Assessing Wildland Firefighter Entrapment Survivability

Wesley G. Page and Bret W. Butler

Figure 1—*Firefighters deploying fire shelters on the Santiago Fire in Orange County, CA, on October 22, 2007. Photo: Karen Tapia-Anderson. Copyright © 2014 Los Angeles Times. Used with permission.*

Wildland firefighters work in complex and dynamic environments, with many dangers that pose serious threats to their safety. Falling snags and rocks, steep and rugged terrain, and rapid increases in fire behavior are just some of the dangers that affect wildland firefighters. Because of the many possible ways that firefighters have been or could be injured, various safety protocols have been developed in the United States to help mitigate the hazards, including the standard firefighting orders (McArdle 1957) and LCES (lookouts, communications, escape routes, and safety zones) (Gleason 1991). Two key elements of the safety protocols are the identification of escape routes and safety zones because past firefighter entrapments have repeatedly demonstrated the value of having a designated place of refuge to retreat to when fire behavior abruptly changes.

Since the late 1990s, safety zone size (that is, the minimum separation distance between firefighters and flames needed to minimize the threat of burn injury) has been estimated as four times the height of the flames (Butler and Cohen 1998). However, recent research has updated how we determine safety zone size by incorporating the effects of slope and wind on convective heating (Butler 2014). While identifying or constructing safety zones of suitable size is and will remain an essential part of firefighter safety, it is also important to recognize that not all goes according plan. For various reasons, firefighters' escape routes to their safety zones can be unexpectedly cut off (fig. 1).

When faced with such a situation, firefighters might have a small but important window of opportunity to select one of several deployment sites. In addition to the recommendations listed in the "Last Resort Survival"

Our analysis found that fire shelter use, slope steepness, flame height, and the separation distance from flames were key variables influencing entrapment survivability.

Wesley Page is a research forester for the Forest Service, Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, MT; and Bret Butler is a research mechanical engineer for the Forest Service, Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, MT.

section of the Incident Response Pocket Guide (NWCG 2014), recent research may further aid in selecting a suitable deployment site. Specifically, we utilized data contained within entrapment investigation reports to understand the factors that influence firefighter survivability (Page and Butler 2017). Our analysis found that fire shelter use, slope steepness, flame height, and the separation distance from flames were the key variables influencing entrapment survivability. This analysis provides an opportunity to discuss and reiterate important concepts related to firefighter entrapments and to demonstrate the potential use of data gleaned from entrapment investigations to enhance future firefighter safety.

LEARNING FROM PAST ENTRAPMENTS

Through a shift in culture and enactment of recommendations compiled following firefighter fatalities (see, for example, TriData 1998), the U.S. wildland firefighting community has made organizational learning a major priority. Organizational learning encompasses several tasks, but the ability to acquire and transfer new information to others within the organization is essential (Zimmerman and Sexton 2010). The creation of the Wildland Fire Lessons Learned Center (https://www.wildfirelessons.net) in 2002 represented a major step in helping to ensure that organizational learning would become a reality by providing useful and relevant products and services to the wildland fire community.

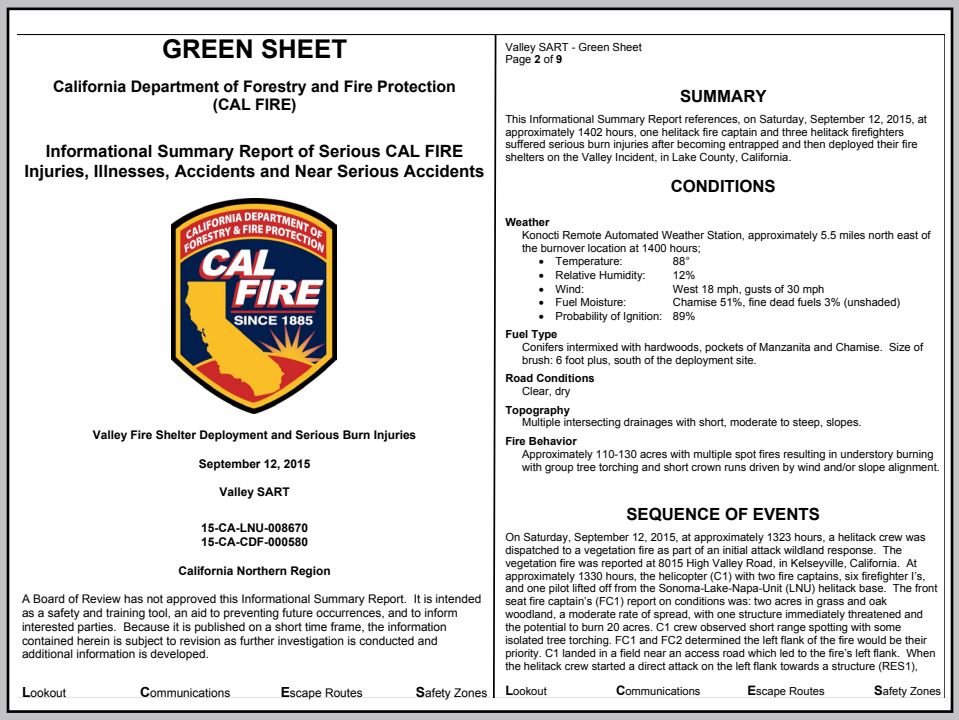
We confirmed that fire shelter use significantly increased the likelihood of surviving an entrapment.

One particularly useful product of the center has been the Incident Review Database, which houses collections of reports, reviews, and investigations related to incidents that involve wildland firefighters. We used the documents in this database to analyze and evaluate the factors that influence firefighter survivability during an entrapment (Page and Butler 2017). Specifically, we compiled and statistically analyzed data related to the fire environment (fuels, weather, and topography) in and around the entrapment area as well as data on how the entrapped firefighters were affected physically (whether there was an injury or fatality).

An important part of such an analysis is relying on the entrapment reports to provide accurate and complete information. Our study revealed that the quality and completeness of investigations related to firefighter entrapments varies widely and that many of the reports failed to provide detailed information about the entrapment area (such as size and shape) (Page and Butler 2017). Additionally, basic information about the fire environment at the time of the entrapment (fuel moisture, wind speed, and so on) was sometimes entirely omitted or buried in the documents, with no standardized format.

However, we found the Green Sheets produced by the California wildland firefighting agency, Cal Fire, to be notable exceptions. The Green Sheets generally follow a standardized format, with clear, concise summaries of the key environmental variables near the beginning of the document (fig. 2). In contrast, Federal agency Learning Reviews or Facilitated Learning Analyses don't share a common organization, are mostly written in a long narrative format, and lack comprehensive summaries. While narratives may be essential in providing adequate context for an incident, they also make it difficult to extract basic information about important aspects of the entrapment, such as the fire behavior and the particulars of the fire environment at the time of the entrapment.

In addition to being difficult to extract from the entrapment reports, the data usually represent only a portion of the range of values needed to produce high-quality statistical models. Owing to the nature of the circumstances in which



GREEN SHEET

California Department of Forestry and Fire Protection (CAL FIRE)

Informational Summary Report of Serious CAL FIRE Injuries, Illnesses, Accidents and Near Serious Accidents

Valley Fire Shelter Deployment and Serious Burn Injuries

September 12, 2015

Valley SART

15-CA-LNU-008670
15-CA-CDF-000580

California Northern Region

A Board of Review has not approved this Informational Summary Report. It is intended as a safety and training tool, an aid to preventing future occurrences, and to inform interested parties. Because it is published on a short time frame, the information contained herein is subject to revision as further investigation is conducted and additional information is developed.

Lookout Communications Escape Routes Safety Zones

Valley SART - Green Sheet
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SUMMARY

This Informational Summary Report references, on Saturday, September 12, 2015, at approximately 1402 hours, one helitack fire captain and three helitack firefighters suffered serious burn injuries after becoming entrapped and then deployed their fire shelters on the Valley Incident, in Lake County, California.

CONDITIONS

Weather
Konocti Remote Automated Weather Station, approximately 5.5 miles north east of the burnover location at 1400 hours;
- Temperature: 88°
- Relative Humidity: 12%
- Wind: West 18 mph, gusts of 30 mph
- Fuel Moisture: Chamise 51%, fine dead fuels 3% (unshaded)
- Probability of Ignition: 89%

Fuel Type
Conifers intermixed with hardwoods, pockets of Manzanita and Chamise. Size of brush: 6 foot plus, south of the deployment site.

Road Conditions
Clear, dry

Topography
Multiple intersecting drainages with short, moderate to steep, slopes.

Fire Behavior
Approximately 110-130 acres with multiple spot fires resulting in understory burning with group tree torching and short crown runs driven by wind and/or slope alignment.

SEQUENCE OF EVENTS

On Saturday, September 12, 2015, at approximately 1323 hours, a helitack crew was dispatched to a vegetation fire as part of an initial attack wildland response. The vegetation fire was reported at 8015 High Valley Road, in Kelseyville, California. At approximately 1330 hours, the helicopter (C1) with two fire captains, six firefighter I's, and one pilot lifted off from the Sonoma-Lake-Napa-Unit (LNU) helitack base. The front seat fire captain's (FC1) report on conditions was: two acres in grass and oak woodland, a moderate rate of spread, with one structure immediately threatened and the potential to burn 20 acres. C1 crew observed short range spotting with some isolated tree torching. FC1 and FC2 determined the left flank of the fire would be their priority. C1 landed in a field near an access road which led to the fire's left flank. When the helitack crew started a direct attack on the left flank towards a structure (RES1),

Lookout Communications Escape Routes Safety Zones

Figure 2—*The first two pages of the Green Sheet produced for the Valley Fire Shelter Deployment on September 12, 2015, by Cal Fire. Note the organization and summary information.*

the data were gathered—that is, either a fatality or a near-miss situation—the data tend to represent the extreme end of survivability in terms of the various environmental variables. When safety zones perform as designed and no significant injuries occur, the details regarding the size of the safety zone and the environmental conditions are less likely to be reported. Capturing the details associated with these "nonevent" entrapments is important, however, because they contain vital information needed to help define various fire and environmental thresholds that affect entrapment survivability.

LESSONS LEARNED

Despite the challenges of analyzing entrapment investigation reports, we made several important findings that both confirm long-held beliefs and provide additional insights related to surviving an entrapment. Although firefighter training emphasizes the importance of fire shelters, there haven't been any quantitatively based assessments of their ability to enhance survivability during actual entrapments. We confirmed that fire shelter use significantly increased the likelihood of surviving an entrapment (Page and Butler 2017). This information is already well ingrained into wildland firefighter training and only confirms what was previously suspected: that fire shelters save lives.

It is important to recognize the dangers that steep slopes pose and to avoid placing firefighters there whenever possible.

Slope steepness has been thought to influence firefighter safety because of its effects on fire spread rate and fire intensity and its common association with previous firefighter fatalities (Wilson 1977). The Incident Response Pocket Guide identifies slope steepness in excess of 50 percent as an indicator of extreme fire behavior, and analyses related to the "trench" or "Coandă" effect suggest that slopes greater than 45 percent are the most prone to flame attachment and thus rapid increases in fire behavior (Gallacher and others 2018).

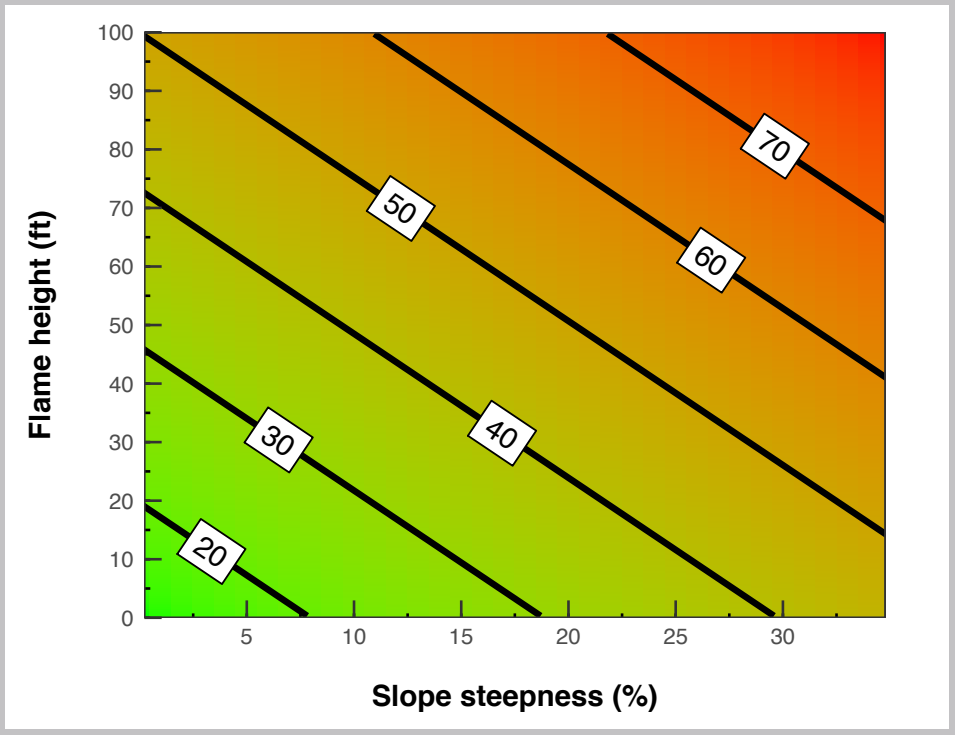

Figure 3—*Separation distances (in feet) needed to ensure a 95-percent probability of surviving an entrapment with a fire shelter deployed. Note that these are distances for surviving an entrapment with a fire shelter and do not represent safety zone separation distances.*

Our analysis confirmed the danger posed by steep slopes and suggested that for each unit increase in slope percent, the odds of a fatality during an entrapment increase by 3 percent (Page and Butler 2017). Additionally, we found that steep slopes limit fire shelter effectiveness, probably due to the effects of increased convective heating on the fire shelter material (Butler and Putnam 2001). It is therefore important to continue to recognize the dangers that steep slopes pose and to avoid placing firefighters on steep slopes whenever possible.

Flame height and separation distance were also two key variables that influenced entrapment survivability. As expected, increasing flame height and decreasing distance between firefighters and flames result in a lower likelihood of survival. One benefit of a quantitatively based assessment of entrapment survivability is that it becomes possible to estimate the separation distances needed to ensure a certain likelihood of survival under a given set of environmental conditions.

Figure 3 shows one such relationship in graphic form. The figure displays the separation distances required to have a 95-percent chance of surviving an entrapment with a fire shelter. These separation distances are generally much less than would be required for a safety zone and would thus probably result in a nonfatal injury for those entrapped. Such a figure is useful for relaying the importance of selecting deployment zones as far away from the flames as possible and on terrain that is as flat as possible.

LOOKING AHEAD

Using the data contained within entrapment investigation reports to ask and answer specific questions not only helps fulfill the promise of organizational learning but also can provide firefighters with useful information. Our analysis shows one

potential avenue for using such data (Page and Butler 2017), but no doubt several others exist. For example, compiling information on the spatial location of firefighter entrapments may help identify areas that may be particularly susceptible to fatal burnovers, such as canyons or drainages, which could then be mapped (see, for example, Page and Butler 2018). Additionally, compiling and analyzing data related to other accident types, such as tree-felling accidents, may also yield useful insights.

In order to facilitate the type of data analysis needed to make quantitatively based assessments, it is important to realize the benefits of adopting a more systematic and comprehensive way to describe, analyze, and store specific information contained within investigation reports. Long narrative documents tend to make gathering data more cumbersome, and the lack of summary information sometimes forces the reader to make generalizations or interpretations that would be better made by the investigation team. While narratives have several benefits, the addition of short summaries with detailed environmental information will no doubt facilitate future analyses.

ACKNOWLEDGMENTS

This work was supported by the Joint Fire Science Program, the National Fire Plan through the Washington Office of Forest Service Research, the National Wildfire Coordinating Group Fire Behavior Subcommittee, and the Wildland Fire Management Research Development and Application Program.

LITERATURE CITED

Butler, B.W. 2014. A study of the impact of slope and wind on firefighter safety zone effectiveness. Missoula, MT: USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory; final report; Joint Fire Science Program, project 07–2–1–20.

Butler, B.W.; Cohen, J.D. 1998. Firefighter safety zones: How big is big enough? Fire Management Notes. 58(1): 13–16.

Butler, B.W.; Putnam, T. 2001. Fire shelter performance in simulated wildfires: an exploratory study. International Journal of Wildland Fire. 10(1): 29–44.

Gallacher, J.R.; Ripa B.; Butler, B.W.; Fletcher, T.H. 2018. Lab-scale observations of flame attachment on slopes with implications for firefighter safety zones. Fire Safety Journal. 96: 93–104.

Gleason, P. 1991. LCES—a key to safety in the wildland fire environment. Fire Management Notes. 52(4): 9.

McArdle, R.E. 1957. Standard firefighting orders. Fire Control Notes. 18(4): 151–152.

NWCG (National Wildfire Coordinating Group). 2014. Incident response pocket guide. PMS 461. [Place of publication unknown]: [Publisher unknown]. https://www.nwcg.gov/sites/default/files/publications/pms461.pdf. (7 March 2018).

Page, W.G.; Butler, B.W. 2017. An empirically based approach to defining wildland firefighter safety and survival zone separation distances. International Journal of Wildland Fire. 26(8): 655–667.

Page, W.G.; Butler, B.W. 2018. Fuel and topographic influences on wildland firefighter burnover fatalities in Southern California. International Journal of Wildland Fire. DOI: 10.1071/WF17147.

TriData. 1998. Wildland firefighter safety awareness study: phase 3—implementing cultural changes for safety. Arlington, VA: TriData Corporation. 48 p. *https://www.nifc.gov/safety/safety_documents/phase3/1Acknow-Sum-WFSAS.pdf*. (4 April 2018).

Wilson, C.C. 1977. Fatal and near-fatal forest fires: the common denominators. The International Fire Chief. 43(9): 9-10, 12–15.

Zimmerman, T.; Sexton, T. 2010. Organizational learning contributes to guidance for managing wildland fires for multiple objectives. Fire Management Today. 70(1): 8–14.