

Decision Modeling for Fire Incident Analysis¹

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Abstract

This paper reports on methods for representing and modeling fire incidents based on concepts and models from the decision and risk sciences. A set of modeling techniques are used to characterize key fire management decision processes and provide a basis for incident analysis. The results of these methods can be used to provide insights into the structure of fire management decision making, including key decision drivers and influences. The methods are applied to two fire incidents to illustrate the various phases of fire management decision making. Both applications identify critical decision points that influenced incident outcomes, including (a) the importance of “worst-case” analysis and scenario generation, (b) accessibility and usability of local fire management knowledge, (c) effects of individual differences in IA/EA decision making, and (d) discontinuities in fire management decision processes.

Keywords: Decision modeling, incident analysis, risk analysis.

Introduction

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

The focus of this research is a method for analyzing fire incidents in terms of decision-making principles, using the language of decision and risk analysis as basis for representing the relationship between fire management decision making and incident outcomes. The basic approach is embodied in one of the central concepts from decision analysis, that of decomposition by which large, complex problems can

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be understood better by breaking them down or “decomposing” them into smaller, more tractable problems that can be solved or characterized in some detail.

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 (Armstrong 2001, MacGregor 2001).

Large-fire decision making is a multi-layered phenomenon and has properties of organizational decision making as well as individual decision making. We first develop the general concept of an incident decomposition and identify a tiered layering of social, organizational and incident factors that influence incident-specific decisions and decision outcomes. A set of relevant theories and models relating to dynamic decision making serves as a basis for identifying concepts and principles that have value in explaining or characterizing incident decision. We then apply this theoretical development to the decomposition of an incident in terms of an event-frame model, by which key events relating to the incident are set out in a temporal sequence and represented according to a set of concepts and principles identified in the overview of models. The structure of an incident is populated with two general sources of information: the documentation generated as part of the incident, and a protocol approach for key incident personnel. The overall approach is illustrated in the context of case studies to illustrate how the language and models of decision theory can be transferred and applied to key decisions on actual fire incidents.

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*).

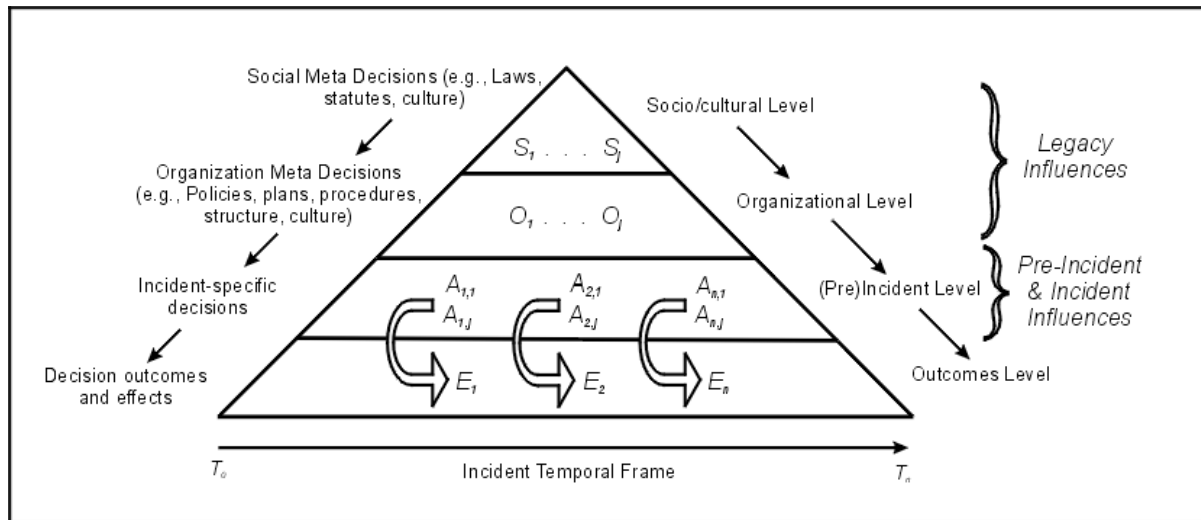


Figure 1 – General model of incident decomposition. Adapted from Paté-Cornell (1993)

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. 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. 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.

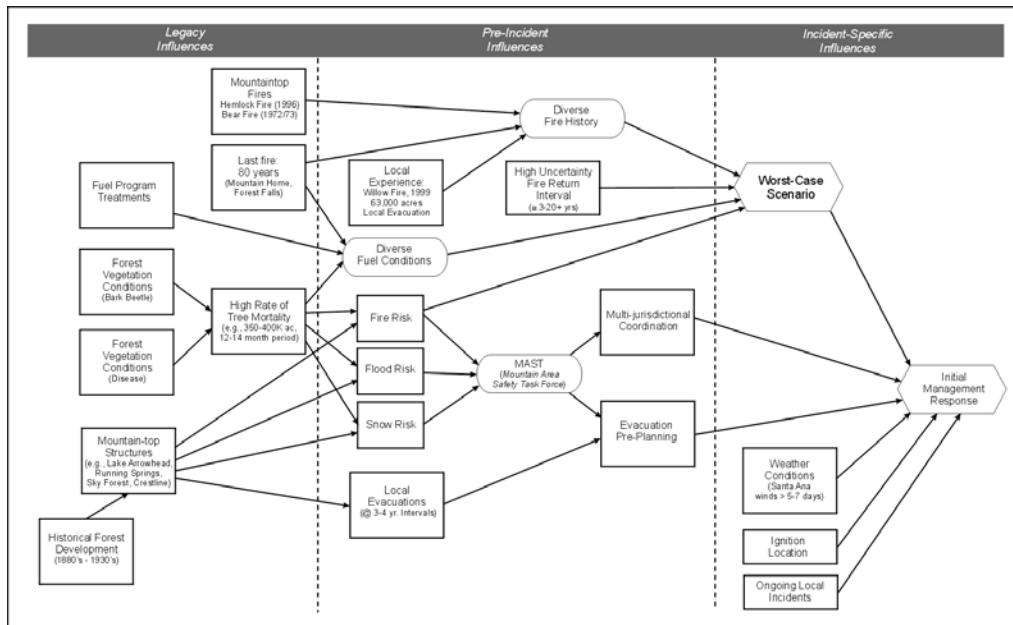


Figure 2 – Influence diagram representation of an initial management response decision based on the Old Fire, San Bernardino National Forest, October, 2003.

Dynamic Decision Making Influences on Decision Outcomes

Cue-based Models

A general model of judgment based on multiple cues is the lens model (Cooksey and Freebody 1985, Cooksey 1996). The lens model draws a distinction between an information environment that is represented by a collection of cues, and the psychological representation of that object in terms of a decision or judgment based on those cues.

The importance of cue-based approaches to decision modeling is their emphasis on discrete information elements in the decision environment and on the recognitional processes that the decision maker uses to select and weight information in forming a decision response. These processes rely heavily on attention resources and on the ability to focus on the most relevant information in dynamically changing environment, as well as reject or filter out irrelevant, redundant or unreliable information. An important aspect of cue-based decision making is the ability of the decision maker to recognize information that is not present in the environment but that should be. Other related theories also conceptualize decision making in terms of the relationship between the decision maker and the decision environment, sometimes accounting for decision performance in terms of critical cues that

stimulate the recognition of decision situations that call for specific behaviors or actions (e.g., Klein and others 1989).

Control Theory Models

A class of decision models that are important in dynamic environments are control theory models (Weiner 1948, Sheridan and Ferrell 1981, Wickens and Hollands 2000). Control theory models conceptualize the human decision maker as an element of a closed-loop system that exercises control through a set of output processes that impact the environment (*fig. 3*). The environmental effects of the output processes are returned to the human decision maker through a negative feedback loop where they are compared with one or more reference points. The results of the comparison yields an error signal that is interpreted by the human decision maker in terms of available control or decision options to effect an environmental change in the appropriate direction.

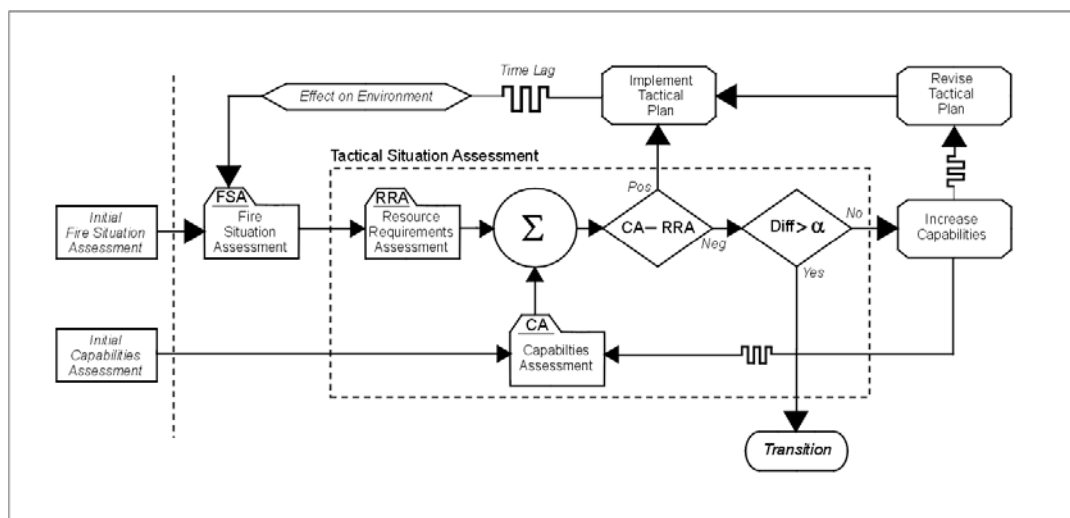


Figure 3 – Control theory representation of IA/EA decision making based on the Fork Fire, Mendocino National Forest, August, 1996.

Reference points are conditions that serve as a gauge by which system effects on the environment are compared. Reference points can be established by a number of means, including directives, policies, elements from training scenarios, cues in the environment (e.g., fire behavior), and affective or emotional conditions of the decision maker.

A second key concept is that of *comparator mechanism* by which the human decision maker evaluates the effect of system outputs under their control in terms of the magnitude and meaning of departures or differences from a reference point. How departures from reference points are evaluated in the comparator process with respect

to *gains versus losses* can have dramatic impacts on decision behavior.

Production Models

An important class of models that relate to control theory are *production models*. Production models represent the human decision maker in the context of a process or product environment that is goal or objective oriented. Fire management organizations can be thought of as acting according to a production model. The various system processes (e.g., procedures, plans, internal communications) result in *products* that are outputs of the production system. These outputs include decisions, actions and communications that are intended to have an effect on the environment within which the system operates (e.g., a fire incident). The impact of the production system on the environment acts as a closed-loop feedback to the input of the system, thereby controlling its actions (Powers, 2005). Essentially, production systems are a form of *cybernetic control system* for which output from the system serves as a basis for the evaluation of how well system processes (e.g., fire management decisions) are meeting the goals and objectives of the system (e.g., perimeter control).

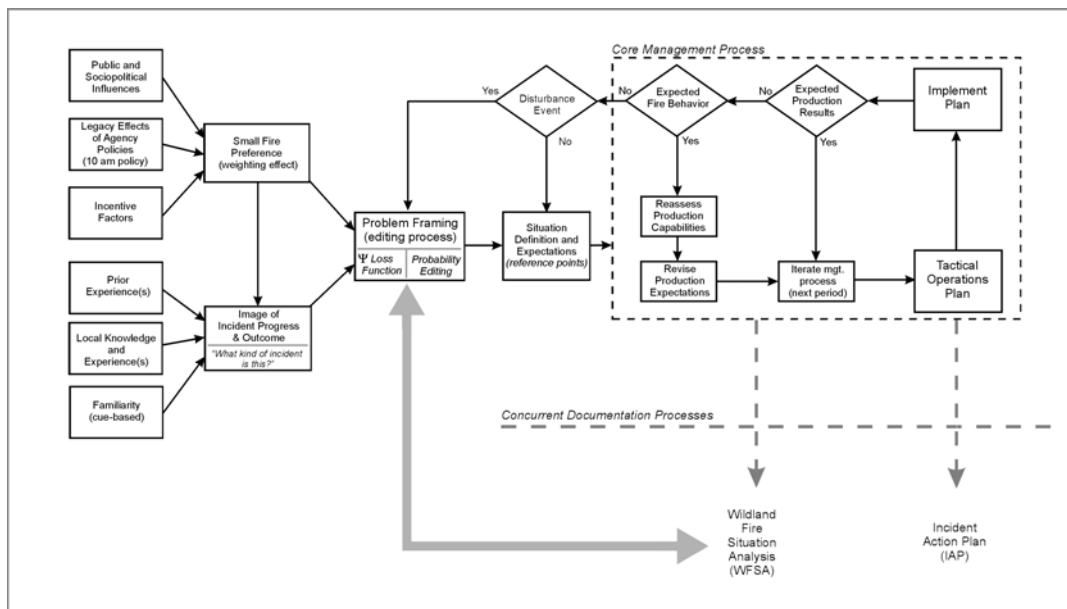


Figure 4 – Production system model of ongoing incident management team operations based on the Fork Fire, Mendocino National Forest, August, 1996.

Summary

The objective of this line of research is to use the concepts, models and language of decision making to characterize the decision processes on large fires. In pursuit of this objective, we have described a range of decision concepts and models and

applied their associated modeling languages to decisions made on two case studies that serve as examples for how we can better represent the basis on which fire management personnel make the decisions that they do.

Decision processes vary according across incidents and according to the events that comprise the incident. As our modeling shows, some incident decisions are actually legacy decisions and the incident itself is an event for which decision making has already occurred but the actions not yet executed. These types of incidents are anticipated incidents—ones for which even extreme occurrences have been envisioned and action contingencies pre-established. Although no large fire can be thought of as a normal occurrence, it is within reason to think of large fires as “normal catastrophes”, to paraphrase Perrow’s description of major technological failures as “normal accidents” (Perrow 1984). Given the precursor combination of forest conditions, weather & climate, and private inholdings, the trigger conditions necessary to produce high impact events may be just a matter of time. And, like technological failures, decision making about their management is part of a larger cycle that involves preparation and analysis well in advance of their occurrence.

Even within ongoing incidents, decision processes can vary considerably depending upon the stage of the incident and upon how management processes are structured and executed. Analysis revealed that local knowledge plays a key role in early management stages as well as in management decision making several days into an incident. We note as well that fundamental and important discontinuities may exist in these different management decision making stages. While fire is a continuous, exponential process that changes seamlessly although abruptly at times, management is a discrete process that changes linearly and in relatively discontinuous stages. This fundamental relationship between fire as a non-linear, continuous process and management as a linear and discontinuous one means that discontinuities in management processes may have the effect of retarding management performance. One definition and operationalization of these concepts may be found in the notion of *decision process discontinuities*. A better understanding how mismatches occur between decision processes at different management stages of fire incidents may help identify how decision processes and fire management training can be improved.

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