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Review

Cohesive fire management within an uncertain environment: A review of risk handling and decision support systems

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ABSTRACT

Wildfire management has been struggling in recent years with escalating devastation, expenditures, and complexity. Given the copious factors involved and the complexity of their interactions, uncertainty in the outcomes is a prominent feature of wildfire management strategies, at both policy and operational levels. Improvements in risk handling and in risk-based decision support tools have therefore a key role in addressing these challenges. In this paper, we review key systems created to support wildfire management decision-making at different levels and scales, and describe their evolution from an initial focus on landscape-level fire growth simulation and burn probability assessment, to the incorporation of exposure and economic loss potential (allowing the translation of ignition likelihood, fire environment – terrain, fuels, and weather – and suppression efficacy into potential fire effects), the integration with forest management and planning, and more recently, to developments in the assessment of values at risk, including real-time assessment. This evolution is linked to a progressive widening of the scope of usage of these systems, from an initial more limited application to risk assessment, to the subsequent inclusion of functionality enabling their utilization in the context of risk management, and more recently, to their explicit casting in the broader societal context of risks and decisions, from a risk governance perspective. This joint evolution can be seen as the result of a simultaneous pull from methodological progresses in risk handling, and push from technological progress in wildfire management decision support tools, as well as more broadly in computational power. We identify the key benefits and challenges in the development and adoption of these systems, as well as future plausible research trends.

Contents

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1. Introduction

Uncertain and highly unpredictable factors, such as weather forecasts, performance of suppression resources, and fire behavior, spread and effects, are the basis of fire management and policy decisions, across multiple levels and scales. Theoretical and computational progress in the last four decades has enabled the development of risk-based Decision Support Systems (DSS) that contribute to improve those decisions, namely by facilitating a structured assessment of the outcomes and costs associated with alternative policies, budgets, and suppression resource mixes.

In recent years, several authors have updated the state of the art on these tools and related challenges. Minas et al. (2012) have updated the review of Martell et al. (1998) on operations research methods applicable to wildfire management. Thompson and Calkin (2011) organize and align sources of uncertainty with decision support tools and methodologies, in order to facilitate cost-effective, risk-based wildfire management and planning efforts. Mavsar et al. (2013) present the economic efficiency analysis theory of fire management measures and use it as a framework to review four fire management DSS in use in America and Europe. Papadopoulos and Pavlidou (2011) make a comparative review of wildfire simulators and Sullivan (2009b) presents a comprehensive survey and review of surface fire spread simulation models. Indeed, some pre-defined spread model is incorporated in most of wildfire simulation models to simulate the behavior of fire across a landscape (Thompson and Calkin, 2011). Bettinger (2010) describes the methods used to integrate wildfires into forest planning models, using operations research techniques, going back to the seminal work of Van Wagner (1979), while more recently Pasalodos-Tato et al. (2013) review the use of decision support tools to address risk and uncertainty in forest management planning.

Our review adopts a higher-level perspective to provide a broader and more complete view of the evolution of the field. We concisely present several important risk-based decision support models for fire management, on the one hand highlighting their usefulness within the scope and the purposes that guided their development, but on the other rendering explicit a number of limitations that they present. Some of these limitations have also been discussed recently, although in a fragmented way, in the literature on challenges in the development and deployment of risk-based decision support systems. We bring together this set of observations, and highlight what seems to us to be an important trend of broadening of concerns from risk assessment, to risk management, to risk governance. This trend frames an increasingly ambitious utilization of these systems, gradually and successively broadened to address each of those areas of concern. This overall evolution pattern is the result of simultaneous methodological progress in risk handling, as well as specific technological progress in wildfire management decision support tools, and generic technological progresses in computation.

The remainder of the paper is structured as follows: in Section 2, we describe several fire growth simulators developed in recent decades in multiple parts of the world, and their connections with different wildfire management DSS based on economic models, as well as developments in the integration of forest and fire management, and more recent efforts aiming at going beyond economic models; in Section 3, we characterize the trend of broadening of risk handling concerns from risk assessment, through risk management, to risk governance, in close connection with the previous section; in Sections 4 and 5 we close the paper, with a discussion and with the presentation of conclusions and suggestions for future work, respectively.

2. From fire growth simulation to economic models and beyond

2.1. Fire growth simulation models

A number of wildfire growth simulation models have been developed over the years (Table 1). Explicit spatial simulation of fire growth requires a fire spread model and the description and mapping of vegetation (fuel) as per the typology required by the spread model. Consequently, spatial fire modeling has been preceded by the ability to estimate fire behavior characteristics for a given point or location from a set of static fuel, weather and slope conditions. Fire spread models usable by fire managers are either semi-physical or empirical in nature. The Rothermel (1972) model is the best known of the former type and is widely used, being at the core of the U.S. fire modeling systems, from the stand – e.g., BEHAVE (Andrews, 1986), now BehavePlus (Andrews, 2014) – to the landscape-level – e.g., FARSITE (Finney, 1993, 2004). Rothermel's model has also been adopted for fire growth simulation elsewhere, e.g., CARDIN (initially based on BEHAVE and later named "Visual Cardin") in Spain (Millan et al., 1991; Martin-Fernández et al., 2002; Rodríguez y Silva and González-Cabán, 2010) and in the module of fire simulation of the KITRAL system in Chile (Julio et al., 1995).

Canadian and Australian fire growth simulators depend on empirical fire spread models and systems (Noble et al., 1980; Forestry Canada, 1992). The Canadian Prometheus has been in development since 1999 (Tymstra et al., 2010). The Australian SiroFire was launched in 1994 (Coleman and Sullivan, 1996) and has now been replaced (Sullivan, 2009b) by PHOENIX Rapidfire (Saeedian et al., 2010; Duff et al., 2012) at the University of Melbourne as a component of a risk management model, being developed by the Bushfire CRC for southern Australia (Tolhurst et al., 2008; Taylor and Freeman, 2010).

Vector-based simulation approaches for fire growth like those based on Huygens principle produce much more realistic fire shapes than raster-based simulations, or cellular automata, among other alternatives (French, 1992; Sullivan, 2009b; Tymstra et al., 2010). Raster-based models deal with heterogeneous fuels and weather better than vector-based models (French et al., 1990). Nevertheless, and although the procedure varies, all the existing North American and Australian fire growth simulators implement Huygens approach (Cechet et al., 2014). Given our focus on systems used by practitioners, there are several other important models