

Toward Evacuation Training in Virtual Reality: Requirements Gathering for Wildfire Experiences

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Abstract

With increasing wildfires in the Western U.S., preparing individuals for evacuations has become vital. However, putting people in the presence of actual flames and smoke would be dangerous. Virtual Reality training provides valuable experience without endangering safety. To be optimally effective, a training should be designed by combining best practices with user insights. This study analyzed interviews with ten evacuees to identify their regrets and needs for future evacuations, informing VR training design. In a thematic analysis, the themes of Communication, Reflection, and Item Management emerged as critical. In a follow-up survey, participants ranked medicine, documents, and a first-aid kit as the most important items to pack during evacuation. By leveraging evacuee insights, VR training can address communication, mitigate regrets, and improve item management, empowering individuals with skills to navigate evacuations confidently.

Keywords

Evacuation, Fire, Virtual Reality, Training

Introduction

Large wildfires in the United States have become increasingly common (Dennison et al., 2014). According to the National Centers for Environmental Information, in 2021 there were 58,733 fires burning more than 7 million acres in the United States (NCEI, 2022). This trend is predicted to rapidly increase with the unresolved climate crisis. From 2010 to 2019, there have been 34,748 deaths due to fires in the U.S. (USFA, 2019). From 2010 - 2019 there has been a 14% increase in deaths and a 6% increase in dollar loss for residential building fires (USFA, 2019).

Residential areas are also rapidly expanding into the Wildland Urban Interface (WUI). WUI's are residential areas that border undeveloped vegetation and consequently are exposed to some of the most extreme wildfire dangers (Radeloff et al., 2005). Due to the overlap between wildland space and residential housing, WUI wildfires are difficult to fight and pose increased risk to the lives of firefighters, local residents, and damage to property in addition to becoming increasingly prevalent (Haynes et al., 2020; Radeloff et al., 2018). This also means that more and more people who have no previous fire experience are moving into WUI's.

Negative effects of poor and delayed evacuation decision making at an individual level are likely to cause disturbances at the community level (Wong et al., 2020). Increased traffic, congestion, shelter overcrowding, and increased death and

injuries can result from an individual's badly timed and poorly planned evacuation practice. Evacuation modeling is often used to help design evacuation plans within communities. The resulting models are usually highly complex as they must consider road conditions and capacity, intersection functionality, traffic behavior, constraints and impediments, access from a fire response perspective, presence of vulnerable populations (e.g., older adults), vegetation impacts to roadways, defensible space conditions, structural vulnerability, locations and capacity of temporary refuge areas, and other factors.

Although some evacuation models can be tailored to a specific community, most models either do not factor in human behavior or do not weight its influence strongly. Human behavior's complexity makes it difficult to validate proxy measures or predict future behaviors (Ronchi, 2021). It requires an interdisciplinary approach that considers several domains of knowledge. Many current models of evacuation rely on "quickest route algorithms" that work optimally to create the shortest route and path necessary for evacuation.

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These models assume that humans will fully follow the suggested solutions. However, in interviews and surveys (which we report below) as well as some published manuscripts, we found that evacuation decision making is affected by several factors (that can be considered illogical), such as warnings from a trusted source, prior experience evacuating, home preparedness, seeing embers, and smelling smoke (e.g., Tancogne-Dejean & Laclémence, 2016). All of these are examples of factors in the decision making process that many evacuation models have trouble integrating (Kuligowski et al., 2020).

Previous work has modeled human behavior in fire as three main stages: interpret, prepare, and act; types of actions include evacuate, fight, warn, and wait (Tong & Canter, 1985). However, Tong and Canter (1985) note that there is a lack of research on how people prioritize different streams of information during a fire to make a decision. The present study aims to first identify the main themes that evacuees identify upon reflection of the evacuation event and then rank the relative importance of those themes.

In contexts like exposure to a fire emergency, gaining the prerequisite experience to act appropriately would be dangerous or costly (FEMA, 2006, 2019). Virtual technology offers a solution to this costly and dangerous training method with increasingly “realistic” experiences in various domains. For example, virtual reality (VR) experiences have significantly reduced errors in real settings, such as medical training (Ahlberg et al., 2007), earthquake safety training (Li et al., 2017), and flight simulation (Hays et al., 1992).

A study on the 2002 Colorado wildfires found that higher coping self-efficacy (CSE) was negatively correlated with the amount of time reportedly needed to evacuate and a predictor of post-traumatic stress symptoms post-fire by 109 surveyed individuals in a WUI wildfire (Benight et al., 2004). Other research suggests that risk perception (RP) during natural disasters is most strongly moderated by previous experience and trust in authorities and is defined as the perception of imminent threat to a person’s life or health (Kinatader et al., 2015). People who have previously evacuated a wildfire are more likely to complete more mitigation measures such as creating an evacuation plan, clearing dead bushes, and mowing lawns because of heightened risk perception (McGee et al., 2022). VR could provide this previous experience. However, the training should be designed by leveraging the previous experiences of evacuees.

We have identified a need in WUI’s to train households and communities on fire evacuation and mitigation practices and we have identified a need to utilize evacuees’ previous experiences to design this training. To increase evacuation preparedness, reduce psychological distress related to evacuation, and reduce traffic congestion during evacuation, we asked multiple individuals with previous evacuation experience about their actions leading up to the evacuation, their evacuation, and the actions that they would change if required to evacuate again. In a follow-up survey, we asked

participants to rank the importance of items they would pack in an evacuation.

Method

Participants

Interviews. We interviewed a total of 10 participants, with one participant not reporting demographic data. One participant was excluded because they did not evacuate. Seven of the nine participants evacuated from the CZU Lightning Complex Fire (2020), one evacuated from the Camp Fire (2018), and one evacuated from 2 separate fires occurring in Colorado (2020 and 2021). The mean age reported from participants was 42.9 years (median age was 47 years), with a standard deviation of 15.3 years. 4 participants reported as female, and the other 4 reported as male. 3 Evacuated voluntarily and 5 were mandated to evacuate by law enforcement.

Survey. 100 Participants (50 Female, Age $M = 34.3$ years, $SD = 12.4$ years) completed the follow-up survey asking for participants to rank items in terms of their importance during an evacuation.

Analysis

Interviews. Semi-Structured interviews were conducted with prepared questions and lasted approximately 30-45 minutes. Questions discussed the timeline in the days leading up to the decision to evacuate, the evacuation, and their thoughts on what they would have done differently based on the experience. Interview transcripts had an average length of 6070.5 words (median = 5138 words).

Thematic analysis is a data analysis method used to identify and report patterns (i.e., themes) in qualitative data (Braun & Clarke, 2006; Terry et al., 2017). According to Braun and Clarke (2006), thematic analysis begins by generating initial codes (i.e., noting relevant features of the data), organizing these codes into themes, iteratively defining and naming each theme, and finally, generating a report using the identified themes.

Interview transcripts were coded by four undergraduate researchers for interesting and relevant phenomena (sentence fragments and phrases). These codes were then grouped into sub-themes and themes. A codebook was created with definitions, descriptions, and example quotes for sub-themes and themes. Interview transcripts were broken down into meaningful quote blocks and rated for the presence of the different themes. Quote blocks would be rated as “1” for a theme that was present and “0” for a theme that was absent. Some quote blocks were rated as having multiple themes and others were rated as having none. Inter-rater reliability was measured using Fleiss’ Kappa, which ranges between 0 and 1; higher values represent greater inter-rater agreement (Landis & Koch, 1977). Values between 0.61 and 0.80 are considered

substantial agreement and values between 0.80 and 1.00 are considered almost perfect agreement (Landis & Koch, 1977). After each round of rating, Fleiss' Kappa was calculated for each of the themes. For any themes with a Fleiss' Kappa below the substantial agreement category threshold, raters would meet to discuss and refine the definition of the theme to improve agreement before completing another round of ratings. During each meeting, the codebook would be updated with changes to theme definitions or additional example quotes. The four raters completed four rounds of rating in total to achieve substantial agreement for all seven themes.

Relative importance of the themes was calculated by first summing the ratings for each theme for each rater. This calculation generated rating scores (number of quote blocks a theme occurred in) per rater for each of the themes. Then, the scores were averaged across raters to determine the mean rating score for each theme. Relative importance was determined by arranging the themes by mean rating score, with higher scores indicating greater importance of the theme.

Survey. A follow-up survey was conducted via Prolific (www.prolific.co) [06/02/2022] (Prolific, 2022) to ascertain the relative importance of items, expanding upon the **Item Management** theme discussed below. Participants were asked to rank the following items from the CAL Fire's Ready for Wildfire website (www.readyforwildfire.org)[06/02/2022] (*Emergency Supply Kit*, 2022) in terms of their personal importance: medicine, canned food, batteries, pet food, lighter, computer, knife, bandages, important documents, clothes, first-aid kit, toilet paper, and toolbox.

Results

Themes and Subthemes

Seven main themes were identified from the evacuation interviews: Item Management, Communication, Factors to Leave, Factors to Stay, Community, Reflection, and Travel. Aside from Item Management, each theme also contained corresponding subthemes.

Item Management was defined as inanimate objects that participants deemed as important or necessary. Examples include important documents, pet supplies, lockboxes, clothes, and gasoline. There were no subthemes for Item Management.

Communication was defined as accessing information related to evacuation from other individuals or through mass communication. Subthemes of Communication included *Media*, *Alerts*, *People*, and *Altruism*. *Media* was defined as accessing information through media, which could include radio, phone, email, etc. For instance, one participant mentioned using "a radio station here in Chico" as a source of information. *Alerts* included being told to leave through news, radio, reverse 911 calls, social media, and other

sources. *People* was defined as accessing information through other people, including communication through text. Examples include local authorities, neighbors, and significant others ("me and my significant other were. . . conversing where we would go, if we had to evacuate"). *Altruism* included instances of neighbors helping neighbors or people volunteering to come back to the fire in order to supply items.

Factors to Leave was defined as reasons contributing towards people evacuating from their homes. Subthemes of Factors to Leave are *Dependents*, *Pets*, *Signs of Danger*, and *Environment*. *Dependents* was defined as having people to take care of such as elderly parents and children ("my mother in law who was 98 at the time. . . no longer could drive"). *Pets* were defined as pets that reside in the household. *Signs of Danger* included signals of the fire danger such as smoke, feeling heat, polluted air, and ash ("we've had a tremendous amount of ash. . . coming down on us"). *Environment* was defined as the interviewees' surrounding environment. Examples include the amount of nearby trees, surrounding houses, and traffic conditions ("when we left there was not traffic surprisingly").

Factors to Stay was defined as reasons why interviewees wanted to stay in their homes rather than evacuate. Subthemes of Factors to Stay were *Tools*, *Skills*, *False Sense of Security*, *Desire to Protect Property*, and *Mistrust*. *Tools* included mentions of having proper equipment to stay and defend property against fire. *Skills* was defined as having the skills and knowledge to stay and defend property against fire. *False Sense of Security* included instances of feeling that the fire was further away, developing an individual plan to stay, and the media not discussing the danger of the fire ("I had NPR on trying to hear anything about the fire and they didn't really say anything about evacuations. . ."). *Desire to Protect Property* was defined as wanting to stay to save personal property. *Mistrust* was defined as having a lack of trust in Cal Fire and authority either in the present or the future that would lead to a desire to stay (" . . .no help from the authorities. Their main priority was not to protect structures, but to evacuate people).

Community was defined as preparations for evacuation at the structural and local level that involve a group rather than an individual. This theme specifically includes preparations that are established in advance, and not spontaneous plans in response to the fire. Subthemes of Community included *Emergency Preparedness* and *Neighborhood Meetings*. *Emergency preparedness* was defined as emergency response effectiveness of the community. These preparations included planning a neighborhood network, collaborating with neighbors, and organizing within a community to meet a common goal ("we often hear about fire risks in our community from a Facebook group. . ."). *Neighborhood Meetings* included regular meetings held by the community to increase preparedness ("I went to meetings in the fire safety council. . .").

Reflection was defined as interviewees thinking back on the fire and how it has affected them. Reflection was restricted to personal thoughts, so thoughts on politics and authorities were excluded from this theme. *Adaptation*, *Effects*, and *Regrets* were the subthemes of Reflection. *Adaptation* was defined as being able to learn and adapt from the experience of fire evacuation. *Effects* was defined as gaining a fear of smoke or fire and trauma from the experience of evacuating (“I have some form of PTSD from any smell of fire. . .”). *Regrets* was defined as when interviewees wished they had acted differently in terms of planning and item management.

Travel was defined as talking about leaving for another place due to the fire. Subthemes of Travel were *Route Planning*, *Navigation*, and *Means of Transportation*. *Route Planning* was defined as being familiar with roads, navigation anxiety, having a place to go (such as having family nearby), traveling apps, and assisted planning from devices (“it’s really hard to find a hotel in the middle of the night”). *Navigation* included any discussion of driving. One participant mentioned hitting “stop and go traffic” while evacuating. *Means of transportation* was defined as talking about different vehicle types used in evacuation. For instance, an interviewee may mention that having a smaller car restricted the number of items that they could pack for the evacuation (“we drive a little Prius so it’s not very big”).

The theme with the highest average rating score was Communication ($M = 60.75$, $SD = 6.60$, $\kappa = 0.70$). Reflection ($M = 59.25$, $SD = 5.68$, $\kappa = 0.70$) had the second highest average, with a very similar rating score to Communication. The rest of the themes in descending order of average rating score were: Item Management ($M = 45.75$, $SD = 5.25$, $\kappa = 0.78$), Travel ($M = 41.25$, $SD = 4.50$, $\kappa = 0.67$), Factors to Stay ($M = 38.5$, $SD = 4.12$, $\kappa = 0.68$), Factors to Leave ($M = 34.75$, $SD = 3.20$, $\kappa = 0.74$), and Community ($M = 21.25$, $SD = 2.87$, $\kappa = 0.68$).

Item Management Survey

For the item management survey, participants ranked medicine as the most important item ($M = 2.89$, $SD = 2.11$), followed by documents ($M = 3.31$, $SD = 3.26$), and a first-aid kit ($M = 5.27$, $SD = 2.92$) tied with canned food ($M = 5.27$, $SD = 2.77$). Clothes ($M = 6.00$, $SD = 3.36$), a computer ($M = 6.36$, $SD = 4.25$), batteries ($M = 7.24$, $SD = 2.39$), pet food ($M = 8.05$, $SD = 3.62$), a knife ($M = 8.78$, $SD = 2.62$), bandages ($M = 8.79$, $SD = 2.71$), a lighter ($M = 9.03$, $SD = 2.48$), a toolbox ($M = 9.69$, $SD = 2.88$), and toilet paper ($M = 10.32$, $SD = 2.60$) followed.

Discussion

Based on the interviews we conducted with prior evacuees, it became clear that a robust communication system that can inform the community with updated information on when

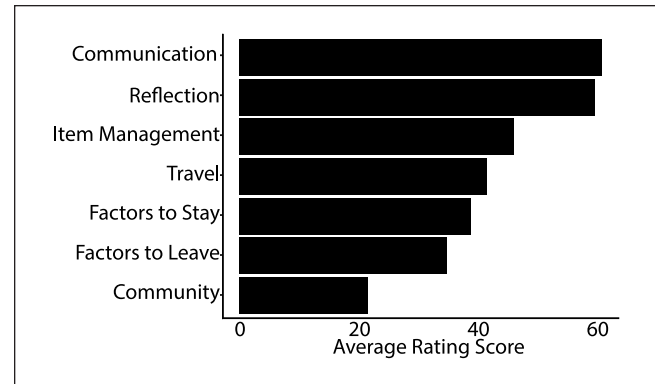


Figure 1. Horizontal bar chart with average rating score on the x-axis and themes on the y-axis.

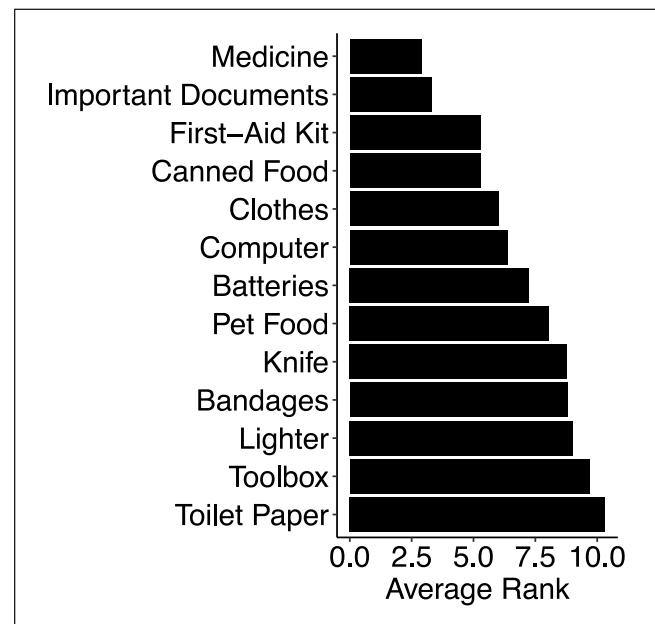


Figure 2. Average ranking for 13 items that participants could bring when evacuating from a wildfire.

and where to evacuate, and the status of the fire spread, is sorely needed. In our thematic analysis of fire evacuation interviews, we found that the three most prevalent themes were **Communication**, **Reflection**, and **Item Management**. The prevalence of communication in the interviews reveals that individuals accessing and sharing information is a critical part of the evacuation process.

In item management, participants selected medicines, documents, and first-aid as the most important items to pack for an evacuation. Coupled with our interviews, prioritizing items due to limited transportation space emerged as a difficult decision and significant cause of regret upon reflection.

Gaining first-hand experience for fire evacuation allows people to offload the cognitive effort of making these decisions to previously planned actions (Boehm et al., 2021), but

it poses physical and psychological risks. A safer alternative is an immersive VR training that is informed by real-world experience. Therefore, people who live in areas with high fire risk could be trained to prepare for evacuation without harm and gain the crucial knowledge required to make informed decisions during wildfire evacuation.

Public safety officials (e.g., firefighters) are often trained to assist the public in evacuations utilizing a combination of real and virtual experiences. However, as our interviews indicated there is disagreement between the public and public safety officials on the process and timing of evacuations. A previous study by Cohn and colleagues (2006) examined behavior during wildfire evacuations using semi-structured interviews to examine the social structure factors of the evacuations. Cohn et al., (2006) also pointed out that evacuees and public safety officials have different perceptions and concerns about the evacuation process. This study focused on the social structure factors of the evacuations rather than preparation or thoughts on the experience (Cohn et al., 2006). Interviews more focused on personal narratives and reflection were more suitable for understanding civilian fire evacuation preparation.

Conclusions

One of the most prevalent themes was regret in response to poor planning and item management during evacuation, usually in response to sentimental items that were not collected or pets that were not rescued prior to evacuation. Interviewees still expressed regret even months after their wildfire evacuation.

A lack of experience left people with regrets over their decisions during the evacuation process. As WUI's continue to expand, more people are experiencing increased fire risk without the critical knowledge of how to prepare for evacuations (Theobald & Romme, 2007). These individuals need guidance for decision making during wildfire disasters. Based on our findings, an open-source evacuation training informed by real-world experience is essential for individuals to reduce stress and increase efficiency when preparing for wildfire evacuation. In identifying these needs, we hope to motivate future research in creating a community-based platform that will help increase fire preparedness and safety for novice fire evacuees in expanding WUI's.

Practical Takeaways

- Accessing and sharing information is a critical part of the wildfire evacuation experience. Individuals who have evacuated from wildfires often expressed regret in response to poor planning and item management due to lack of experience.
- Based on our findings, we can leverage the experience of wildfire evacuees to create a virtual reality wildfire evacuation training to better prepare communities at risk for wildfire disasters.

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