

Concepts for Future Large Fire Modeling¹

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Abstract: A small number of fires escape initial attack suppression efforts and become large, but their effects are significant and disproportionate. In 1983, of 200,000 wildland fires in the United States, only 4,000 exceeded 100 acres. However, these escaped fires accounted for roughly 95 percent of wildfire-related costs and damages (Pyne, 1984). Thus, future research efforts logically will focus on the difficult and complicated task of modeling large fires.

Large fires often demonstrate higher fireline intensities, different modes of propagation and different distribution patterns through time than do steady-state fires. It is essential, although difficult, to simulate, model, and predict large fire management considerations. In the future, wildland fire modeling efforts are likely to focus on the concepts and peculiarities that large fires present in terms of behavior, suppression and control attributes. This paper reviews the problems that large fires pose to fire analysts.

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CONSIDERATIONS FOR MODELING LARGE FIRES

No known computer model is currently available that can reliably simulate the behavior of large fires. The reasons are several:

1. Heterogeneous conditions of weather, fuel, and topography are encountered during a large fire because of the lengthy burning times and the large size that the fire finally attains. Hence, every model's inherent assumptions of fuel and weather continuity and uniformity are violated by large fires.
2. Large fires spread by means other than a flaming front through surface fuels. Crowning and spotting are different modes of propagation that often occur during a conflagration.
3. Fire-related phenomena--such as firewhirls, horizontal roll vortices, and convection columns--not common during small fires, often are present during large fires. Those phenomena magnify the spread and heat output rates and make the suppression efforts more difficult.
4. Large fires often demonstrate sudden, exponential increases in fireline intensity ("blow-up" phenomenon) accompanied by violent convection, which is sufficient to preclude direct control or to upset existing suppression plans. Fires seem most likely to blow up when high loads of heavy and dry fuels, unstable atmosphere, and windspeeds greater than 20 miles per hour exist simultaneously (Byram, 1959).

5. Large fires burning over extended periods of time, under the influence of wind and topography, assume irregular shapes that do not follow the typical elliptical fire shape that most models assume.

6. Large fire suppression includes various methods of fire control, other than fire containment through fireline construction. Common containment models, used in fire simulation, cannot realistically represent complicated fire suppression tactics.

7. It is difficult to plan a potential large fire suppression organization since the use of shared resources makes the availability of firefighting forces unpredictable.

8. Fire suppression strategies differ among fire control officials, and they are almost impossible to generalize and to model.

9. Large fires are stochastic events with changing occurrence probabilities over time, and therefore, historical data for large fire distributions would give a wide variation in predicted fire sizes and behaviors.

Traditional fire simulation approaches and fire gaming procedures are the two methods applied to large fire modeling in the past.

Mathematical Simulation

Traditional mathematical fire simulation procedures are used in National Fire Management Analysis System (NFMAS). NFMAS assumes that fires over the escape threshold grow to sizes consistent with historical large fire distributions. Also, fires that exceed the defined maximum size (1,000 acres), or time limit (8 hours), or the capabilities of the suppression forces supplied by the user, are identified as escaped.

Acreage for each fire identified as an escape by the initial attack module is automatically assigned within the program from a user-established "escaped fire table" based on the program-calculated annual frequency of each escape event. The size is based on the assumption that, for a given area, the historical escaped fire size/annual frequency relationship can be used reasonably to represent the average fire size for escaped fire events of a similar frequency in the analysis. Professional judgement is required to establish

the fire size classes and to determine whether a particular size class is appropriate for a given fire management zone.

The NFMAS procedures for escaped fires have two disadvantages: (1) They rely heavily on the user. The user decides the number of escaped fire size classes and the expected annual frequency of each size class, and (2) Large fires are stochastic and not periodic events and therefore their annual frequencies cannot be predicted from their historical distribution.

Rothermel's (1972) mathematical model predicts the rate of spread, reaction intensity and flame length of surface fires burning in a steady-state condition, in a homogeneous, continuous fuel bed contiguous to the ground. Fire suppression models measure suppression effectiveness as a fireline construction rate. When the total fireline construction rate exceeds the fire's rate of perimeter increase, and the time limits are not exceeded, the fire is considered contained. In the initial attack analysis (IAA) program, the probability of violating this assumption increases with the size of the fire.

Fire Gaming

On the other hand, fire gaming procedures depend on consultation with fire experts to simulate fire suppression effectiveness and fire behavior. Schultz (1966) used the fire gaming technique to study the decisionmaking processes of fire bosses. Fire gaming has the advantage over the use of historical data in that it may be possible to categorize an expert's opinion and decision criteria, thus gaining insight into the problem being analyzed. However, fire games are essentially nothing more than educated guesses in which it is difficult to separate true understanding from personal bias. Additionally, it has been almost impossible to convert expert opinions to computer programming, although Fire Economic Evaluation System (FEES) and Fire Operational Characteristics Using Simulation (FOCUS) are two programs that use the gaming process in order to deal with large fire outcomes based on statistical fire size data (Mills and Bratten 1982).

Certain questions regarding expected fire behavior and possible suppression methods require fast and correct answers for successful and cost-efficient large fire control: How fast will the fire spread? By what means? What will

be its final size? Also, how will we attack the fire? At what cost? What is the best combination of fire suppression techniques? By what criteria will we decide on the best of alternative solutions in an escaped fire situation analysis?

Depending on their behavior characteristics, fires can be classified into conflagrations and mass fires (Pyne 1984). Both categories demonstrate high energy output rates resulting from high spread rates in the case of conflagrations and from large areas of combustion in the case of mass fires. Mass fires remain stationary with well formed convection columns, while conflagrations move fast, forming a well defined front. During a large fire, the means of propagation change dramatically. Spotting, crowning, firewhirls and blow-up are phenomena that have to be modeled and incorporated in large-fire simulation models. To do this, more fundamental work in the field of fire physics is needed to understand, explain, and adequately simulate these extreme fire behavior phenomena.

The use of stochastic procedures that would yield probabilistic estimates of large fire frequency and size versus the point estimates of deterministic mathematical models appears to be one realistic means for large fire prediction. Large fires are not periodic events and, therefore, their distribution patterns through time cannot be predicted from existing fire data. Fire history and statistical analysis, although more simple to analyze and model, do not seem to be useful in predicting large fire frequency.

The least-cost-plus-loss theory in fire economics is not sufficient for large fires since there is lack of correlation between presuppression expenditures and area burned when the fire load exceeds the maximum capabilities for which the fire suppression organization was designed (Mills and Bratten 1982).

The selection of proper decision criteria is often a serious problem that arises during analysis of an escaped fire situation. Cost-efficiency cannot always be the most important criterion for the selection of the best alternative in all cases. On the other hand, a consistent decision procedure is needed for the selection of the appropriate large fire suppression alternative.

The incorporation of the escaped fire situation analysis in the computerized programs of a fire management system and the use of linear programming for the best allocation of suppression forces seem to be appropriate. Computerized models will be able to conduct the escaped fire situation analysis fast and effectively, coming up with the best alternative based on multiple decisionmaking criteria.

RECOMMENDATIONS

The following suggestions are offered for large-fire modeling efforts:

1. The use of stochastic simulation models seems to be the most appropriate for large fire modeling. Stochastic models are preferred because they give probabilistic estimates of large fire frequency and size versus the point estimates that a deterministic model would yield. This suggestion is based on the fact that large fires are not periodic events and seem to follow a frequency-intensity distribution rather than a time distribution. Also, since the physics and interactions of extreme fire behavior are very complicated, and presently unknown, a simulation model would be more preferable over a mathematical model based on the fundamental laws of physics. Since large fire behavior is erratic and difficult to measure, the creation of an empirical model does not seem feasible. On the other hand, a simulation model, which attempt to simulates the real world situation, even though simplistically, makes the analysis relatively understandable.

2. More research in the field of fire physics is necessary to understand and explain the means of fire propagation during extreme fire behavior. Dimensional analysis offers one powerful means of predicting extreme fire behavior. In such situations, where we know many of the physical variables involved but not the mathematical relations among them, combining several variables into a few dimensionless groups will enable us to model fire behavior under a wide range of conditions.

3. Fire effects models are necessary for the appraisal and prediction of fire-related damages. Fast and effective decisionmaking during escaped fires will be possible with the computerization of the procedures of an escaped fire situation analysis.

4. The application of linear programming for the optimal use and allocation of suppression forces should be considered.

5. A revision of the present fire economics least-cost-plus-loss theory would be helpful for money allocation during presuppression fire planning, and other means must be available for analysis of large fires.

CONCLUSIONS

Fire management decisions will increasingly rely on computerized fire simulation models. Thus, large-fire modeling is an area of fire science that requires special and increased attention.

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