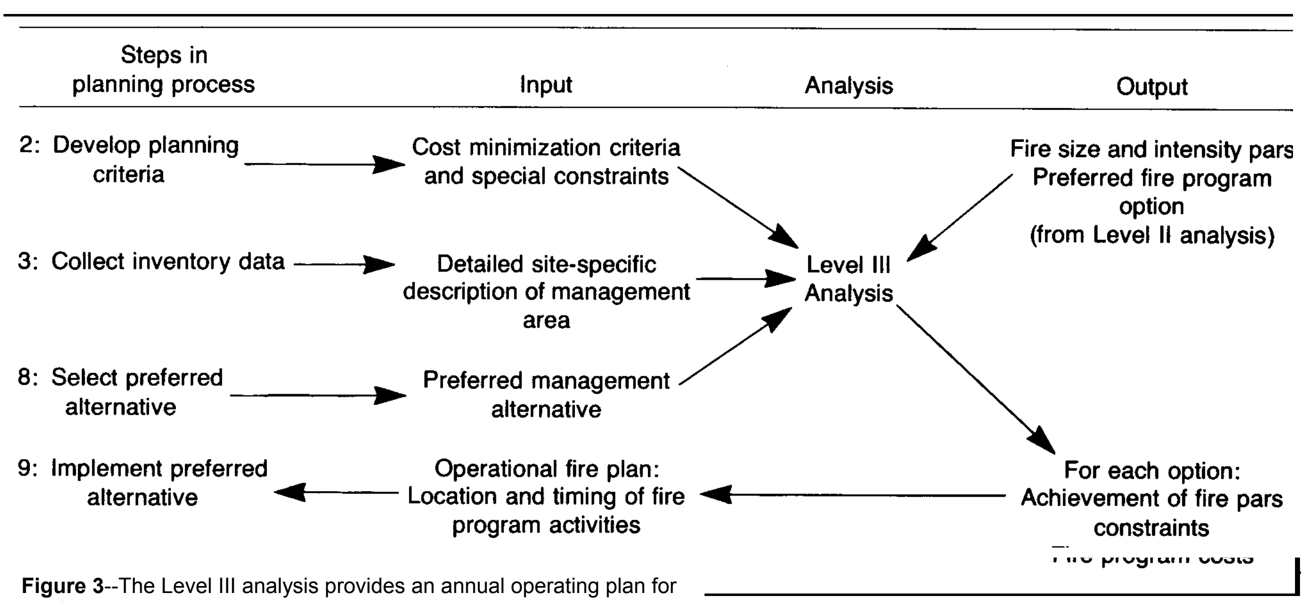

Figure 3--The Level III analysis provides an annual operating plan for the fire program.

The spatial dimension is incorporated by a complete transportation network and a full list of fire locations, either historical locations or potential locations. FOCUS does not provide fire-induced resource output changes or resource values but it does yield estimates of fire sizes and suppression costs which are needed in Level III.

Level IV

The Level IV analysis evaluates program options for individual fire events and develops an action plan for the one option most consistent with the management objective (*fig. 4*). Some of the Level IV analysis may be done in advance of the fire, such as prescribed fire project plans, while others must be completed in real-time, such as escaped fire situation analyses. The following discussion concentrates on escaped fire situation analyses, although similar principles apply to other Level IV analyses.

The output from previous levels provides first approximations of Level I V inputs which are then adjusted in light of the site- and time-specific description of the fire. One input is the expected resource output for the area that the fire may burn, another is the planning criteria (economic efficiency and risk). Additional criteria are special constraints and public safety. Next is a time-specific description of the fire location. Spatial variation and juxtaposition are important here. Three or four future weather time streams and their probabilities are also identified.

The fire suppression options are evaluated for each weather time stream and then weighted together by their respective probabilities to yield an expected outcome. Risk is displayed through the probabilities of each weather pattern and their associated consequences.,

The first Level IV output is C + NVC. Second is the expected resource output effects by resource category. Third is the effect on special contstaints [sic] and public safety. Fourth is the risk depicted by the consequences of weather variations. Consistency is more important in Level IV than in earlier levels because first approximations of Level IV input data comes directly from prior levels.

Instructions for preparation of an escaped fire situation analysis are contained in the Forest Service Manual (FSM 5130.3) (U.S. Dep. Agric., Forest Serv. 1981a). Seaver and others (1983) describe further advances in the analysis of alternative escaped fire strategies that are possible.

COMPARISON OF ANALYSIS LEVELS

Similarities

In all levels, analysis begins with a statement of the integrated management objective, even though the form of the objective differs: tentative management alternative (Level I), formulated alternative (Level II), or preferred management alternative (Levels II and IV). Several fire program options are evaluated in each level against several planning and decision criteria. Maximizing economic efficiency and minimizing the

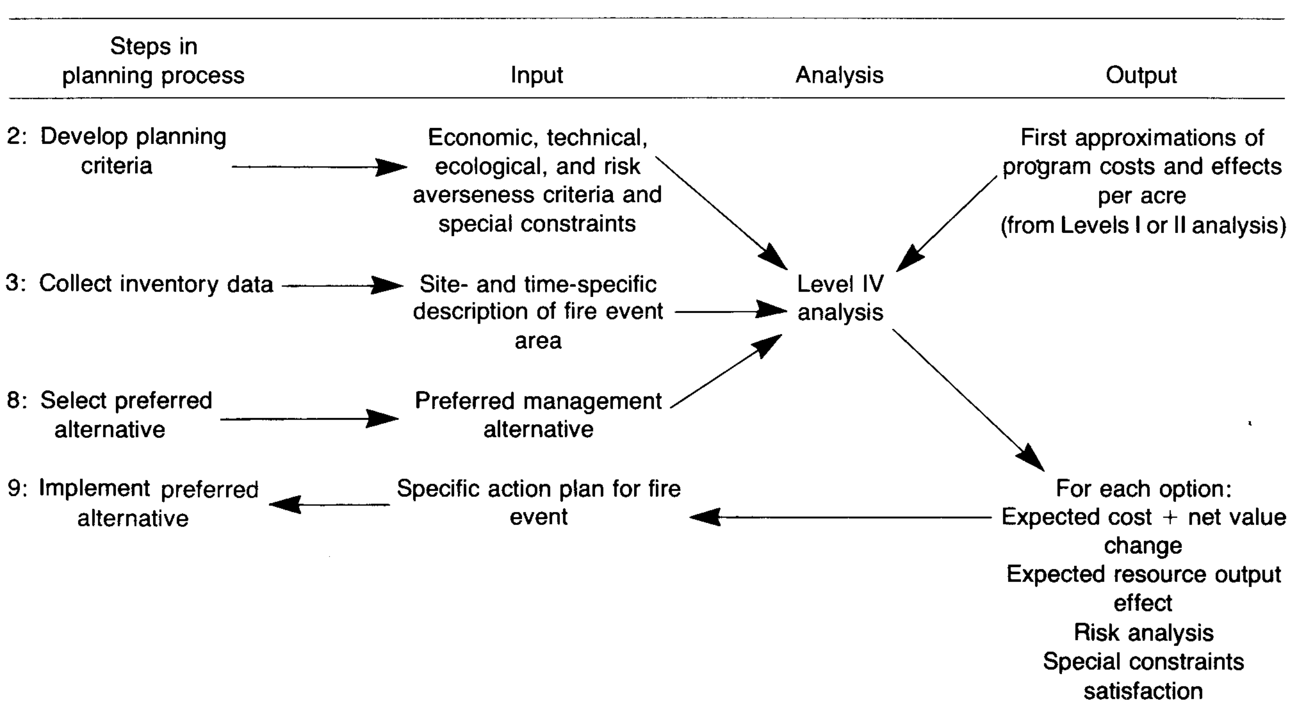

Figure 4--Level IV of the fire management analysis provides an action plan for an individual fire event.

net detrimental effect of fires on resource outputs are common selection criteria in all levels except III, where they are replaced by acre burn pars.

The stochastic impact of fire weather variations is included in all levels and fire occurrence variability is considered in Levels I-III. This variation is reflected through expected value calculations (Levels II and III) or as a probability distribution which accompanies the expected value (Level I and IV).

Differences

Some of the planning criteria differ among the levels. Site-specific, special constraints, such as the exclusion of fire from areas with particularly fragile soils, are considered in Levels II, III, and IV, but are excluded from Level I. The full display of probability outcome is only derived in Level I because probability models require extensive data and are difficult to build. The fullest risk consideration is in Level I so that conclusions reached there can guide analyses in Levels II-IV.

The four levels differ in the breadth of fire program options evaluated. The broad range of options considered in Level I are condensed to a few for the detailed Level II analysis. Level II yields an even narrower range for evaluation in Level III. Different questions are addressed at each level by evaluating a successively narrower set of fire program options.

A progressive increase in temporal and spatial resolution occurs from Levels I to I V. Level I does not require a site-specific area description in the locational sense of juxtaposition of separate parcels of land. Situation-specific "kinds" of fire management situations are evaluated instead in Level I to permit easier extrapolation of results to management areas with similar characteristics, thereby avoiding unnecessary analysis repetition. On the other hand, site-specificity is essential in the operational level planning in Level III and the planning for individual events in Level IV Higher resolution analysis is restricted to the fire program options which warrant that degree of detail. The cost would be prohibitive if the model and data "resolution of Levels III or IV were used to evaluate the broad scope of program options which must be addressed in Level I.

The similarities ensure consistency and efficient progression of closer resolution analysis on a successively narrower range of program options. The differences permit the tailoring of the various models to the questions pertinent at the respective Steps of the integrated planning process.

Modifications

Although the parameters which affect analysis complexity are fairly obvious, such as high fire occurrence levels and high resource values, the optimum relationship between fire program complexity and analysis sophistication is not (*table 1*). The cost of added fire program information should be no greater than the opportunity cost of a less than optimal decision that would result from missing information. In the absence of a complete sensitivity analysis, proposals for complexity-related analysis modifications are judgmental.

Level I is needed in areas of moderate complexity, but Level II is not. The Level I first approximations are sufficient. Level III is needed in areas of moderate complexity, but relatively more reliance may be placed on historical experience. The range of fire program options addressed at all levels can be reduced. If the individual fire event is moderately complex, the first approximations derived from earlier analysis levels may be refined by judgment rather than by analysis.

Level I analysis is still important in low complexity areas, but the number of program options evaluated can be reduced even further. Level I can also be reduced from a full probability model to an estimate of expected values alone. The Level II analysis can be dropped, just as it was under moderate com-

Table 1--*Effects of fire management analysis complexity on management objectives, by levels of fire management analysis*

	Fire management analysis complexity		
Level	High	Moderate	Low
I	Not site-specific Numerous fire program options Full risk consideration	Same as for High with fewer options and data resolutions	Few fire program options Expected value output only Lower data resolution
II	Site-specific refinements of Level I results Special constraints included program options	Remove Level II analysis model Consider special constraints in Level I or in the interdisciplinary team	Les Same as for Moderate
III	Very site-specific estimate of cost, location and timing Moderate number of fire program options	Less site-specific Fewer fire program options	Derive output from judgmental prorating of historical information using Level I output
IV	Very site-specific and time-specific Use Level I and II output Moderate number of fire program options Full risk consideration	Expected value results only Use Level I and II output as input with less refinement	Few fire program options with onsite judgment adjustments

plexity and the Level III analysis model can be greatly simplified or perhaps removed. The mathematical analysis in Level III could be replaced by judgmental adjustment of Level I output and site-specific historical experience. In a low complexity fire event, Level I V would evaluate fewer options and greater reliance can be placed on analysis of hypothetical fire events.

CONCLUSIONS

The objective of a fire management analysis is to identify the program option that contributes most to the integrated management objectives. If the fire management analysis models are developed in the absence of a complete system design, major analysis gaps will occur in some places, and substantial overlaps will result elsewhere. The analysis and data resolution may be mismatched with the program options and the range of options tested may be too narrow.

This report describes the framework for a set of interrelated models, each one tailored to answer questions relevant at various steps of the resource management planning process. The analysis efficiencies that can be gained from the use of a completed set of models are likely to far outweigh their cost of construction.

The conceptual framework of the system described refines and extends previous work. Although currently available models approximate these design criteria for some of the components, the complete system is not yet operational. Full development of the framework will improve complementarity among analyses and reduce analysis overlap, ensuring that particular analyses are performed at the most efficient point in the sequence of questions answered during planning.

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