Assessing the Accuracy of Wildland Fire Situation Analysis (WFSA) Fire Size and Suppression Cost Estimates

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ABSTRACT

To determine the optimal suppression strategy for escaped wildfires, federal land managers are required to conduct a wildland fire situation analysis (WFSA). As part of the WFSA process, fire managers estimate final fire size and suppression costs. Estimates from 58 WFSAs conducted during the 2002 fire season are compared to actual outcomes. Results indicate that estimates of fire size and suppression costs are systematically biased. Modifications to the WFSA process are suggested to address these problems.

Keywords: WFSA; wildfire; economics; suppression; probability

Both the average size of wildfires and the cost of fire suppression are increasing in the United States. Indeed, in 2000 and 2002 federal land management agencies spent 1.4 and 1.6 billion dollars, respectively, on wildfire suppression (NIFC 2003a). These record high expenditures are part of an approximately 30-year upward trend in suppression costs. Average wildfire size on federal land has also increased from 21 acres in 1972 to 78 acres in 2002 (NIFC 2003a). This increase in average fire size is significant as although only a small proportion of wildfires become large, those that do are disproportionately costly to suppress. For example, in 2002 less than 2% of wildfires escaped initial attack. Among wildfires that escaped, those that exceeded 300 acres accounted for 95% of total acres burned and 85% of total suppression expenditures (USDA Forest Service 2003). Consequently, considerable attention is being focused on containing large fire costs (NAPA 2002, USDA Forest Service 2003).

The suppression of large, escaped wildfires is undertaken jointly by local land managers and incident command teams. Incident command teams assume responsibility for tactical wildfire suppression decisions, although' local land managers provide overall strategic guidance. To determine the appropriate suppression strategy, land managers are required to carry out a Wildland Fire Situation Analysis (WFSA) when one of the following occurs. First, a wildland fire escapes initial attack or is expected to escape initial attack. Second, a wildland fire being managed for resource benefits exceeds prescription parameters. Third, a prescribed fire exceeds its prescription and is declared a wildland fire (NIFC 2003b). If fire conditions change sufficiently, additional WFSAs may be conducted. Indeed, on large wildfires, fire managers may conduct as many as five or six WFSAs.

The WFSA process is designed to help managers select a suppression strategy. However, the WFSA process is not prescriptive; rather it is a decision analysis tool that requires land managers to evaluate different suppression strategies. A WFSA has three stages (MacGregor 2000). First, criteria for evaluating suppression alternatives are identified, for example, firefighter safety, potential resource damage, and loss of private structures, and for each criteria measurable objectives are established. Second, suppression alternatives are developed. Each alternative must focus on firefighter and public safety, be implementable, have a strategic plan of action, estimate resources required given those available at the time, calculate the probability of success, and estimate time to containment, final fire size, resource damages, and suppression costs. Third, suppression alternatives are analyzed. Managers are directed to consider the compatibility of a suppression strategy with forest plan objectives, safety, probability of success, and then select the alternative that minimizes the sum of resource damages and suppression costs. For example, if a wildfire is threatening resources that are of particular concern, a land manager may recommend that the incoming incident command team use an aggressive suppression strategy.

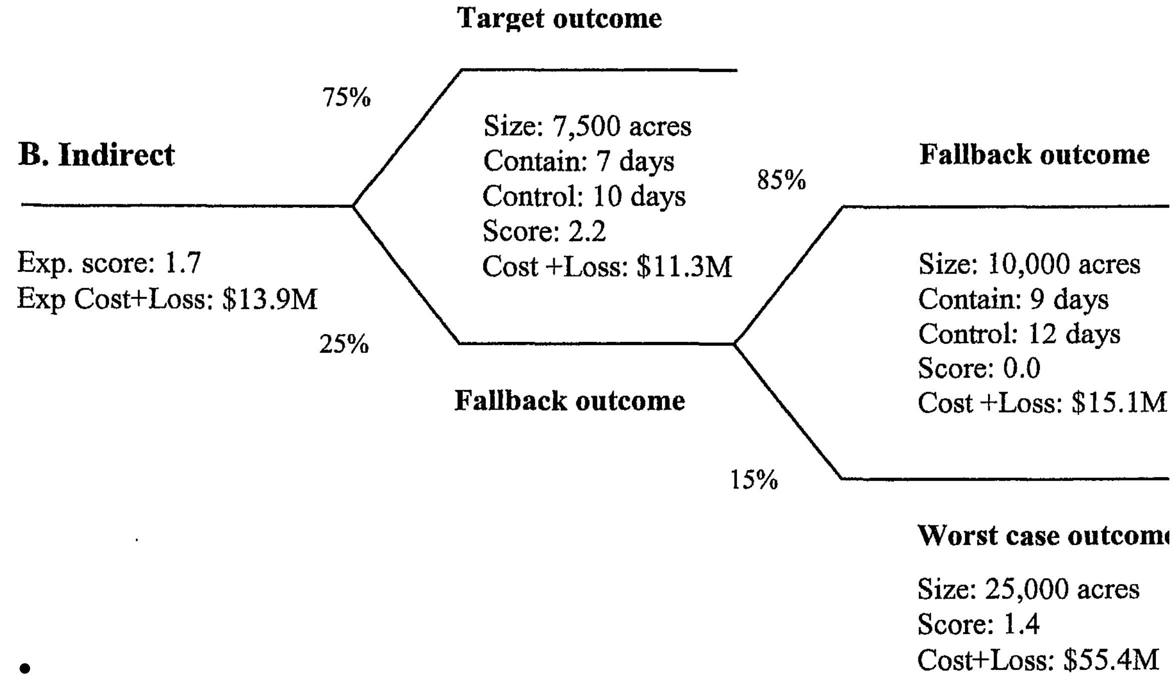

Figure 1. WFSA decision tree, Grizzly complex fire, Lake County, Oregon.

Managers use several variables and probability estimates to assign an overall score to alternative suppression strategies. The alternatives evaluated are typically described by either their objective (minimize fire size, minimize suppression costs, etc.), or by the suppression strategy to be employed (direct attack, indirect attack, etc.). Most WFSAs evaluate two or three different alternatives. For each alternative, users are required to define a target outcome and a worst case outcome and are given the option to define an intermediate fallback outcome. For each of these outcomes, users must estimate the probability of that outcome occurring, associated suppression costs and resource damages, final fire size, and objective score. This objective score indicates how well a particular outcome meets a series of objectives; the default categories are safety, economic, environmental, social, and other, although users may define their own additional categories. For each alternative, an expected objective score is calculated by multiplying the probability of each outcome by its objective score, and summing the resulting three scores. The same procedure is used to calculate the expected value of suppression cost plus resource damage.

Probability estimates are used to calculate expected fire size and expected suppression cost. In turn, expected fire size and expected suppression cost are used to select between different suppression alternatives. Given that suppression strategy is the most important determinant of suppression cost that is under management control, these cost and probability estimates have the potential to significantly influence suppression costs.

A decision tree displays alternative suppression strategies and their associated scores. Figure 1 shows a decision tree used to evaluate an indirect suppression strategy on the Grizzly complex fire, which burned in Lake County, Oregon during July 2002.

Most people have difficulty estimating probabilities (Kahneman and Tversky 1979, Baron 2000). Generally, people tend to overestimate the probability of unlikely events occurring and underestimate the probability of likely events occurring. For example, (Lichtenstein et al. 1978) asked respondents to estimate the number of people who died in the US annually from a number of causes. Respondents tended to overestimate the probability of dying from unlikely causes such as botulism or tornadoes, and underestimate the probability of dying from common causes such as heart disease and cancer.

No studies have examined the accuracy of WFSA probability and cost estimates. There have been two published studies that have addressed other aspects of the WFSA process. (Gonzalez-Caban and MacGregor 1998) questioned WFSA users about their experiences using an earlier version of WFSA. Most respondents found the process to be at least somewhat useful, though many expressed concerns that the analysis was too lengthy, especially as it is typically conducted at a time of high stress. In addition, respondents often felt they had inadequate experience or information to correctly complete a WFSA. The authors conclude that an education and training program would mitigate many of the concerns raised by users.

(MacGregor 2000) reviewed the WFSA process and recommended several improvements. First, more emphasis should be placed on the strategic role of the WFSA process, integrating it with other decision support tools. Second, the role of incident command teams in the WFSA process should be expanded and formalized. Third, WFSA users should be offered more training. Fourth, he notes that despite the importance of the WFSA process there have been no studies that have compared WFSA predictions with actual wildfire outcomes.

Therefore, in this paper we compare estimates of suppression costs, fire size, and probability of success from WFSAs prepared during the 2002 fire season to actual outcomes. Systematic differences between WFSA estimates and actual outcomes might significantly affect the choice of suppression strategy and, therefore, suppression costs.

Methods and Results

Incident command teams are required to keep daily records of suppression costs and wildfire size. These records are collated nationally by the USDA's national information technology center (NITC). For the 2002 wildfire season NITC has records for 157 wildfires in the continental US west of the Rockies. Unfortunately, WFSA data are not collected nationally. Therefore, we contacted the local land managers responsible for each of the 157 wildfires (for which we had data on actual fire size and suppression costs) and requested their completed WFSAs. We received WFSAs from 49 fires. Of these, 42 were from fires where only one WFSA was conducted, and seven were from multiple WFSA fires, giving a total of 58 WFSAs. The geographical distribution of the total sample and the responses received is shown in Figure 2.

There was considerable variation in response rate by state, with no responses from Washington or Montana, and a disproportionately low response rate from Arizona, Nevada, and Wyoming. Therefore, when interpreting results it should be noted that the majority of responses come from five states. The 49 fires for which data were collected varied in size from 87 to 150,696 acres, burned a total of 804,347 acres, cost $311,603,896 to suppress, and had an average per acre cost of $387.

To determine the accuracy of WFSA probability estimates, we compared the estimated probability of success of the target outcome with actual outcomes. Success was measured in two ways. First, was actual size smaller than target size? Second, was actual cost smaller than target cost? Across all WFSAs the mean estimated probability of success of the target outcome was 71 percent. Actual fire size was smaller than target fire size for 63 percent of WFSAs, and actual costs were lower than target costs for 44 percent of WFSAs. This indicates that fire managers tend to underestimate the probability of a given wildfire exceeding its target size and costs, although fire managers appear better at predicting fire size than costs. These results are consistent with previous work showing that people tend to underestimate the probability of likely events occurring. In this case fire managers underestimated the probability, that actual fire size and cost would exceed estimated target size and costs.

A similar process was used to determine the accuracy of worst case probability estimates. Across all fires the mean estimated probability of the worst case outcome occurring was 16 percent. Actual fire size exceeded worst case fire size 7 percent of time, with actual costs exceeding worst case costs 19 percent of the time. Fire managers overestimated the probability of actual fire size exceeding worst case size, which is consistent with previous work showing that people tend to overestimate the probability of unlikely events occurring. However, fire managers slightly underestimated the probability of costs exceeding worst case costs.

This apparently inconsistent result may be explained by considering how fire managers estimate suppression costs. We hypothesize that fire managers estimate suppression costs by first estimating fire size and then estimating per acre cost, with suppression cost being the product of these two estimates. To determine the accuracy of per acre cost estimates we compared actual, worst case, and expected per acre costs (Figure 3).

The lines in Figure 3 are trend lines, and do not imply a strict linear relationship between per acre costs and fire size. For the purpose of this paper the general relationship between fire size and per acre cost is sufficient; therefore, individual data points are excluded for clarity.

The difference between estimated worst case and actual per acre costs help explain why worst case probability estimates are approximately correct. For fires smaller than 18,000 acres (39 of the 49 fires in the sample were less than 18,000 acres) worst case per acre costs underestimate actual per acre costs. We have already shown that fire managers overestimate the probability of a fire

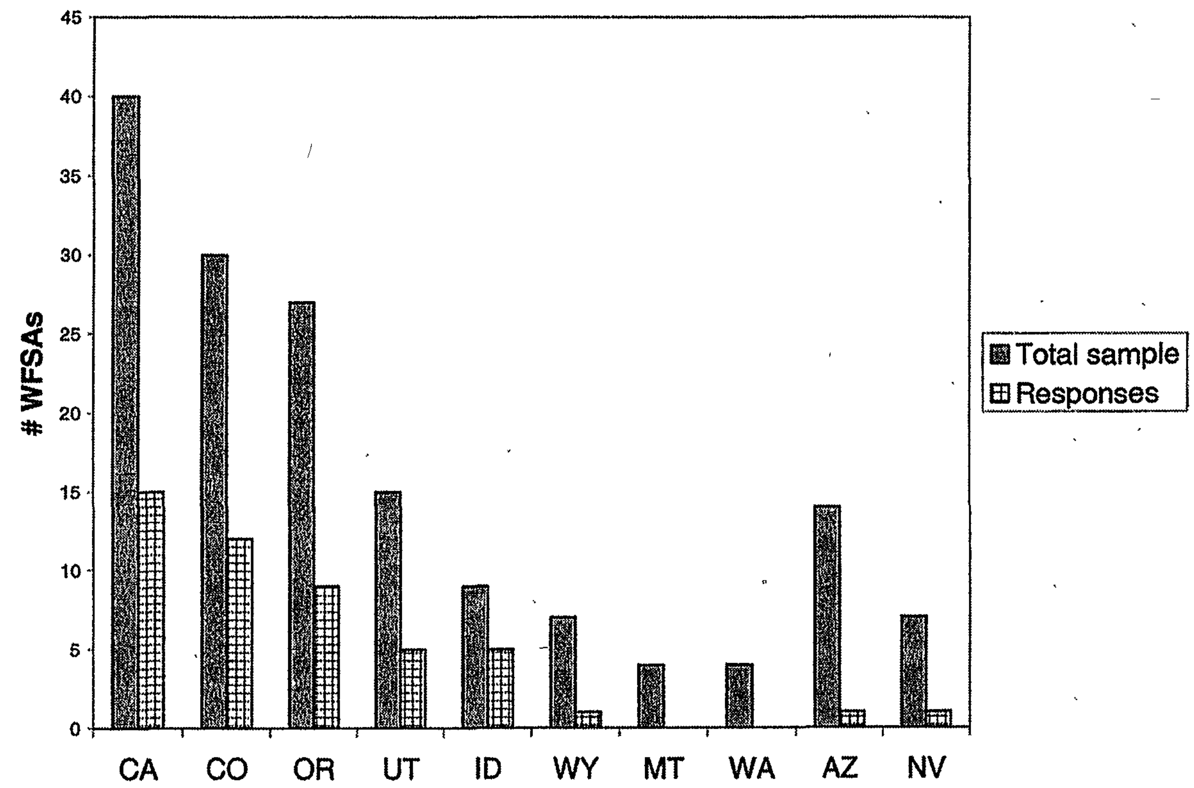

Figure 2. Geographical distribution of wildfires for which a WFSA was conducted and those from which a response was received.

exceeding its worst case size, which for a given probability is equivalent to overestimating fire size. If an overestimated fire size is multiplied by an underestimated per acre cost, the two errors in estimation will tend to cancel each other out; explaining why worst case cost probability estimates are about right.

This hypothesis also explains why target cost estimates are less accurate than target size estimates. Figure 3 shows that for all fires estimated target costs underestimate actual per acre costs. We have already shown that fire managers underestimate the probability of a fire exceeding its target size, which for a given probability is equivalent to underestimating fire size. If an underestimated fire size is multiplied by an underestimated per acre cost estimate the result is a cost estimate that underestimates actual cost more frequently than target size underestimates actual size. Our hypothesis also explains why expected fire size exceeded actual fire size for 76 percent of fires, whereas expected cost only exceeded actual cost on 60 percent of fires.

The data in Figure 3 raise the question of whether there should be a difference in per acre cost between target and worst case outcomes. Fire size, fuel type, topography, weather, and resource availability clearly have the potential to affect per acre costs. However, there seems to be no *a priori* reason why labeling an outcome as worst case or target should affect per acre costs. Such a classification is necessarily subjective and does not affect fire behavior, values at risk, or resource availability. It appears that the over optimism associated with target outcome estimates also affects per acre cost estimates, which for the majority of fire sizes are lower than worst case per acre cost estimates. In addition, target per acre cost estimates decline more rapidly with increasing fire size than worst case per acre cost estimates. In contrast, worst case per acre cost estimates tend to be higher and show little decline with increasing fire size.

Discussion

In 2002 fire managers in the western US underestimated the probability of actual fire size exceeding target fire size, and overestimated the probability of actual fire size exceeding worst case fire size. They also generally underestimated per acre suppression costs. Consequently, the probability of actual costs exceeding estimated target costs was significantly underestimated, whereas the estimated probability of actual/suppression costs exceeding worst case suppression costs was approximately correct. These results are consistent with longstanding theories of human choice showing that people tend to underestimate the probability of likely events occurring and overestimate the probability of unlikely events occurring.

Estimates of fire size and cost are used by managers to select the appropriate suppression strategy for an escaped wildfire. Inaccurate estimates therefore influence suppression costs. Given the attention being

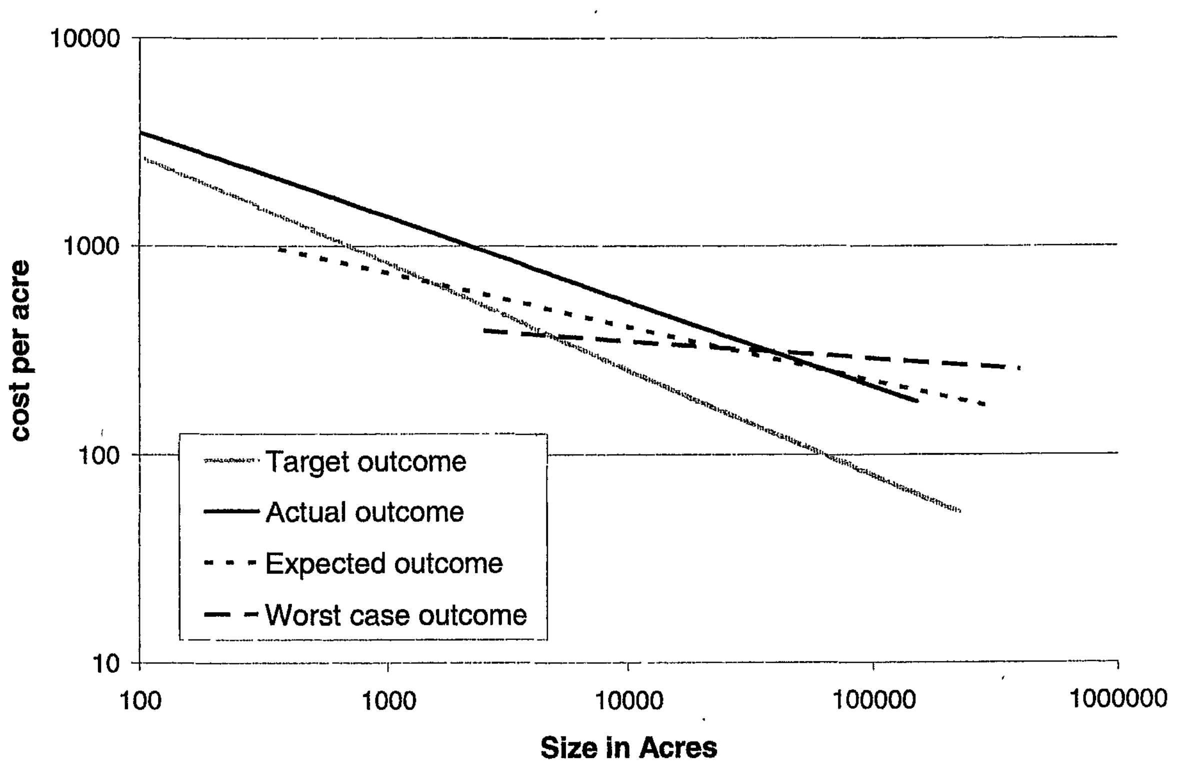

Figure 3. Per acre costs as a function of fire size for target outcome, worst case outcome, expected outcome, and actual fires.

focused on controlling large fire costs it is important to address problems we have identified. Doing so would improve the WFSA process, enabling fire managers to make more informed decisions.

Our results identify two systematic errors made by fire managers: probability estimates and per acre costs. There are several potential strategies that could be used to improve the accuracy of WFSA probability estimates. Research has shown that one reason that people misestimate probabilities is that they seek evidence to confirm an initial belief, giving less weight to contradictory evidence (Baron 2000). In the context of the WFSA process a fire manager may believe that a wildfire will be contained under its target size. Given this initial belief, a favorable weather forecast will be seen as supporting evidence, whereas a report that needed suppression resources may not be available will be given less weight. This bias may be addressed by requiring fire managers to list the factors that may influence the success or failure of a suppression strategy before estimating the probability of its success. This approach has been shown to increase the accuracy of probability estimates.

Estimates of per acre costs also show systematic errors. Although the WFSA process does not require users to directly estimate per acre suppression costs, they are easily derived from fire size and suppression cost estimates. Our analysis identified two main problems with these estimates. First, in general, per acre cost estimates were too low. Second, per acre cost estimates varied between target and worst case outcomes. These problems could be addressed by using standard per acre cost estimates based on regional or national data. Fire managers would enter the appropriate fuel model and estimate of tire size. The WFSA model would then use historic per acre fire costs to estimate total suppression costs.

Other aspects of the WFSA process that are not addressed in this paper warrant further investigation. For example, it is not clear to what extent suppression costs are controlled by the completion of a WFSA. It has been suggested that the WFSA process primarily tracks costs rather than controls them. Similarly, it is not clear whether the WFSA process is used to select a suppression strategy or to justify a choice that has already been made. In addition, there has been no published work examining alternatives to the current model architecture.

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