Measuring the Wildland Firefighting Safety Culture Change—An Analysis of Entrapment Rates from 1994 to 2013

Bob Loveless, Kent Fire Department Regional Fire Authority, Kent, WA (retired) and Instructor, Technical Fire Management, Washington Institute, Duvall, WA; and **Adam Hernandez,** Captain, Kings River Hotshots, USDA Forest Service, Sierra National Forest, Clovis, CA

Abstract—*The tragic fatality events of the mid-1990s and subsequent studies led to a concentrated effort to increase safety in the US federal wildland firefighter community beginning in 2000. Addressing human factors (HF) as a causal agent in accidents was a major focal point for this cultural change. To examine the effectiveness of this change, we hypothesized a decline in firefighter entrapment rates after implementation. Seasonal data on entrapment numbers and exposure amounts were collected on a national level for federal and non-federal wildland firefighting agencies for the years 1994-2013. The rate of wildfire entrapments (number/1000 person-hours fire line exposure) was estimated using generalized linear mixed models. Since program inception in 2000, rate ratio estimates indicate a 72 percent reduction in entrapment rates for federal wildland firefighters after controlling for variation in acres burned, number of fires and exposure time compared to pre-2000. A similar 46 percent reduction in entrapment rates was estimated for non-federal firefighters. Other non-HF changes such as improved weather forecasting may account for some of this reduction. We recommend continuation of the HF focus as a significant contributor increasing safety in the firefighting culture.*

Introduction

The 1994 US wildland fire season tragically resulted in the deaths of 34 firefighters, 14 in the South Canyon Fire in Colorado. Subsequent agency investigations identified an aspect of firefighting poorly understood by the wildland firefighting culture—the role that human factors (HF) played in the outcomes of these tragic events (Putnam 1995). HF are generally regarded as the social and psychological dimensions potentially leading to human error in decision-making, particularly in risky and dynamic situations. These dimensions of decision-making include the interacting roles of crew and personal dynamics, leadership, risk-taking, stress and communication on the fire ground. Comparatively, the physical and biological processes, such as fire behavior and spread, were relatively well known compared to the HF aspects of firefighting. These events and investigations provided an incentive to better understand the HF connection at individual, crew and organizational behavior levels—a top-to-bottom examination of human error in accident causes.

Once the magnitude of role HF played in firefighter safety became apparent, the National Wildfire Coordinating Group (NWCG) authorized the Wildland Firefighter Safety Awareness Study (WFSAS) in cooperation with the TriData Corporation. This three-phase study (TriData 1996a, 1996b, 1998) identified the agencies' cultural and organizational traits having a negative effect on firefighter safety and suggested changes. The WFSAS became a blueprint for cultural change within the federal wildland firefighting agencies with some 86 goals and over 200 recommendations, of which the majority were HF related. Foremost was the goal simply stated "to become a self-learning, self-correcting, high reliability organization."

The NWCG is a consortium of five agencies responsible for fire management on federal wildlands: U.S. Forest Service (USFS), Bureau of Land Management (BLM), Fish and Wildlife Service (FWS), National Park Service (NPS) and Bureau of Indian Affairs (BIA) and it began implementing a large number of the WFSAS recommendations beginning with the 2000 fire season. One recommendation implemented was the Human Factors/Leadership (HF/L) training series (the L-series courses) and is largely recognized as the flagship for the cultural change. Six courses were designed to provide a new skill set for firefighters relating to the human dynamics of firefighting. The first course of the series, Human Factors in the Wildland Fire Service (L-180), is now required to obtain a 'red card' (certification) allowing a firefighter to work on the fire line.

Also in 2000 a method of non-punitive reporting, SAFENET, was implemented allowing frontline federal firefighters to document unsafe situations (http://safenet.nifc.gov [January, 2014]). In 2002, the Wildland Fire Lessons Learned Center (LLC) began operations to improve safety, advance organizational learning and share knowledge across all wildland fire organizations (http://wildfirelessons.net). Numerous conference and workshop proceedings have been held that document what the agencies have done to improve the safety culture within the federal wildland firefighting community from a HF/L perspective. Tangentially to the WFSAS study,

In: Keane, Robert E.; Jolly, Matt; Parsons, Russell; Riley, Karin. 2015. Proceedings of the large wildland fires conference; May 19-23, 2014; Missoula, MT. Proc. RMRS-P-73. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 345 p.

the USFS began ‘entrapment avoidance’ projects in 1999 (Dreissen and others 2005).

Omodei and others (2005) identified HF as the primary cause in approximately 80 percent of wildland fire accidents and near misses. Larson and others (2007) provide a summary of HF in the wildland fire culture. But little documentation exists quantifying any success or progress for this cultural overhaul. In Phase II of the WFSAS, TriData suggested annual citizen and firefighter surveys, anecdotes, interviews and trained observers as methods to measure periodic progress. Survey and interview methodologies were used by most authors including Dreissen and others (2005), McDonald and Shadow (2005), Wright (2009), Black and others (2012), Jahn (2012), and McBride and Black (2012). These studies largely show that perceptions of the safety culture has improved, with some variation between agencies, and by position/seniority of the individuals interviewed. Quantitative analyses of injury rates or other measures of safety that document the impact of the WFSAS changes are few. McDonald and Shadow’s study used surveys to compare trends in attitude ratings along several organizational and HF dimensions from 1998-2004. They intended to document the effect of the L-series course start-up, comparing before and after measures, although no statistical analysis was reported. Using only USFS data, Saveland and Pupulidy (2009) found higher injury rates in 2007 compared to 1998 for all operations including fire. Britton (2010) used logistic and negative binomial regression to relate firefighter injury rates to fire-level factors for 2003 to 2007 Department of Interior (DOI) large fires. This study further examined job assignment and injury mechanism in relation to the nature and severity of the injury.

In this observational study, we model firefighter entrapment rates separately for federal and non-federal firefighters before and after implementation of the WFSAS study’s findings. The research hypothesis is that entrapment rates from 2000 to 2013 should be less than the rates from pre-2000 if the cultural change has had the desired effect. Also, we hypothesize that any decrease in entrapment rates should be greater on federal fires compared to non-federal fires. In the models, we control for seasonal variation in acres burned and fire numbers.

Entrapment rates are only one measure of the federal wildland fire community’s efforts to improve safety. Other measures such as vehicle accidents, fatalities, injuries and time-loss reports could (and should) be used in an overall evaluation of program change. But the need to reduce firefighter entrapment was the catalyst for the change and is the focus of this analysis.

Methods

Data

The NWCG Glossary of Wildland Fire Terminology (2012) defines entrapment and burnover as:

Entrapment: A situation where personnel are unexpectedly caught in a fire behavior related, life threatening position where planned escape routes or safety zones are absent, inadequate, or compromised. An entrapment may or may not include deployment of a fire shelter for its intended purpose. These situations may or may not result in injury. They include “near misses.”

Burnover: An event in which a fire moves through a location or overtakes personnel or equipment where there is no opportunity to utilize escape routes and safety zones, often resulting in personal injury or equipment damage.

Entrapment**,** for this study, will be used to describe these two events. However, *entrapment rate* is a count per exposure unit. For this study, we used person-days of work by fire line personnel exposed to entrapment as the exposure measure. Overhead, command staff and aviation resources committed to a fire were excluded. Entrapment rates were modeled separately for federal and non-federal wildland fires using generalized linear mixed model (GLMM) methods.

Information available online through the National Interagency Fire Center (NIFC) (www.nifc.gov*)* provided most of data. National entrapment statistics for the years 1994 to 2013 are found in the NWCG’s Safety and Health Working Team’s annual report known as the “Safety Gram” (http://www.nwcg.gov/branches/pre/rmc/safety-grams.htm [January, 2014]). Statistics for acres burned and number of fires are available from the National Incident Management Situation Report (SIT) (http://www.nifc.gov/nicc/ [March, 2014]).

Estimates of fire line exposure are not part of any data collection process used by NIFC. However, from 1994 to the present, the SIT report provides an estimate of the resources used on fires greater than 100 acres for timber fuel models and greater than 200 acres for grass/brush fuel models. Resources listed as total personnel, crews, and engines were used to estimate an exposure indicator of person-days for fire line personnel. The SIT report is released at least weekly during the off-season and daily during Preparedness Levels greater than 1 by the Predictive Services Intelligence Section of National Interagency Coordinating Center in Boise, ID. A full description of the SIT Report contents can be found online at http://www.predictiveservices.nifc.gov/intelligence/Reading_the_Situation_Report.pdf.

Candidate variables and attributes are displayed in table 1. All values were recorded per season and are national totals, separated by federal and non-federal incidents. Three distinct fire season periods are identified: Season 1 (SEA) is defined as January through May, Season 2 as June through August and Season 3 as September through December. Person-days of exposure (PD) indicates the amount of time fire fighters are exposed to entrapment situations—the number of person-days on the fire line engaged in suppression activities for large fires. The timeframe (1994 to 2013) was split into two mutually exclusive periods. ERA_0 includes the years 1994 to 1999 and ERA_1 covers 2000 to 2013 to coincide with cultural change implementation. Acres burned (AC) and fire numbers (FI) are seasonal totals as reported to NIFC through the eleven Geographical Area Coordinating Centers (GACC).

We randomly sampled 10 SIT reports for each season for each year and counted the number of crews and engines

Table 1—Candidate variables, measures and data sources.

Variable	Units/Scaling	Type	Data Source
Entrapments, EN	Number	Dependent	Safety Gram
Exposure Indicator, PD	Person-days (x10^3)	Off-set (dependent)	SIT Reports
Season, SEA	Categorical (1 = Spring, 2 = Summer, 3 = Fall)	Independent, random	
ERA	Categorical (0 for years 1994 to 1999 and 1 for years 2000 to 2013)	Independent, fixed	
Total Acres, AC	Number (x10^5)	Independent, fixed	SIT and Annual Reports
Total Fires, FI	Number (x10^3)	Independent, fixed	SIT and Annual Reports

reported on new incidents. Assuming 20-person crews and 5-person engines provided an estimate of personnel on the fire line. We compared the fire line personnel estimate to the total personnel reported on new incidents and adjusted this estimate (usually a reduction) if needed. The seasonal average fire line personnel per day was then multiplied by the number of days for each season to obtain an exposure indicator of person-days for large fire suppression work. Resources assigned to non-fire incidents were not counted.

For each calendar year, cumulative acres burned and fire numbers are recorded in the SIT reports for federal and non-federal fires. We used the year-to-date totals for May 31, August 31 and the end of the year to generate seasonal totals. Data collection was completed in February 2014. Some variables were scaled as shown in table 1 to avoid leading or trailing zeros in the data and estimated coefficients.

Statistical modeling

Seasonal entrapment rate (EN_i) was computed as number of entrapments per 1000 person-days exposure

$$EN_i = \frac{Entrapments}{Exposure\ Indicator} = \frac{EN_i}{PD_i} \tag{1}$$

We consider this dependent variable as count data expressed as a rate and fit a GLMM with Poisson errors. The log function is the natural link function so the basic model is

$$\ln(EN_i) = \ln(PED_i) + \boldsymbol{x}_i^T \boldsymbol{\beta} \tag{2}$$

where the design matrix $\boldsymbol{x}$ contains the independent variables from Table 1 and any interaction and polynomial terms. $\boldsymbol{\beta}$ is a vector of coefficients to be estimated and the $\ln(PD_i)$ is the offset term.

Repeated measures issues may arise because the SEA may be considered as three measures of entrapments within one year. Conceptually, a busy fire year could have higher entrapment rates for all three seasons. Incorporating SEA as a random effect in a generalized linear mixed model accounts for any potential serial correlation (Crawley 2013) and the inherent seasonal variation in wildland firefighting.

The model expressed in equation 2 was estimated for federal and non-federal entrapment rates. Residual plots were used to verify statistical assumptions for the models. Polynomial terms of the explanatory variables were used to check for non-linearity and improvement in the residual plots. Model fitting was done using the glmer function in the lme4 package (Bates and others 2014) of R (R Core Team 2014).

Results

Table 2 presents summary statistics for the variables grouped by *ERA* and *SEA* separately for federal and non-federal fires. Comparing the two time periods of interest we see the mean entrapment count decreased in ERA_1 for all seasons for federal fires but increased for non-federal fires for the spring and summer seasons. Except for federal fires occurring in the fall, the average fire line exposure (*PD*) and acres burned (*AC*) increased substantially for ERA_1. The average number of fires (*FI*) changed little between the two time periods with a slight decrease for non-federal fires in all seasons.

Figure 1 for federal fires and figure 2 for non-federal fires are time series plots showing the seasonal variation and trend lines for *AC* and *FI*. Both figures show the trend for increasing acres burned and fewer numbers of fires for the time period studied. Comparing the two figures, seasonal variation has a considerably stronger cyclical component in the federal data with definite and regular peaks during the summer season at every third data point. The seasonal means for federal fires in table 2 shows substantially larger means for all variables in the summer season. For non-federal fires *EN*, *PD* and *AC* averages have the largest means in the summer season but the average *FI* is larger in the spring.

Modeling

Statistical modeling results are presented in table 3. All variables are significant in both the federal and non-federal models. No significant improvement in the AIC statistic or residual plots was achieved by incorporating interaction or polynomial terms into the models.

Rate ratios are the usual interpretation of the coefficient estimates and are found as the antilog of the estimate. A one-unit change in the explanatory variable results in a multiplicative effect on entrapment rate, assuming the remaining variables are constant. For this study, the variable *ERA* is of main interest. By construction it is a binary (0,1) variable so the coefficient expressed as a rate ratio gives the percent change in *EN* associated with *ERA*. Interpretation of the federal model rate ratio, 0.2793, means that the entrapment rate

Table 2—Summary statistics for variables grouped by *SEA* and *ERA*[a] for federal and non-federal fires.

	Season *SEA*	Statistic	Entrapments *EN(count)*		Exposure *PD(x10³)*		Acres burned *AC(x10⁵)*		Number of Fires *FI(x10³)*	
			ERA_0	ERA_1	ERA_0	ERA_1	ERA_0	ERA_1	ERA_0	ERA_1
Federal	Spring	Mean	9.0	1.9	24.8	33.9	1.42	2.54	3.32	3.59
		sd	19.6	2.0	21.6	22.0	0.82	1.41	0.22	0.55
		Median	1.5	1.5	15.5	35.7	1.13	2.11	3.34	3.55
	Summer	Mean	39.8	13.1	250.4	287.7	18.39	30.95	10.71	9.86
		sd	46.3	12.9	153.2	165.1	10.56	15.02	2.54	1.93
		Median	21.5	8.5	231.5	341.9	19.29	30.48	9.95	9.07
	Fall	Mean	3.8	1.6	137.1	105.2	3.80	5.91	3.55	3.54
		sd	5.7	3.1	150.9	85.7	3.05	3.46	1.07	0.80
		Median	1.0	0	82.5	90.3	2.94	5.28	3.56	3.56
Non-federal	Spring	Mean	2.7	4.8	7.1	40.0	6.00	8.49	33.14	26.74
		sd	2.9	4.5	1.7	30.4	3.08	7.62	11.35	7.58
		Median	1.5	3.5	6.9	37.9	4.61	5.96	32.03	25.76
	Summer	Mean	10.3	15.6	121.8	269.5	5.78	14.07	16.47	16.18
		sd	11.0	13.3	60.5	210.4	2.30	6.60	5.36	5.94
		Median	6.0	12.0	123.0	208.8	5.77	13.76	16.44	13.93
	Fall	Mean	4.2	4.1	74.2	120.4	2.83	5.85	15.94	14.72
		sd	5.5	5.7	46.4	112.2	1.66	3.12	4.20	5.13
		Median	2.5	3.0	51.8	86.9	2.53	5.26	16.59	15.38

[a]*ERA* is coded 0 for years 1994 to 1999, n = 18; and coded 1 for years 2000 to 2013, n = 42.

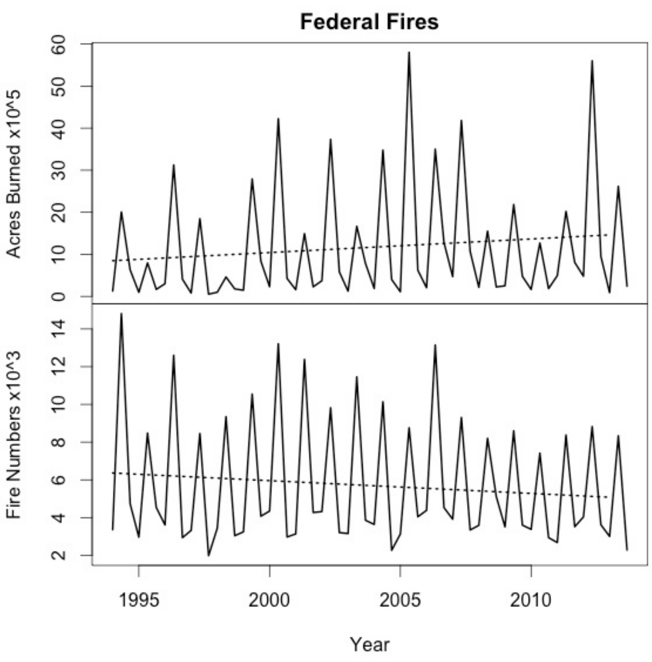

Figure 1—Seasonal time series plots of acres burned and fire numbers for federal agencies. The dashed line represents a simple linear trend line. The y-axis measures are seasonal, not annual values.

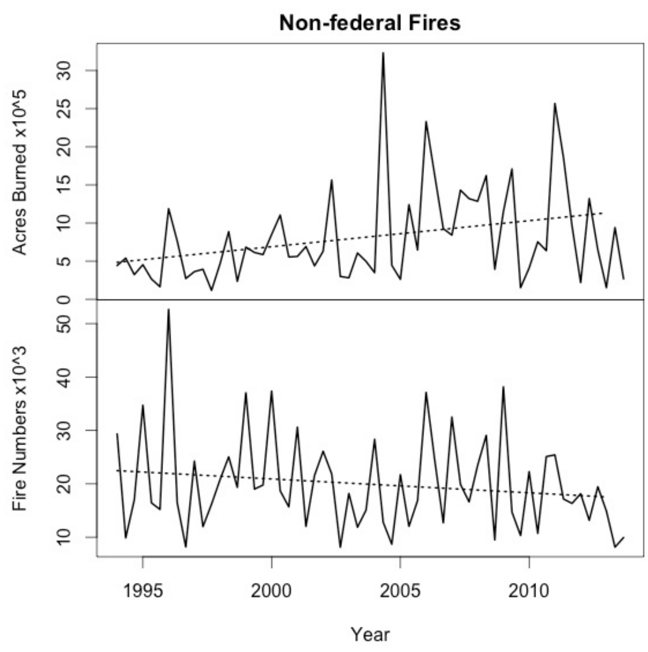

Figure 2—Seasonal time series plots of acres burned and fire numbers for non-federal agencies. The dashed line represents a simple linear trend line. The y-axis measures are seasonal, not annual values.

for ERA_1 is about 28 percent of the rate for ERA_0, a 72 percent reduction in entrapment rates. In the non-federal model the entrapment rate for ERA_1 is about 54 percent of that for ERA_0, a 46 percent reduction. The continuous variable rate ratios are similarly interpreted. For example, in the federal model, a 100,000-acre (one unit) increase in *AC* increases the entrapment rate by $e^{0.03188} = 1.0324$, times, about a 3.24 percent increase in entrapment rate.

For both models the algebraic signs for the *ERA*, *AC* and *FI* coefficients agree with the summary statistics in table 2. At first glance, the negative sign for *FI* in the non-federal model seems curious, in that it would imply a higher entrapment rate for fewer fires. Indeed, this is what the data show—smaller number of fires but a larger number of entrapments for ERA_1 for non-federal fires compared to ERA_0.

Table 3—Estimated coefficients, statistics and rate ratios.

Variable	Estimate, β	SE	P-value	Rate Ratio = e^{β}
	Federal Agencies Model, AIC = 417.4			
Intercept[a]	-3.73952	0.7461	<0.0001	
ERA	-1.27536	0.1047	<0.0001	0.2793
AC	0.03188	0.004855	<0.0001	1.0324
FI	0.19005	0.0240	<0.0001	1.2093
SEA	Random effect, Variance = 1.551			
	Non-federal Agencies Model, AIC = 693.1			
Intercept[b]	-1.42779	0.4913	0.0037	
ERA	-0.62496	0.1281	<0.0001	0.5353
AC	0.024859	0.008442	0.0032	1.0252
FI	-0.04770	0.008805	<0.0001	0.9534
SEA	Random effect, Variance = 0.6343			

[a] Incorporating the seasonal random effect into the intercept term gives the prediction coefficients of -2.0207, -4.9245 and -4.2555 for the federal agencies model.

[b] Incorporating the seasonal random effect into the intercept term gives the prediction coefficients of -0.3557, -1.7242 and -2.1900 for the non-federal agencies model.

Figure 3 shows time series plots of the model fit using the prediction coefficients and the observed values. The federal model predictions follow the observed values fairly well frequently matching the seasonal peaks associated with the summer season. For the non-federal model the fit is not quite as good.

Discussion and Conclusions

In 2000, the US federal agencies responsible for wildland fire implemented a top-to-bottom effort to improve the firefighter safety culture. This effort at cultural shift centered on addressing the HF role in decision-making in risky and dynamic situations. Other efforts in this shift included improved local weather forecasting, risk reduction through assignment turndown protocols and changes in tactics to decrease fire line exposure such as increased use of aerial suppression and departure from full perimeter control. Reducing firefighter fatalities and injuries spurred these changes after some significant entrapment and fatality events in the 1990s.

We have found that firefighter entrapment rates measured as the number of entrapments per 1000 person-days of fire line exposure appear to have decreased significantly since 2000 after accounting for the seasonal variation in acres burned and number of fires. The entrapment rate reduction is more dramatic for federal fires than for non-federal fires, 72 percent compared to 46 percent. This is an observational study and not a causal study so we cannot say that the cultural shift "caused" the entrapment rate reduction. This study only shows that the reduction in entrapment rates is associated with the safety culture shift.

Non-federal entrapment rates do not serve as a control or comparison group for the federal rates. Most non-federal agencies cooperate with federal agencies, particularly in training and large campaign fires, and so are exposed to the changes and influences occurring in the federal culture. The 46 percent reduction in non-federal entrapments is possibly due to a spillover effect in these cooperative efforts. The poorer fit of the non-federal model compared to the federal model most likely results from the smaller *SEA* random effect and thus a larger residual error. This is also shown in the lack of a strong seasonal pattern as shown in figure 2 compared to the federal data in figure 1.

The exposure indicator we used, *PD*, is somewhat problematic. Ideally this measure would be the actual number of hours spent by personnel on the fire line and exposed to entrapment situations. This measure does not exist as far as we know. Our estimate is based on a random sampling of the number of crews and engines assigned to fires in the SIT report. The data for these reported fires represent resource assignments for only about three percent of the total number of active fires across the nation. However NIFC intelligence estimates that 85 to 90 percent of the nation's firefighting resources is captured in the SIT reports (Kari Boyd-Peak, personal communication). We feel our estimate reflects the exposure risk experienced by fire line personnel over the study time period and consider it an exposure indicator rather than a direct measure of exposure.

We conclude that the safety culture shift within the federal wildland firefighting community largely implemented post-1999 is associated with a significant reduction in the probability of entrapments on a national basis. Further, there appears to be a spillover effect in entrapment reductions to non-federal agencies. These reductions in entrapment probabilities are estimated after accounting for the seasonal variation in acres burned and number of fires.

Further investigations using quantitative measures are needed to monitor, refine and expand the estimates of the safety culture change. This culture change is not static but a dynamic and continuous process. Do vehicle, machinery, ATVs, aviation and medical incidents show similar trends? Would separate estimates for each GACC show geographic areas of the nation with high levels of achievement for others

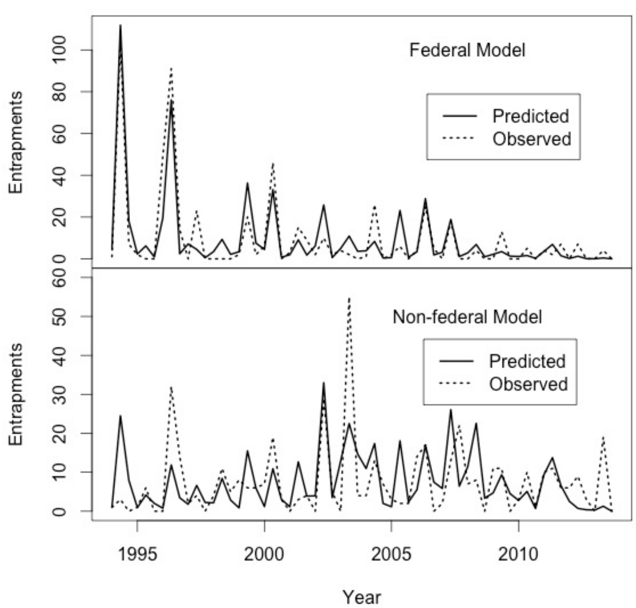

Figure 3—Time series plots of seasonal model predictions and observed values. Note the scale differences between the two y-axes.

to emulate? Are the L-series courses delivered in a timely and efficient manner? These questions, and others, are consistent with the goal of becoming self-learning, self-correcting, high reliability organizations.

Authors

Bob Loveless, 20122 Fremont Ave N, Shoreline, WA 98133; phone: 206-546-4217; email: bloveless7@gmail.com

Adam Hernandez, Kings River Hotshots, USDA Forest Service, Sierra National Forest, Clovis, CA 93611; phone: 559-855-8321 ext. 3431; email: achernandez@fs.fed.us

Acknowledgments

A Technical Fire Management student project by Adam Hernandez provided the impetus for this paper. The authors would like to thank the anonymous reviewers and Mary Kenady, Reid Kenady and Stew Pickford for helpful reviews of earlier drafts. We thank Shawn W. Baker, Sam Marouk and Van Arroyo for initial input and suggestions for this project.

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