Assessing Firefighter Safety Zones Using LIDAR Remote Sensing

Philip E. Dennison, Gregory K. Fryer, Michael J. Campbell, Thomas J. Cova, and Bret W. Butler

Safety Zones

Safety zones are designated areas that reduce firefighter heat exposure to tolerable levels by providing separation between personnel and fuels. Along with Lookouts, Communications, and Escape routes, Safety zones are a component of the "LCES" procedures for reducing risk of injury and fatality (Gleason 1991). Firefighter safety and entrapment avoidance are dependent on accurate determination and effective use of safety zones. Guidelines have been developed for determining the safe separation distance (SSD) needed between fuels and firefighters (Butler 2014a), and minimum safety zone size can be calculated by using the SSD and adding the area required for the number of personnel and equipment needing protection. Based on modeled radiative heat exposure, Butler and Cohen (1998) recommended that SSD should exceed a minimum of four times the flame height. The National Wildfire Coordinating Group has used this four times flame height guideline for SSD, but also recommends increasing SSD downwind or upslope from a fire (National Wildfire Coordinating Group 2014). Continuing research suggests that the SSD should increase significantly as wind speed exceeds 5 miles (3 km) per hour or as slope exceeds 25 percent (Butler, 2014b).

Philip Dennison and Thomas Cova are professors, and Michael Campbell is a Ph.D. student in the Department of Geography at the University of Utah. Gregory Fryer is a captain of the Cedar City Interagency Hotshot Crew. Bret Butler is a mechanical engineer at the Forest Service, Rocky Mountain Research Station.

Safety zones are typically determined onsite, based on perceptions of safety zone suitability and anticipated weather and fire conditions. However, perceptions of appropriate SSD and safety zone size may be flawed (Steele and others 2000). Light Detection and Ranging (LIDAR) remote sensing can be used to map vegetation height, providing fire managers with the ability to assess potential safety zones and their suitability over large areas prior to fire events. This article describes a spatial model for automated mapping of safety zones presented in Dennison, Fryer, and Cova (2014). The model used high resolution imagery and LIDAR data, along with adjustable parameters, such as flame height, maximum safety zone slope, and number of personnel, to determine safety zone suitability. Additional outputs such as distance to the closest road and the presence of isolated trees can be used to further assess whether a safety zone might be appropriate for use by firefighters under specified conditions.

LIDAR

LIDAR remote sensing uses pulses of laser light to measure distance between the instrument and one more reflecting surfaces. Typically acquired from an aircraft, discrete elevations of both the vegetation canopy and the ground surface can be determined using LIDAR data. Vegetation height can be calculated using the difference between the "first return" from the top of the canopy and a "bare earth" elevation model calculated for the ground surface. Figure 1 contains a profile of first return and bare earth elevations, showing vegetation height as the difference between the two elevations.

Dennison, Fryer, and Cova (2014) used a study area comprised of mixed conifer forest in the Sierra National Forest in California. LIDAR data was collected over an area of 5,400 acres (22 km^2) in August 2010 by the National Center for Airborne Laser Mapping. Gridded 3 feet (1 m) first return and bare earth elevation models were made available through the Open Topography Project (http://www.opentopography.org). Both vegetation height and ground surface slope were calculated from the elevation models at 3 feet (1 m) resolution over the entire study area. Color infrared orthoimagery, also at 3 feet (1 m) resolution, was used to calculate a vegetation index for separating vegetated cells from nonvegetated cells.

Safety Zone Mapping

Dennison, Fryer, and Cova (2014) calculated SSD as four times flame height for flame heights ranging from 7 feet to 46 feet (2 m to 14 m) in 3 feet (1 m) increments. The SSD buffered all cells with a LIDAR-derived vegetation height of greater than 3 feet (1 m). The study evaluated remaining unbuffered cells below the vegetation height threshold as potential safety zone cells using a decision tree. The vegetation height threshold and decision rules were empirically determined using the LIDAR and orthoimage data, but could easily be adjusted based on expert knowledge or training using known safety zone attributes. Safety zone cells were required to have vegetation height of less than 0.7 feet (0.2 m), a contiguous area of unbuffered cells at least 512 feet^2 (156 m^2) sufficient for 20 firefighters and 2 vehicles, and slope less than 10 degrees. Additional criteria and decision tree details are described in Dennison, Fryer, and Cova (2014).

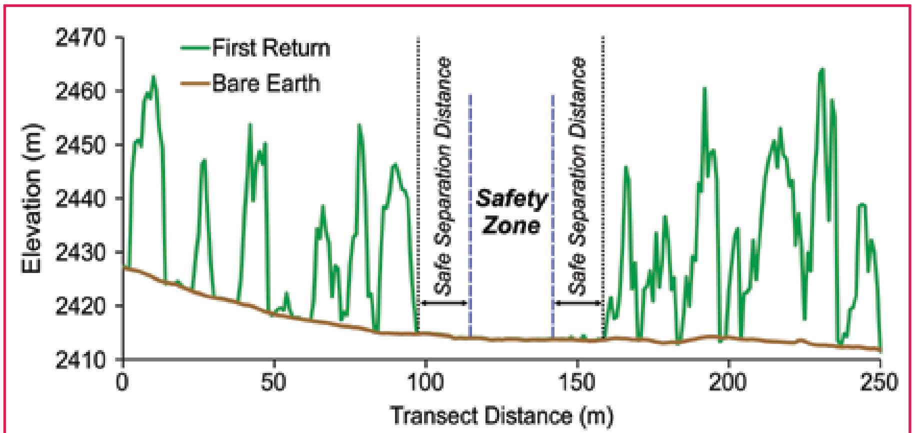

Figure 1.–*An elevation transect showing individual tree canopies and a potential safety zone. Vegetation height is the difference between the first return and bare earth elevation models. Scaling on the Y-axis has been exaggerated to improve visibility of vegetation height.*

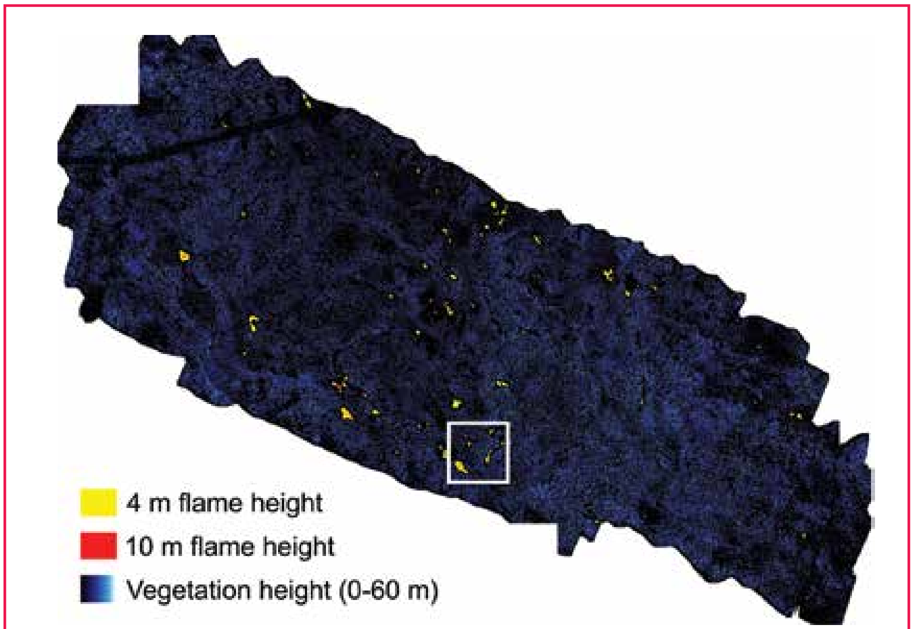

Figure 2.–*Safety zones mapped within the study area for 13 feet (4 m) and 33 feet (10 m) flame heights. LIDAR-derived vegetation height shown in the background is scaled from 0 feet to 200 feet (0 m to 60 m). The 82 feet (25 m) kernel was used for this example. The white box indicates the subset area shown in figures 3–5.*

Some potential safety zones might become adequate with treatment. For example, a few isolated trees in a large meadow could be removed. To increase safety zone size in situations where fuels treatment might be possible, an 82 feet (25 m) kernel was used to calculate the percentage of cells exceeding the 3 feet (1 m) vegetation height threshold. If less than 10 percent of the cells in the 82 feet by 82 feet (25 m by 25 m) matrix kernel exceeded the vegetation height threshold, then tree cover was considered sparse and the cell was not buffered by the SSD. Safety zones calculated using no kernel and safety zones calculated using the 82 feet (25 m) kernel were compared.

Most of the study area was found to be unsuitable for use as safety zones due to vegetation height or slope exclusions. For a flame height of 13 feet (4 m) and no kernel used to exclude isolated trees from being buffered, 42 safety zones were found. These safety zones covered less than 0.2 percent of the 5,400-acre (22 km^2) study area. As flame height increased, the number and size of safety zones decreased. At 20 feet (6 m) flame height, 13 safety zones were found. At 33 feet (10 m) flame height, only 3 safety zones were found. Using a kernel to exclude isolated trees from being buffered resulted in a modest increase in the number of safety zones; 75 were found at 13 feet (4 m) flame height, 30 were found at 20 feet (6 m) flame height, and 5 were found at 33 feet (10 m) flame height (Figure 2). Mean safety zone size increased when the kernel was used.

Figure 3 shows an example of safety zones determined by the spatial model for an approximately 62 acre (0.5 km^2) subset of the study area. The subset has a much higher density of clearings relative to the study area as a whole (figure 2), but was selected to provide examples of mapped safety zones with a range of characteristics. At 13 feet (4 m) flame height (52 feet SSD from the forest edge), a total of 6 safety zones were found. The portions of the clearings not shown as safety zones were excluded because of SSD, slope, and/or vegetation height criteria. At 20 feet (6 m) flame height (24 m SSD), only 2 of the safety zones are large enough to contain 20 firefighters and 2 vehicles. Figure 4 presents the same safety zones, but coded by the maximum flame height calculated for each cell in the safety zone. The safety zone in the lower left corner of the subset permits up to 33 feet (10 m) flame heights, while still sheltering 20 firefighters and 2 vehicles. Within the entire study area, no safety zones were found for flame heights greater than 13 feet (14 m) (56 m SSD).

Spatial modeling allows determination of both the area within each safety zone and the distance to the closest road, both important considerations for safety zone selection. At 13 feet (4 m) flame height, 3 potential safety zones are within a short distance of a road (figure 5). Two of these safety zones are relatively small, however. Only one of the three safety zones exceeding 0.25 acres (1,000 km^2) is close to

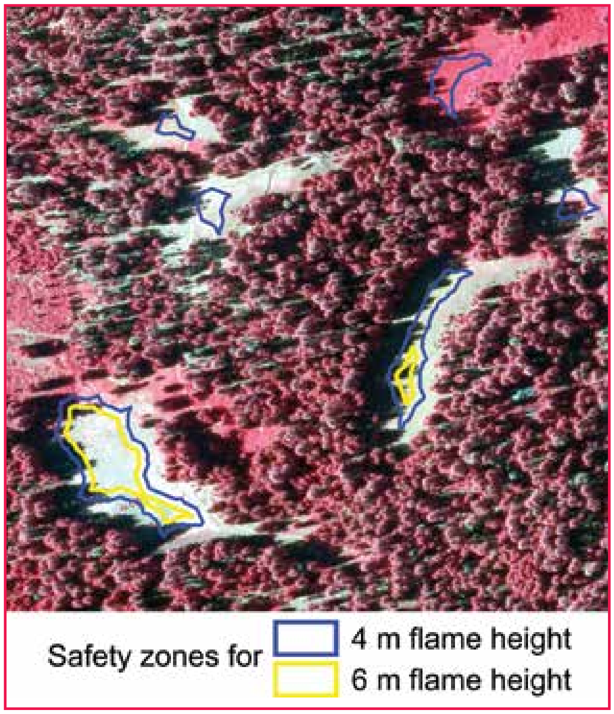

Figure 3.–*Safety zones calculated for 13 feet (4 m) and 20 feet (6 m) flame heights. The background image is a near infrared false color composite derived from the orthoimagery, with live vegetation displayed in red tones. Subset area is approximately 62 acres (0.5 km2).*

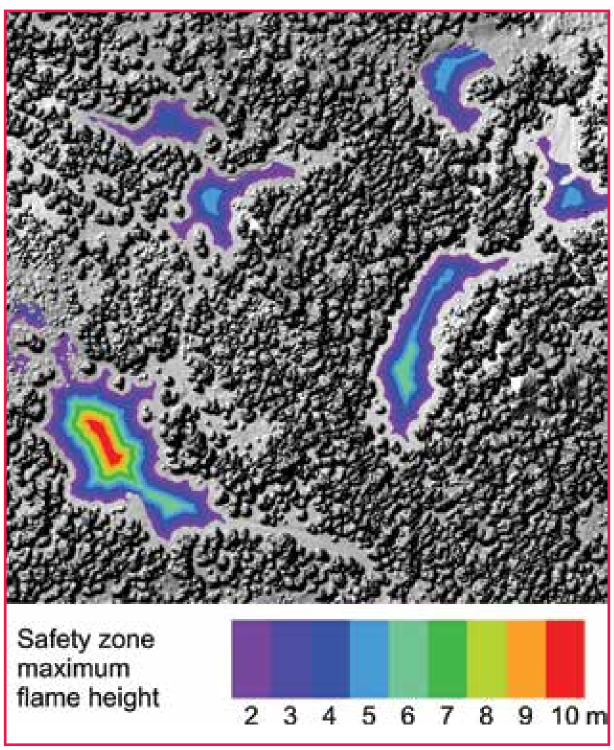

Figure 4.–*The maximum flame height that permits each cell to be part of a safety zone, while still maintaining sufficient space for 20 firefighters and 2 vehicles. The background image is a hill shaded first return surface showing individual tree canopies.*

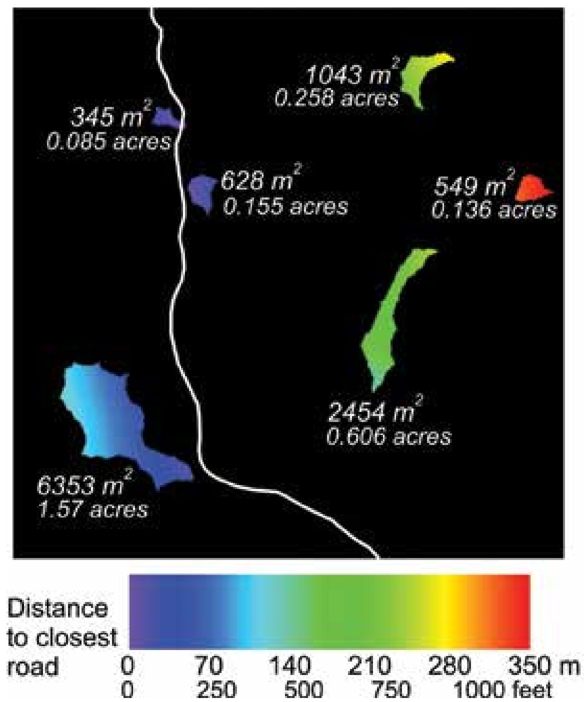

Figure 5.–*Safety zones calculated for 13 feet (4 m) flame height. Distance to a road (shown as a white line) is indicated by colors within each safety zone, while italicized numbers represent the total area of each safety zone.*

a road. Longer distances from the road and intervening terrain may make access more difficult for the safety zones on the right.

Discussion

The spatial model presented in Dennison, Fryer, and Cova (2014) provides a flexible framework for identification of safety zones in advance of resource deployment. Assessment of safety zones using this type of spatial model could provide important advantages to fire managers for determining safety zone viability, allocating resources, and assessing the feasibility of proposed operational strategies. LIDAR data allow accurate measurement of safety zone size, ensuring adequate SSD. Safety zones identified using LIDAR data will still need to be verified by resources on the ground, but vegetation cover within safety zones can be partially determined using high resolution imagery and LIDAR data, allowing assessment of potential improvements that may be required to make a safety zone suitable for use. Mapping of safety zones in advance will also allow access and travel time to be assessed, addressing the escape routes component of LCES. While LIDAR data are currently only available for limited areas, data availability will improve in the near future with national-scale programs such as the U.S. 3D Elevation Program (http://nationalmap.gov/3DEP/).

Dennison, Fryer, and Cova (2014) used uniform flame heights to map safety zones. Recent proposed improvements to safety zone guidelines are based on vegetation height and multipliers for slope and expected wind conditions (Butler, 2014b). Vegetation height and slope can be easily calculated from LIDAR data, and both variables can be mapped at high spatial resolution. Thus, the spatial model presented in Dennison, Fryer, and Cova (2014) should be readily adaptable to evolving safety zone guidelines based on vegetation height and slope. The authors of this article are currently working on comparing how LIDAR-assessed safety zone characteristics change when different safety zone guidelines are used. Travel time to safety zones and accessibility, both on foot and using vehicles (Fryer, Dennison, and Cova 2013), will also be included in future versions of safety zone spatial models. LIDAR identification of safety zones may be useful in the wildland-urban interface for determining whether structures have sufficient defensible space and for assessing structures and locations that may be suitable for shelter actions (Cova and others 2009).

References

Butler, B.W. 2014a. Wildland firefighter safety zones: a review of past science and summary of future needs. International Journal of Wildland Fire. 23(3): 295-308.

Butler, B.W. 2014b. The how, what, and where of safety zones: recent findings. <http://youtu.be/3Z-q3us2X8w>. YouTube Presentation, December 2, 2014 (Accessed January 2015).

Butler, B.W.; Cohen, J.D. 1998. Firefighter safety zones: A theoretical model based on radiative heating. International Journal of Wildland Fire. 8(2): 73-77.

Cova, T.J.; Drews, F.A.; Siebeneck, L.K.; Musters, A. 2009. Protective actions in wildfires: Evacuate or shelter-in-place? Natural Hazards Review. 10(4): 151-162.

Dennison, P.E.; Fryer, G.K.; Cova, T.J. 2014. Identification of firefighter safety zones using lidar. Environmental Modelling and Software. 59: 91-97.

Fryer, G.K.; Dennison, P.E.; Cova, T.J. 2013. Wildland firefighter entrapment avoidance: modelling evacuation triggers. International Journal of Wildland Fire. 22(7): 883-893.

Gleason, P. 1991. LCES – A key to safety in the wildland fire environment. *Fire Management Notes*. Volume 52, Number 4: 9.

National Wildfire Coordinating Group. 2014. Incident response pocket guide. PMS 461. <http://www.nwcg.gov/pms/pubs/pms461/pms461.pdf >. (15 July 2015).

Steele, J. 2000. Effective firefighter safety zone size: a perception of firefighter safety. In: Butler, B., Shannon, K., eds., 4th International Wildland Fire Safety Summit. International Association of Wildland Fire; 10-12 October 2000; Edmonton, AB: 171-177.