Defining Initial Response: Integrating Fire Use With Initial Attack[1]

Stephen J. Botti,[2] Douglas B. Rideout,[3] Andrew G. Kirsch[3]

Abstract

Fire use enables fire managers to take advantage of the beneficial effects that natural ignitions may have on the landscape. Under the right circumstances, fire managers may choose to forgo initial attack in favor of monitoring and managing natural ignitions in ways that improve the condition of the ecosystem. As our knowledge and techniques for managing fires have advanced, so has fire policy and fire use. With increasing interest in fire use, comes a greater need for improved programmatic approaches and analysis. Here we explain how program management and planning efforts can integrate fire use into the initial attack planning and budgeting. We show how an integrated programmatic framework can take advantage of the important relationships that fire use has with initial attack. For example, because many of the fire management resources that are employed for initial attack are also those employed on use fires, an integrated program can take advantage of joint costs to realize potentially significant cost savings. We show how an integrated program can improve the efficiency of both initial attack and fire use while better informing the budgeting process. Such an integrated programmatic approach is currently in the developmental stages for the Fire Program Analysis (FPA) system currently under construction.

Introduction

Fire use refers to ignitions where the best response may be to manage and monitor the fire for resource objectives in lieu of aggressive suppression. These purposes are stated in land management plans and fire management plans (FMP). As defined by Zimmerman and Bunnell (1998) [1], wildland fire use is:

> "The management of naturally ignited wildland fires to accomplish specific restated resource management objectives in predefined geographic areas outlined in FMP's."

The new integrated federal wildland fire management policy recognizes fire as an integral part of managing ecosystems and encourages managers to consider the full range of management options [2]. Evidence suggests that fire use is increasingly accepted and relied upon as a management tool that is finding its way into more land and resource management plans (e.g. Rideout and Botti, 2002 [3]). However, the employment of fire use may vary depending upon the fuels and fire behavior conditions, agency, land management goals, objectives and other considerations. Fire use strategies are unevenly accepted and applied among the federal land

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[2] Manager, National Fire Program, USDI National Park Service, Boise, ID.

[3] Professor and graduate student, Fire Economics Laboratory, Department of Forest, Rangeland and Watershed Stewardship, Colorado State University, Fort Collins, CO 80523.

management agencies. In some agencies or administrative units, wildland fire use may be extensively applied while in other units it may be considered inappropriate.

Fire use represents a modeling hybrid between initial attack fire suppression and prescribed burning that poses unique challenges. The spatial and temporal extent of prescribed fires generally can be planned in advance. However, fire use fires are unplanned events, and the specific time, location, weather, and topography of each event are unknown. This is true even though fire use events may conform to a basic fire prescription specifying spatial and temporal conditions and a range of weather conditions. Like prescribed burning, fire use is used to restore or maintain natural conditions. Like unwanted wildfires, the conditions under which fire use fires occur are fraught with uncertainty.

Despite this uncertainty, initial response to wildfires and use fires can be modeled as a means of preparing for future fire seasons. These models are used to guide strategic decisions about the staffing and equipment required to prepare for fire seasons, not to make tactical decisions about how to manage real-time events. For both wildfires and use fires, the specifics of future events are unknown and therefore introduce issues of modeling accuracy and precision.

Fire use and suppressed wildfires represent two points on a continuum of appropriate management response strategies that can be applied to a given naturally-ignited wildland fire as shown in Figure 1.

Figure 1—*Continuum of appropriate initial response*

As stated by Zimmerman and Bunnell (1998) [1], "When the Fire Management Plan has been completed and approved, and wildland fires are from natural ignition sources, the full extent of management options is available, depending upon resource management objectives presented in the FMP." These options include suppression only strategies where wildland fire is damaging, monitoring only strategies where it benefits ecosystems, or a combination of monitoring and holding strategies where it benefits resources in some areas but threatens values to be protected in other areas.

The resource benefit objectives that drive fire use are similar to those that drive the ecological use of prescribed fire. For this reason, early modeling discussions focused on combining fire use with prescribed fire and other fuels treatments. However, the uncertainties surrounding fire use events, along with the fact that an initial response is required for all wildland fires regardless of the management strategy employed, argue for including fire use within an overall strategic preparedness module.4 Because the staffing and other resources employed on use

[4] Resources to prepare for wildland fire use generally are funded from budgeted operating accounts, while costs to manage events generally are funded from emergency accounts. This is because management costs are unpredictable, varying significantly each year depending on the number, size and location of fires. The strategic planning model presented here is designed to identify local resources required for managing use fires, not the resources

fires and initial attack suppression fires compete for the preparedness budget, it makes sense to analyze them together and determine the cost-effectiveness of all initial response strategies jointly within one module. Use fires and suppression fires draw upon a similar fire management resource base such that many resources acquired for one purpose can serve the other. For example, helicopters can transport fire crews to suppress an unwanted wildfire, or the same crew to monitor and manage a use fire. This multi-functionality of wildland fire preparedness resources suggests that an integrated management and budgeting approach should be considered.

A preparedness organization requires the capability to make an initial response to all wildland fire ignitions regardless of the strategy employed. The nature of that response should be guided by the benefits and costs of the fire as identified by measurable criteria, such as goals and objectives, from the fire or land and resource management plan. By modeling the full range of initial response strategies, managers can strategically plan the integrated use of initial response resources for monitoring, holding actions and limited suppression actions. This will incorporate management actions, such as modified and limited suppression strategies in Alaska, that may not be called fire use but which mirror the objectives of fire use in other areas.

While there is no option for modeling fires that begin with suppression strategies and are converted to monitoring strategies, this type of management rarely occurs and has little impact on initial response needs. The management requirements of fires that escape initial response, whether they escape initial attack and are converted to monitoring strategies or escape from fire use and are converted to suppression strategies are to be addressed separately.

Integrating Fire Use in Initial Response Planning

This modeling approach will provide fire managers with a much more powerful analytic process than has been previously available. This approach combines a rule-based system for defining management and monitoring requirements for AMR fires with production functions for containing wildfires, and makes this information directly available for an integrated optimization of initial response. This process will better inform the manager of resource use and resource interaction between initial attack suppression and fire use (and other AMR) at alternative budget levels in ways that have not been previously available. For example: the model will solve for optimal staffing of management and monitoring (M&M) resources used on wildland use fires. Management actions would include holding actions and other efforts to herd or influence the burning pattern, intensity, or extent of a fire use fire within a maximum manageable area without converting to a suppression strategy. It will show how M&M resources are shared with and complement the initial attack program. And it will show the development of a unified budget to address both fire use and initial attack suppression.

This approach quantifies and makes the objective basis explicit for current management decisions regarding the deployment of resources between fire use and initial attack. Figure 2 summarizes the overall approach.

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required if they become large fires requiring contingents of non-local holding or suppression resources.

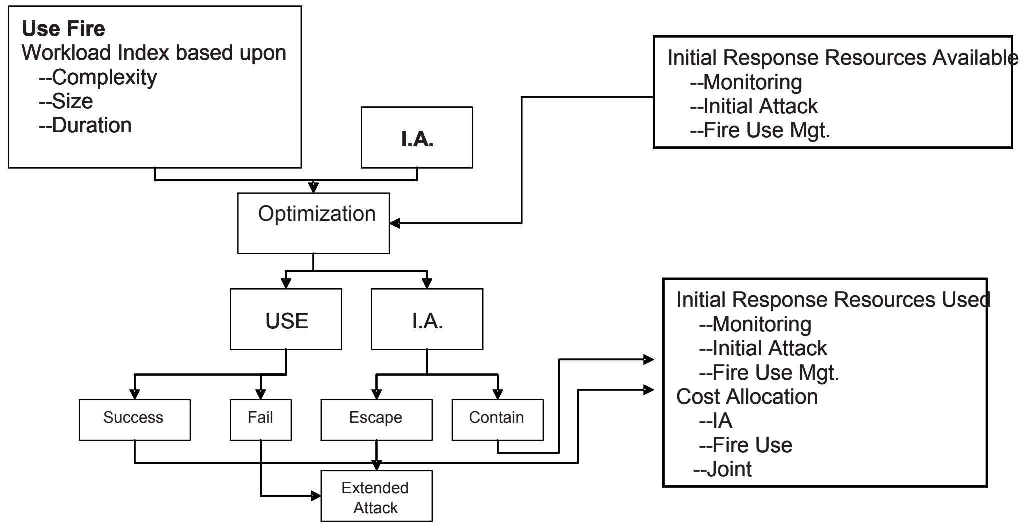

Figure 2—*Fire use integrated into optimization model.*

Think of the use fire as being managed by the following series of steps:

Sorting Fires

A planning unit would sort fires to be modeled for the preparedness planning process into two categories: those that are suitable to accomplish resource objectives and those that threaten values to be protected. Use fires would be fully defined regarding all of their meaningful characteristics including size, duration, complexity, location etc. An important distinction is that use fires have a defined size derived from historic records, whereas initial attack suppression fire size depends upon the vigor of attack. The optimizer will utilize data on these characteristics to model the M&M requirements for fire use fires. The scope of initial response would include only use fires meeting the planning unit level criteria. Fires that would require regional or national resources would be modeled through a different process from the one that would identify local preparedness requirements.

Fire Use Workload

Given the goals and objectives of the unit, historical data are analyzed and ignition estimates for the planning season are generated. Fire planners will sort initial attack suppression fires from fire use fires based on a combination of historical occurrence and planning standards and guidelines. Using this approach, current land and fire management objectives guide the sorting process and not the actual response strategies reflected in the historic data. Thus, the balance between the fire use workload and the initial attack workload is responsive to changing management needs, the current policy [2], and will accommodate plans for expanded fire use, rather than being constrained by the way decisions were made in the past. For example, fire management strategies associated with a geographic zone may change with time. Historic ignitions that were suppressed because they were within a full suppression zone at the time might now be managed as fire use fires because of changing land and fire management objectives within the geographic zone.

Wildland use fires would be sorted again based on their management workloads. How difficult or easy the fire is to manage would depend, in part, upon its complexity, size and duration. For example, more complex fires would generate higher workloads. This second sort would separate fires whose complexity, size, and duration could be managed by local resources from those that would require regional or national resources. Those that could be managed with local resources would then compete with initial attack fires for the preparedness budget.

The data and process for generating a fire workload score for M&M could be accomplished by using a multiple regression framework. Analysis of data records could be used to estimate M&M workload scores for each fire and record each fire's complexity score, size, duration and other potentially relevant information. A list of fires could be generated with varying complexities, sizes and durations. This data would be recorded and analyzed according to the following functional form to produce a workload score—one for fire use management and one for fire use monitoring.

$$FireMgtWorkloadScore=\hat{\beta}_{MGT}=\beta_a+\beta_1+Complexity+\beta_2Size+\beta_3Duration+...$$
$$FireMonitoringWorkloadScore=\hat{\alpha}_{MTR}=\alpha_o+\alpha_1Complexity+\alpha_2Size+\alpha_3Duration+...$$

$Beta_o$ and $alpha_o$ suggest that any use fire may require some management or monitoring regardless of its complexity, size and duration. Beta1 and alpha1 one would indicate how much an increase in the complexity value would add to the workload scores. Beta2,3 and alpha2,3 would quantify how much an increase in size (duration) would contribute to the workload scores.5 It is possible that additional elements would need to be evaluated, but the suggestion is to keep the estimation process as simple and effective as is practical and defensible. After each of the alphas and betas are estimated, it is then possible to enter complexity, size and duration data for fires to estimate a M&M score. Establishment of a workload index for each potential use fire is a crucial step for this approach. The workload scoring process suggested here would quantify the decision process that managers have been using to determine how many resources are needed for managing and monitoring fire use fires. Bringing this rule-based decision approach into an optimizer would model more accurately the underlying multi-purpose nature of preparedness resources, rather than assuming that fire use resources are managed separately from initial attack resources

Management and Monitoring Resources

M&M resources would need to be organized for input into the optimizer. For initial attack, each potential firefighting resource carries an attribute that indicates how much it contributes toward cost and fire line production. Fire use would necessitate that these resources also carry a score identifying how effective they are in monitoring or managing use fires. Such a score would reflect how much the resource would contribute to fulfilling the workload associated with the fire. Workload fulfillment scores, one for monitoring and one for management, would be estimated

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[5] Care would be taken to ensure that potential correlations between size and duration were properly managed, for example a combined variable might need to be constructed.

for each fire resource. Some resources might receive zero scores, i.e. an engine that would not be used for monitoring would receive a zero monitoring score.

Combining Fire Workload with Resource Workload Score

Various combinations of resources could be used to fulfill M&M fire workloads. Specifying the resource combination that most efficiently fulfills the fire workload can be addressed through a straightforward constraint set such as:

$$\hat{\beta}_i^{MGT} \leq \sum R_{i,r}^{MGT} \text{ and}$$
$$\hat{\alpha}_i^{MTR} \leq \sum R_{i,r}^{MTR}$$

where "R" denotes the resource management score that is "turned on" if the resource is used. The symbol "i" denotes a particular fire and "r" a particular resource. This will enable the optimization program to "deploy" the most efficient mix of fire management resources to the fire use fire while fulfilling the fire workload (β+α). The optimizer will choose that combination that maximizes effectiveness for a given budget.

This approach will enable the system to take advantage of jointness that is a crucial feature of the cost structure between initial attack and fire use. Many firefighting resources can be used for fire fighting as well as monitoring, holding, and limited suppression actions on fire use fires, while others could be specialized to one or the other. For example, a fire crew may serve as an initial attack resource on some fires and the same crew may be used to hold one side of a use fire occurring at a different time during the fire season, or to monitor the progress of that fire. This formulation prevents the system from effectively building two entirely separate sets of resources: one for initial attack and another for fire use. A corollary is that the fixed cost of having a resource on site is effectively To optimize the deployment of resources, the optimizer can weigh the relative importance of treating different acres through initial response. Acres that achieved resource benefits by being burned by fire use fires would be assigned a weight to indicate the relative importance by treating these acres through fire use. The number of acres burned times the weight would provide the weighted acres improved (WAI). WAI would represent the performance measure, or effectiveness of each wildland use fire. Acres protected by suppressing unwanted wildfires also would be assigned a weight. The number of acres burned by suppressed wildfires would be subtracted from the total acres that would burn without suppression to determine the acres protected. The acres protected times the weight of each acre would be the Weighted Acres Protected. The total weighted acres protected plus the total weighted acres improved would provide an integrated measure of weighted acres managed by these elements of the initial attack program. This is shown below in the integrated objective function.

Workload Contribution Scores

While scoring individual resources for their workload contribution may seem abstract, this overall approach would likely be required of any viable system that related fire use staffing and equipment needs to thresholds of workload and program complexity outside an optimizer. This is the rule-based system referred to under Fire Use Workload above. This scoring process requires a clear quantification and insertion at the point in the process where the information can be used to its greatest advantage. Also note that scoring resources for fire use management is analogous to the scoring of resource productivity for initial attack: in initial attack the score is line productivity making the analogy direct.

Weighted Acres

To optimize the deployment of resources, the optimizer can weigh the relative importance of treating different acres through initial response. Acres that achieved resource benefits by being burned by fire use fires would be assigned a weight to indicate the relative importance by treating these acres through fire use. The number of acres burned times the weight would provide the weighted acres improved (WAI). WAI would represent the performance measure, or effectiveness of each wildland use fire. Acres protected by suppressing unwanted wildfires also would be assigned a weight. The number of acres burned by suppressed wildfires would be subtracted from the total acres that would burn without suppression to determine the acres protected. The acres protected times the weight of each acre would be the Weighted Acres Protected. The total weighted acres protected plus the total weighted acres improved would provide an integrated measure of weighted acres managed by these elements of the initial attack program. This is shown below in the integrated objective function.

Organizing Information for Processing

The concepts and suggested processes require careful organization before submitting to the optimizer. First, we recognize that the cost of fire fighting and managing resources depends upon their employment in fire use and in initial attack. This can be expressed as:

Cost of Resource (r) = Variable (IA) Cost + Variable (UF) Cost + Fixed Cost

Many resources would be available for use in initial attack and for use fires. Others might only be used for one. This is specified by the input data associated with the resource as supplied by the user. A more specific cost (focusing on fire use) can be expressed as:

$C(r) = \Sigma Di*\text{Unit Cost} + \text{IA Cost} + \text{Fixed Cost}$

Because use fires are of a defined duration, the approach in the above equation is to multiply a cost per unit time by the duration (D) that the resource would be deployed. These cost concepts can be organized as reflected in Table 1:

The first section of Table 1 (rows 4-6) shows the information that would be entered for each potential use fire. Cells E6 and G6 are optional. The binary variable f appears in the objective function below (Fig. 3) to indicate selection of the wildland fire use project (1), or (0) that the scarce budget is better allocated elsewhere. Fire use effectiveness is evaluated as an input to the process and would be the product of the fire size (F6) and the weight (H6). The second section (rows 9-16) shows entries for a particular use fire. The resource column would list the set of individual management and monitoring resources that would be available to deploy to the fire. Each of these would be associated with a monitoring and management score that would be used to evaluate its potential for satisfying the fire workload scores (C6 and D6). Enough resources (B11-B16) would have to be deployed to the use fire to satisfy these scores.

In this suggested approach, there are three options for each preparedness dollar:

- allocate funds to initial attack,

- allocate funds to fire use (M&M),
- a joint allocation (fixed costs),

Table 1—*Fire use resource input data.*

	A	B	C	D	E	F	G	H	I	J
1	**Data suggestions for integrated optimizer.**									
2										
3	**Use fire data**									
4				Workload Scores						
5	Variable	Success/Failure	Mgt	Mtr.	Complexity	Size	Duration	Weight	Effectiveness (F6*H6)	
6	f =	0/1	β	α	#	#	#	#	#	
7										
8	**For a specific use fire:**									
9			Scores			Variable UF cost				
10		Resource	MGT	Mtr	Unit Cost	Unit Cost * Duration	$R_{i,t}$			
11		1	#	#	#	#	0/1			
12		2	#	#	#	#	0/1			
13		3	#	#	#	#	0/1			
14		4	#	#	#	#	0/1			
15		5	#	#	#	#	0/1			
16		6	#	#	#	#	0/1			
17										
18										
19	Some of resources 1-n must be chosen to satisfy workload constraints indicated in cells c6 and d6.									
20	Otherwise the use fire is considered a failure and a suppression costis charged.									

The optimizer will evaluate a potential use fire to designate as accepted or unaccepted successful depending upon its cost and effectiveness relative to the cost and effectiveness of alternative uses of the budget, such as initial attack fires.

Integrated Objective Function

Integrating fire use with initial attack into the same optimizer requires adjustment of the objective function. Whereas the initial attack objective function would use only measures of weighted acres protected, the reformulation Fig. 3. adds a set of terms to reflect the effectiveness added by (weighted) acres improved by fire use. This reformulation will aid with communicating the initial attack/fire use integration process and the approach to initial response. We suggest an objective function[6] like the one in Figure 3.

$$MAX(WAM) = WAM_o \overbrace{\overbrace{-\sum W_{i,t}^{IA} \times A_{i,t}^{IA} \times f_{i,t}^{IA}}^{\text{Weighted Acres Protected}} + \overbrace{\sum W_i^{UF} \times A_i^{UF} \times f_i^{UF}}^{\text{Weighted Acres Improved}}}^{\text{Effectiveness of Initial Response}}$$

Figure 3—Initial response objective function

In Figure 3, weighted acres managed (WAM) from initial response are maximized and they are comprised of two parts: weighted acres protected through

[6] There is no t subscript on use fires because, unlike initial attack fires, their duration is an input.

initial attack and weighted acres improved through fire use. Acres protected are as before where each acre that burns from an unwanted fire is multiplied by a weight to indicate the relative value of protecting it. The subscript (i) denotes a particular fire and the subscript (t) denotes the fire duration. Weighted acres that would burn with no management are indicated by WAMo and this value need only be large -- it is not required to be accurate or precise. Weighted acres protected are defined as WAMo minus weighted acres burned. For example, if our FPU has 1,000 weighted acres to manage (WAMo) and 200 weighted acres burn, then we have protected 800 weighted acres. The greater the number of acres that burn, the lower the value of our objective function.

Weighted acres improved through fire use are arrived at by multiplying each acre improved by its weight. If, through fire use, we improve 500 weighted acres, then we would improve the value of the objective function by 500 WAM.

To include both protection and improvement, assume that the weighted acres burned (200) was arrived at by multiplying 50 acres by a weight of four and that the 500 acres improved were arrived at by multiplying 250 acres by two. Computation of WAM would include 800 weighted acres protected and 500 weighted acres improved as follows:

$$\text{WAM} = 1{,}000 - 4*50 + 2*250 = 1{,}300$$

Note that in both applications the weights on acres are positive. We expect that managers will better relate to positive weighting for both applications. The meaning of the weights remains unaffected. For example, a weight of two in protection means that it is twice as valuable to protect as an acre with a weight of one. Similarly an acre improved with a weight of six is twice as valuable to improve as an acre with a weight of three. Finally, it is three times more valuable to improve the acre weighted six than it is to protect the acre weighted two. There is only one rule regarding weighting. That is, all weights must represent proportionate valuation or importance.

Enriching the Output

There are many ways in which including fire use as part of an integrated initial response process will greatly enrich the output available to managers at the unit level and to program managers. Some examples include showing how resources can be organized to address the integrated management of use fires and initial attack fires over the season, showing which fires would produce the greatest return in effectiveness from scarce budgets and at different budget levels. To demonstrate how these kinds of enhancements could aid with decision making, consider the following example that shows how the integrated response funding can be identified by fire use vs. initial attack component.

The example is purposefully simple for illustrative purposes. Suppose our integrated program is funded at a hypothetical level of $860,000 that is to be divided between initial attack and fire use program components as organized in Table 2.

Table 2—*Program component formation from allocation of the preparedness budget.*

	A	B	C	D	E
1		**Cost**			
2	**Resource**	**I.A. Variable**	**U.F. Variable**	**Fixed**	**Deployed to:**
3	Engine #1	100,000	120,000	75,000	I.A.
4	Engine #2	150,000	300,000	75,000	I.A. & UF
5	Crew #1	75,000	50,000	30,000	UF
6	Monitors	0	50,000	30,000	UF
7					
8	**Program**	**Program Cost**			
9	I.A.	325,000	=B3+D3+B4		
10	U.F.	460,000	=C4+C5+D5+C6+D6		
11	Joint between I.A and U.F.	75,000	=D4		
12	Total	860,000			

In Table 2, there is only one initial attack fire, one fire use fire, and no unmanaged events. Four resources were made available to the optimizer for potential use in both fires. Suppose that the optimizer chose to send Engine #1 only to the initial attack fire, Engine #2 to both fires, Crew # 1 only to the use fire, and Monitors only to the use fire. Crew # 1 and Engine #2 would represent management resources to be used for holding actions along the fire use perimeter, and Monitors would represent monitoring resources to assess the daily progress of the use fire. The total preparedness budget of $860,000 (B12) would be allocated among the fire program components as in cells B9-B11. The initial attack program component would be the variable costs of the resources sent to initial attack fires (B3+B4) plus the fixed cost of Engine #1 (D3) because it was only sent to the initial attack fire. The allocation to the fire use program component (B10) would be arrived at similarly. Engine #2 was sent to both fires and has a fixed cost of $75,000 which is a cost that is jointly held between the programs and cannot be meaningfully allocated between them.

Unsuccessful use fires are fires that the optimizer did not have enough funds to manage as use fires, or found better uses of funds in initial attack. The optimization routine works with a limited budget and not all wanted initial responses may be afforded with a fixed budget. Fires that are not managed as use-fires within the initial response optimizer are managed under extended response. Extended response refers to management actions taken by non-local resources. This could occur because either the initial sort of use fires by size, duration and complexity indicated that fires could not be managed by local resources, or because the optimizer found a more cost-effective use of available resources than deploying them on these fires.

CONCLUSION

Integrating wildland fire use with initial attack in preparedness planning furthers interagency efforts to form an integrated initial response planning system. This provides a major step towards implementing the new interagency wildland fire policy where planners are encouraged to consider the full range of potential responses to each natural ignition, depending on the threats or benefits it presents to protection of life and property and resource values. The process outlined here provides a straightforward approach for integration. The fact that most of the firefighting resources that would be deployed in initial attack would also be the resources employed for wildland fire use means that modeling these as separate programs is problematic. Many fire management resources are associated with significant fixed and procurement costs that cannot be allocated between separate programs. Integration to achieve an initial response preparedness program enables a more informed process for evaluating the purchase, location, and deployment of various firefighting resources that is not possible under separate programs.

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