

# Frameworks for Representing Large-Fire Decision Processes and Outcomes<sup>1</sup>

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## Abstract

Although the vast majority of wildland fires are suppressed effectively in initial or extended attack, on relatively rare occasions fires become exceptionally large, resulting in unusual resource damages, significant financial impacts and/or loss of life. Understanding how to better manage large fires and to improve methods for controlling their costs and impacts requires a detailed knowledge of the decision making processes that were ongoing at the time of the incident. Fire reviews undertaken *post hoc* tend to focus predominantly on incident characteristics and not on the broader decision making context within which incident management occurs. The research described in this paper uses analytical approaches from the decision and risk sciences to develop a model for decomposing and reconstructing large-fire decision processes, including influence diagrams, decision tree analysis, multi-attribute utility analysis (MAU), and other models based on decision process tracing methodologies. A preliminary model for incident decomposition and reconstruction is developed based on the concept of an “Event-Frame Model” by which a sequential set of “Event Frames” are defined by temporal and contextual factors, and that lead to a visual representation of an incident decomposition. The set of event frames decomposes an incident into discrete units of analysis that can incorporate other models or processes (e.g., decision analysis) to describe decision elements of a fire incident. The paper describes progress to date on the modeling approach, including efforts to apply the model in the context of an actual incident.

## Introduction

Each year, thousands of fires occur on public lands. The vast majority of these fires are effectively suppressed in initial attack at a relatively small size, usually an acre or two, or less. Of fires that exceed initial attack, most are suppressed in extended attack and rarely exceed 100 acres or more. However, for a small proportion of all fires, generally less than 1 percent, unusual environmental, fuel or resource capability conditions can result in particularly large or uncharacteristic fires that have as outcomes high monetary costs, loss of high-valued public or private resources, and (in the extreme case) loss of human life. Though large fires are relatively rare, they tend to lead to a high level of post-incident analysis to determine (a) the possible causes and attributions of the catastrophic outcomes, and (b) actions or steps that can be taken to help prevent or mitigate similar occurrences in the future. An accounting

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of the incident is required in terms of decisions and decision factors that influenced the outcome.

This paper reports on the development of a process for analyzing fire incidents to help improve fire management practices. The focus of the research is to develop a method for analyzing fire incidents in terms of decision-making principles and to use the language of decision and risk analysis as basis for representing the relationship between fire management decision making and incident outcomes. The essential spirit of the approach is embodied in one of the central concepts from decision analysis, that of decomposition. The essence of decomposition is that large, complex problems can be understood better by breaking them down or “decomposing” them into smaller, more tractable problems that can be solved or characterized in some detail. The individual components of the decomposition are then reconstructed or assembled into a whole. Decomposition is the fundamental principle on which decision and risk analysis are based (Frohwein and Lambert 2000; Haimes 1998; Keeney and Raiffa 1976; Raiffa 1968), and has been applied in numerous other contexts including judgmental forecasting (e.g., Armstrong 2001; MacGregor 2001).

## **Social and Organizational Influences on Decision Outcomes**

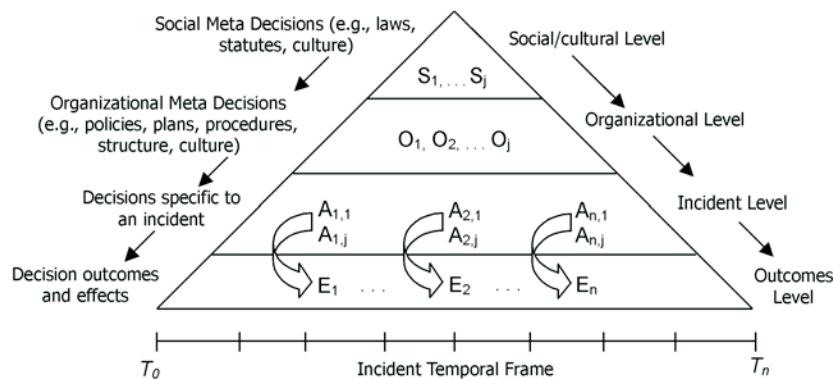
The process of analyzing fire incidents based on their outcomes is generally one of working backwards or upstream to determine the proximal causes of the outcomes. Most generally this is done in terms of one of three general categories of causal factors: environmental conditions (e.g., weather, fire behavior, fuels), technological conditions (e.g., equipment failure), or human error. As relatively clear causal influences emerge, the analysis becomes bounded and the pattern of causation becomes fixed. This approach contains key assumptions about the relationship between incident factors and incident outcomes. First, it assumes that the diagnostic or causative weight of an incident factor is greater the closer it is in time and space to the outcome. Second, it assumes that a “bottom up” approach will capture the majority of influences that are present in an incident management situation and that account for incident outcomes. Third, it assumes that the links between incident factors and incident outcomes is deterministic or strictly causal, rather than probabilistic.

The root influences on incident decisions and decision outcomes can come from factors far removed in space and time from the incident itself. As has been shown in other contexts, such as technological failure, accidents and events that result in monetary and material losses (including loss of human life) may evolve from “normal” operations, and the antecedents of decision outcomes can only be understood by resort to factors that are part of the social and organizational context within which events occur (Perrow 1984). As an example, Paté-Cornell (1993; Paté-Cornell 1990) used a combination of influence diagramming and decision analysis to model the failure of an offshore drilling platform (*Piper Alpha*) in the North Sea oil field. She found that the original failure analysis of the drilling platform accident was heavily driven by technical and engineering factors, which tended to focus the inquiry in such a way as to produce technical solutions to the problem. However, a more careful and extended analysis of the roots of engineering failure identified a number of organizational decisions that influenced failure probabilities in ways that were not readily identifiable by examining details of the incident alone. As a result

of the analysis a general model was developed that decomposed incident outcomes into a combination of social, organizational, and incident-specific factors.

## Toward a General Model for Incident Decomposition

Decomposing a fire incident requires a guiding structure that identifies the factors influencing incident decisions and outcomes. A framework for this decomposition represents incident decisions and outcomes as the result of factors specific to an incident as well as factors and influences present at higher organizational and social contextual levels (fig. 1). The framework is comprised of multiple levels of influence beginning at a broad social level that includes laws, statutes and cultural values ( $S_i$ 's in the model). These general influences are exterior to the organization but influence organizational meta decisions ( $O_i$ 's in the model) that include policies, plans and procedures that set an organizational contextual frame for how decisions specific to an incident are structured and evaluated. These incident-specific decisions are shown in the model as a set of alternatives ( $A_{i,j}$ 's) associated with decision problems that are linked to a temporal dimension associated with the incident. In the course of a given incident, a number of such decision situations arise and can be given a temporal location. Likewise, decision outcomes and effects ( $E_i$ 's) resulting from incident decisions can be given a temporal location as well. In an actual incident analysis, decision outcomes and effects are linked to subsequent decisions.



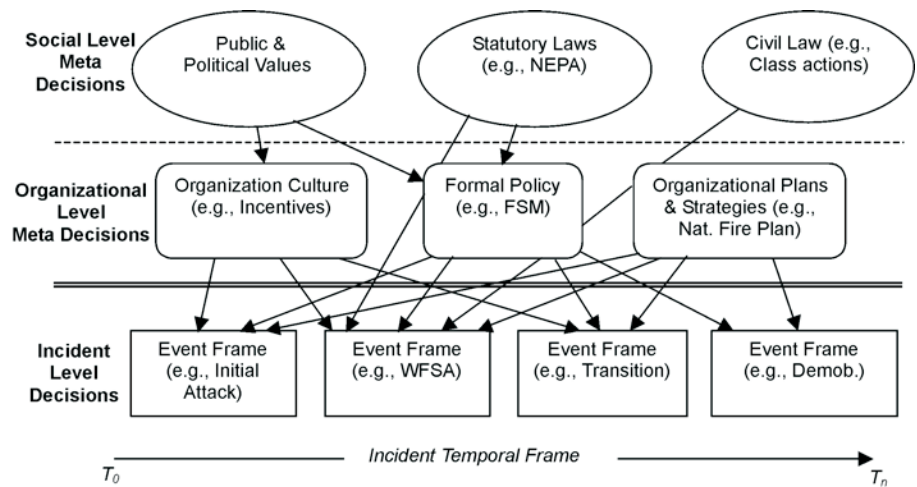
**Figure 1** – General model of incident decomposition. Adapted from Pate-Cornell (1993)

### An Influence Diagram Representation

The essential elements of the model can be represented as an influence diagram depicting the relationship between components at each of the levels. Influence diagrams are a form of visual representation that depicts relationships between components of a decision problem (e.g. Oliver and Smith 1990). Arrows between components denote an *influence*, where an influence expresses knowledge about relevance. A causal relationship is not necessarily implied, but an influence exerts a force such that knowing more about A directly affects our belief or expectation about B.

For an actual case, an influence diagram would be complex and would show not only the relationships between levels, but also the relationships between concepts at each level as well as the relationship between incident outcomes and the societal and

organizational levels. A relatively simple model serves to illustrate how the relationships might be portrayed in terms of influences using some general elements at each level (*fig 2*). Starting at the bottom of the model is a sequence of major incident events starting at time  $T_0$  and continuing through to the end of the incident at time  $T_n$ , where  $n$  can vary through a range of days, weeks or even months depending on the length of the incident. At the top level of the representation is the Societal Level, comprised of three components: Political/Public Values, Statutory Law, and Civil Law. In the middle is the Organizational Level, represented by three components: Organizational Culture, Formal Policy, and Plans & Strategies.



**Figure 2** – Influence diagram representation of a simplified fire incident.

### **Social Meta Decisions**

These are decisions made at a broad social level and reflect general cultural views and values. The decisions themselves are embodied in laws and statutes that govern and guide what organizations can do. Cultural values relevant to these laws can range from the general to the specific with respect to fire and its management. For example, broad sociopolitical values about the appropriate role of government in regulating organizations and the lives of individuals captures, perhaps, the broadest sense of this concept. More specific to fire and its management, social values about the environment, environmental protection, the role of fire in ecosystems and the like also impact social meta-decisions. As an example, the various federal statutes and laws that provide for protection of environmental amenities (e.g., threatened & endangered species, air quality, water quality) are the result of a combination of scientific and political processes that operate at the highest levels in society and that reflect a determination that overarching goals and objectives (many of them protective) be met as part of any actions that impact the environment (e.g., NEPA).

These influences can be thought of as upstream factors that exert their effects in a number of ways. They may take the form of specific standards and guides that organizations are required by law to abide by as part of their operations. Air quality standards, for example, fall into this category as do water quality, species protection laws and occupational safety standards. In some cases, these standards and guides

will be directly passed through to the organizational level, and in other cases they may be interpreted and incorporated into an organization's culture. Also, they may have an impact by sociopolitical pressures they exert on organizational decision making. For example, an imperative to reduce large-fire costs may be reflective of a relatively non-specific sociopolitical goal of cost reduction but without a specific rule or guide to identify either the means to use to achieve cost reduction or the specific cost-reduction end to achieve.

Another category of influence at the social level results from broad public views about factors relating to fire management decision making. Public attitudes about fire and fire management, including activities that have an impact on fire management such as the use of prescribed fire for fuels management, can exert powerful effects on how organizations frame decision problems and set priorities for fire management actions. For example, the *precautionary principle* as applied to risk management decision making is generally reflective of a broad public attitude that favors a conservative interpretation of risk and that corresponds to a generally risk-averse public attitude with respect to outcomes that are perceived as severe or catastrophic (e.g., Graham 2001; MacGregor, Slovic and Malmfors 1999; Sandin 1999; Slovic, 2000). In essence, the precautionary principle is a "better safe than sorry" view that prescribes protective action even when no harm is certain to occur. One consequence of this principle is a conservative interpretation of science by organizations charged with risk management: in the absence of science confirming the presence of harm, protective action should be taken until such time as science confirms the opposite.

### **Organizational Meta Decisions**

Decisions at this level are reflected in a number of influences. Three general categories include Formal Policies of the organization, Organizational Culture, and Organizational Plans and Strategies (*fig. 2*). Organizational culture is comprised of many components not shown here, such as the history of the organization and its organizational values, as well as the incentive structure (both explicit and implicit) that exists within the organization and that influences individual preferences and decisions. Formal policies include specific policies and manuals (e.g., Forest Service Manual; Interagency Standards for Fire and Fire Aviation Operations) that provide the general standards and guides that serve as the business framework for day-to-day activities and operations. Included here as well are periodic directives that may highlight, modify, or expand on a particular element of policy. Finally, there is a relatively large body of organizational plans and strategies (e.g., National Fire Plan; Cohesive Strategy) that serve to provide general management direction and strategy.

### **Incident-specific Decisions**

At the incident level are decisions specific to the particular fire management action on the ground, depicted as a series of events, each of which could be further decomposed to reveal underlying decisions specific to the event (*fig. 2*). The term "event" is used in this context to refer to the components of a fire incident that include elements of judgment and decision making. To express events having multidimensional or multi-attribute characteristics, we use the concept of an "Event Frame" (discussed below). For example, an Event Frame containing a WFSA

(Wildland Fire Situation Analysis) can be decomposed into a number of specific WFSA elements, each of which may be influenced by higher-level social and organizational meta-decisions, such as Air Quality Standards (Social Level, Statutory Law), Public Values (Social Level), and Organization Culture.

## Structure of an Incident Analysis

The process of structuring an incident analysis begins by constructing a series of event frames along an incident temporal dimension (*fig. 3*). The initial set of event frames is based on incident documentation. Large-fire incidents are generally documented in part through the Wildland Fire Situation Analysis and other procedural documents (e.g., Delegation of Authority) that provide a convenient and authoritative basis for collecting a set of initializing information, including the fire situation early in the incident, preliminary information about values at risk, strategic alternatives for fire management, and other land management issues that reflect decision priorities.

The general framework takes the form of a set of schematic event frames located along a temporal dimension that ranges from the beginning of an incident (Time =  $T_0$ ) to the end of an incident (Time =  $T_n$ ).  $T_0$  corresponds to the date and time of fire ignition;  $T_n$  corresponds to the date and time the fire is determined to be out. In principle, the number of discrete event frames is unlimited. In practice, however, the number of event frames is determined by the desired granularity of the analysis and by pragmatic factors such as (a) characteristics of the incident, with longer and/or more complex incidents requiring a greater number of event frames, and (b) availability of information.

Each event frame is characterized by a set of event frame elements that include (a) values, goals and objectives, (b) decision alternatives, (c) expected outcomes associated with each alternative, (d) sources of uncertainty, (e) tradeoffs, (f) sources of risk, and (g) costs. Methods for representing these elements include multi-attribute value trees and decision trees. Risks associated with each event tree can be represented in terms of a basic risk assessment model that characterizes risk in terms of (a) events or scenarios that can happen, (b) the likelihood that each would happen, and (c) the consequences associated with their occurrence (e.g., Haimes, 1998; Kaplan and Garrick 1981). Further elaboration on this approach could extend to utilizing the Kaplan and Garrick Theory of Scenario Structuring (TSS) Model (e.g., Kaplan, Haimes and Garrick 2001). In practice, the extent to which more sophisticated methods for analyzing each event frame can be used are dictated somewhat by the value of greater analytic detail and rigor, and by the availability of information.

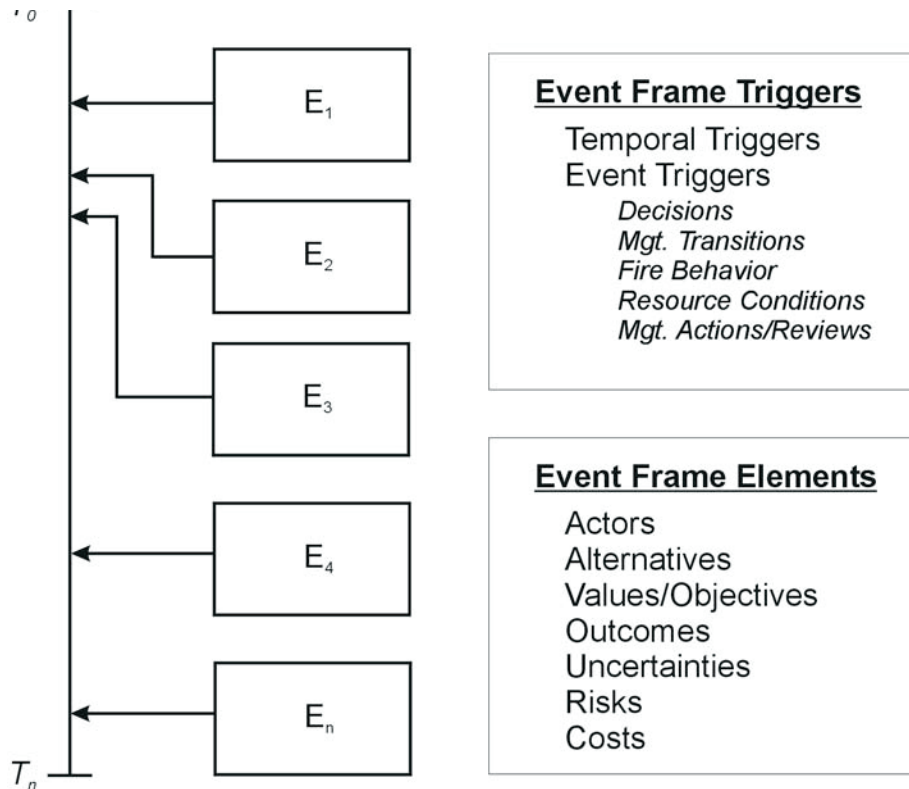


Figure 3 – General structure of the event frame model.

### ***Information Sources: Incident Documentation.***

Primary information for incident analysis comes from documents that are produced during the course of an incident. Incident documentation provides the basis for initial construction of an event frame model. Among the various federal wildland fire agencies in the the United States, typical documentation for large fires includes:

- Fire Situation Analysis (FSA)
- Briefing Documents
- Wildland Fire Situation Analysis (WFSA)
- Incident Complexity Analysis (ICA)
- Delegation of Authority
- Shift Plans
- Transition Plans
- Final Fire Report (e.g., FS 5100-29)

For example the Wildland Fire Situation Analysis (WFSA) is developed early in a fire incident and is continually updated (and in some cases redone) as part of incident management. The WFSA provides primary information about land management objectives and values at risk, strategic alternatives for fire management,

and preliminary estimates of fire suppression costs and monetized losses to the resource base. Monetary cost elements are periodically reviewed and updated, and provide the basis for a set of periodic event frames that directly relate incident costs to values at risk.

Information also comes from periodic plans and documents developed as part of incident management, including shift plans and transition plans. Shift plans can be used to structure a protocol process whereby incident decisions are reconstructed on the basis of (a) tactical alternatives and a chosen alternative, (b) control objectives for the incident, (c) critical resource concerns and values at risk, (d) resource allocations, and organization personnel assignments. Shift plans indicate the chosen tactical direction, but do not indicate other tactical alternatives that may have been considered, nor do they indicate the outcomes that are expected or the basis on which outcomes are evaluated. The decision problem structure that is (partially) implied by the tactical direction in shift plans must be supplemented with interviews to obtain a more complete representation of the structure.

### ***Information Sources: Decision Process Tracing Protocol (DPTP).***

Incident documentation provides an efficient means for identifying key parameters of incident decisions, including how decision problems are structured. Additional information pertaining to how decisions are actually made can only be gained by direct involvement with fire management personnel. To elicit this information requires the development of a Decision Process Tracing Protocol (DPTP) that serves as an interview guide for working with fire management personnel to reconstruct incident decisions. The framework for the DPTP comes from the incident documentation structured according to the event frame model described above. The DPTP provides a means for identifying a number of incident-related factors. These include:

- Influences that act upon incident decision processes;
- Decision problem structuring done by fire management personnel;
- Values at risk or fire management objectives not explicit in incident documentation;
- Individual preferences for risk that influence incident decisions;
- Patterns of information utilization;
- Communication protocols that influence incident decisions.

### ***Case Study: Fork Fire.***

A case study that illustrates the application of the event frame methodology is currently under development. The purpose of the case study is to demonstrate how the decision structure of an incident can be elicited and represented using the model and methods discussed in this paper. The selected case (the *Fork Fire*) is a fire that occurred in the summer of 1996 on the Mendocino National Forest (USDA Forest Service Region 5, California North Zone). The incident began on August 11, 1996, and continued for approximately 18 days, burning a total of 82,980 acres. The case

was chosen because of its size and complexity, as well as the availability of incident documentation and access to fire management personnel who took part in the incident.

A preliminary event model has been constructed based on the Wildland Fire Situation Analyses (WFSAs) conducted during the incident, periodic tactical plans and incident objectives, and the final fire report. The event model is currently being used to develop a protocol for interviewing fire management personnel and to identify additional incident documentation that may be required.

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