Travel Behaviour and Society 35 (2024) 100729

Contents lists available at ScienceDirect

Travel Behaviour and Society

journal homepage: www.elsevier.com/locate/tbs

Analyzing Risk Perception, Evacuation Decision and Delay Time: A Case Study of the 2021 Marshall Fire in Colorado

Ana Forrister [a], Erica D. Kuligowski [b,*], Yuran Sun [a], Xiang Yan [a], Ruggiero Lovreglio [c], Thomas J. Cova [d], Xilei Zhao [a]

[a] Department of Civil and Coastal Engineering, University of Florida, US
[b] School of Engineering, RMIT University, Australia
[c] School of Built Environment, Massey University, New Zealand
[d] Department of Geography, University of Utah, US

ARTICLE INFO

Keywords:
Wildfires
Evacuation
Decision-making
WUI
Bushfires
Delay Time

ABSTRACT

Climate change is increasing the threat of wildfires to populated areas, especially those within the wildland-urban interface (WUI). The 2021 Marshall fire forced the evacuation of over 30,000 people in Boulder, Jefferson and Adams Counties in Colorado, US. To improve our understanding of wildfire evacuation response, we surveyed individuals affected by the Marshall fire to analyze their evacuation decisions and resulting behavior. We used linear and logistic regression models to determine the factors influencing individuals' risk perceptions, their decisions to evacuate or stay, and the associated evacuation delay times. We found higher levels of risk perception at the time of the evacuation decision were associated with higher levels of pre-fire perceived risk, having mid-level household income, the receipt of fire cues and having a medical condition. Increased pre-event risk perception increased the likelihood of evacuating, along with gender (female-identified), being aged between 55 and 64 years, and having a higher household income. On the other hand, having a prior awareness of wildfires had a negative effect on evacuation likelihood. Additionally, having previous experience with fire damage, owning their home, having a larger household size and being alerted later in the fire event reduced the delay time; whereas engaging in preparation activities and having children in the home led to longer delay times. These research findings can be used by emergency managers to better prepare WUI communities for future wildfire events.

1. Introduction

Climate change and population growth in areas closer to the wildlands are increasing the frequency and intensity of wildland fires across the globe (Bowman et al., 2020). Looking to the future, a recent report estimates a 14 % global increase in extreme fires by 2030, a 30 % increase by the end of 2050, and an increase of 50 % by the end of the century (United Nations Environment Programme, 2022). These changes highlight the importance for emergency planners and decision-makers at all levels of government to develop safe and effective strategies to protect the public from current and future fire scenarios. A policy often enacted during wildfire events is evacuation – assisting people to leave areas exposed to fire before the fire (and even the smoke) fronts arrive.

Evacuation planning and decision-making require an understanding of the behavior of the people affected by these fire events. Wildfire evacuation behavior studies have been conducted to identify the factors that can shape evacuation decisions. The literature has suggested that important factors affecting the decision-making process include warnings and fire cues, individuals' prior experience and knowledge, and their socio-economic and demographic characteristics (Folk et al., 2019; McLennan et al., 2019). However, most of these studies have primarily focused on studying areas categorized as rural or *peri*-urban (also referred to as the wildland-urban interface, or WUI) (Comfort et al., 2019; Kuligowski et al., 2020; McLennan et al., 2013; Mozumder et al., 2008; Strahan and Watson, 2019; Whittaker et al., 2020). More recently, there has been a growing number of fires affecting more densely populated areas such as the suburb or urban fringe of large cities, which have been increasingly exposed to fire risks (Radeloff et al., 2018; Kuligowski et al., 2022; Wong et al., 2022). For example, while only 4 %

* Corresponding author at: School of Engineering, STEM College, RMIT University, Melbourne, VIC 3000, Australia.
E-mail address: erica.kuligowski@rmit.edu.au (E.D. Kuligowski).

https://doi.org/10.1016/j.tbs.2023.100729
Received 14 July 2023; Received in revised form 6 November 2023; Accepted 25 November 2023
Available online 11 December 2023

of the 89 California wildfires that burned between 1985 and 2013 and destroyed at least one building actually burned non-WUI urban areas, 25 % of the total destruction caused by the 2017 Tubbs fire in California impacted non-WUI urban areas (Kramer et al., 2019). Since these areas often have sociodemographic and built environment characteristics distinct from WUI areas, it is uncertain if the prior knowledge is transferable. As such, there is the need for more research on wildfire evacuations in more densely populated regions to assess the differences between evacuation outcomes in rural or *peri*-urban areas and evacuation outcomes from suburban areas.

This paper aims to provide new data and insights on how individuals located in densely populated regions make decisions in wildfires. To this end, we analyzed the evacuation behavior of individuals during the 2021 Marshall Fire, which impacted a suburban area in Colorado, US from December 31, 2021, to January 1, 2022. This fire resulted in the evacuation of more than 30,000 people from an area not typically exposed to wildfire risk (Whelton et al., 2023). Expanding upon two previous survey studies (Kuligowski et al., 2022, 2020), a similar survey was disseminated to towns affected by the Marshall fire to understand individual risk perceptions and evacuation decisions as well as the decisions that evacuees made regarding departure times during their evacuation process. Comparing the results from the Marshall fire with the results of other case studies (in California and Tennessee) investigated using a similar questionnaire, can provide some insights on the applicability of previous studies to more densely populated areas.

This study contributes to the existing literature by providing new empirical evidence from the 2021 Marshall fire, which had a very short lead time and fire duration and exposed significant gaps in the local emergency alert systems (McKinley, 2022). By studying risk perception and evacuation decisions, the findings of this work will help to confirm and expand the current theory on evacuation decision-making during wildfires (Kuligowski et al., 2022). Additionally, due to limited research on departure times during wildfires, this study will improve our understanding of evacuation behavior by investigating how different individual, social and environmental factors influence delay times.

The paper is structured as follows: Section 2 provides a comprehensive review of existing literature on wildfire evacuation decision and departure time modeling with a focus on the influential factors and their relationship with evacuation decision-making. Section 3 introduces the methods used in this paper, including the study site selection, the sampling strategy, the survey instrument, and data processing and analysis. Section 4 provides the quantitative results from the survey, including descriptive statistics and regression analysis predicting risk perception, evacuation decision, and delay time. Section 5 discusses the major findings of the work and compares these with previous US fires studied by the author team; and Section 6 concludes the paper.

2. Literature review

Most of the studies predicting wildfire evacuation behavior focus on understanding the factors that influence the binary evacuation decision of stay or go as well as wait and see decisions (Folk et al., 2019; Lovreglio et al., 2019; McCaffrey et al., 2018). To date, existing literature puts less emphasis on the perceptions that influence evacuation decisions and subsequent evacuee travel behaviors, including choices of departure timing (Kuligowski, 2021). The following sections will review the factors that influence the evacuation decision in Section 2.1, risk perceptions (at the time of evacuation decision) in Section 2.2, and departure time collected from studies of wildfire events in Section 2.3.

2.1. Modelling evacuation decisions

Many factors have been identified by previous wildfire studies as influential of the decision to evacuate (i.e., stay and defend/shelter or leave). First, higher levels of risk perception are strongly linked with the decision to evacuate (Katzilieris et al., 2022; Kuligowski et al., 2020, 2022; McLennan et al., 2015a; Mozumder et al., 2008; Strahan et al., 2019; Strawderman et al., 2012; Wong et al., 2022); however, not all studies have found support for this relationship (Paveglio et al., 2014). Additional factors include prior actions and experience, social and environmental cues, emergency alerts and warnings, and characteristics of the individual or household, each of which will be described in the remainder of this section.

Pre-event preparation actions and previous experience with fires can also influence evacuation behavior. In particular, having an evacuation plan in place has led to a greater likelihood of evacuation (Kuligowski et al., 2020; McLennan et al., 2012); while performing mitigation actions on the property prior to the wildfire event had the opposite effect (Kuligowski et al., 2020; McCaffrey et al., 2018; Strahan and Watson, 2019). Additionally, having a past experience with a wildfire event (Mehta et al., 2022), experiencing property damage (Mozumder et al., 2008) and/or evacuating from a previous wildfire (Penman et al., 2016; Strawderman et al., 2012) has been found to influence individuals to evacuate in future wildfire events. However, not all studies agree (Wong et al., 2022).

Other factors that have been found to influence evacuation decision-making are emergency alerts and warnings and social and environmental cues. The probability of evacuation has been found to increase when the individual receives a mandatory or voluntary evacuation order (Kuligowski et al., 2022; Strawderman et al., 2012; Wong et al., 2022). Receiving this order from a trusted source also increased the likelihood of evacuation (Kuligowski et al., 2020), and the receipt of information from unofficial networks (e.g., friends, family, and neighbors) has also influenced individuals' evacuation decisions (Whittaker et al., 2016). Additionally, the observance of environmental cues, e.g., smoke, embers, flames, and the receipt of information on the fire location helped influence evacuation decisions (McLennan et al., 2012); however, another study found the opposite, mainly because people who witnessed cues from the fire were those who had already decided to stay (Kuligowski et al., 2022). Those who decided to wait and see relied on environmental cues as part of their decision-making process (McCaffrey et al., 2018).

The final notable factors that influence evacuation behavior are individual and household characteristics. Age (older), gender (men) and lower household income were found to increase the probability of deciding to stay (Alsnih et al., 2005; Eriksen et al., 2010; Katzilieris et al., 2022; Kuligowski et al., 2020; Paveglio et al., 2014; Whittaker et al., 2016). However, other studies have found that those with higher income were more likely to stay in place (McCaffrey et al., 2018). In addition, having a longer residence time, pets or livestock, and an emotional attachment or personal responsibility to defend their property contributed to a higher likelihood to stay and defend (Kuligowski et al., 2022; McLennan et al., 2013; Mozumder et al., 2008; Wong et al., 2022). Also linked to staying and defending were having lower levels of education or a perception that the house was well-built and safe for a wildfire (i.e., staying home was safer than evacuating) (Kuligowski et al., 2022). Finally, households with children (McLennan et al., 2012; Wong et al., 2022) and individuals who owned their homes (Katzilieris et al., 2022; Kuligowski et al., 2022) were linked with an increased likelihood of evacuation.

2.2. Risk perception

A fewer number of studies examine the factors that influence people's levels of risk perception *during an event* in reference to their evacuation decision-making during a fire event (Kuligowski, 2021). From the studies that have been conducted, the factors found to increase levels of risk perception include having higher education levels (i.e., graduate degrees) (Kuligowski et al., 2022; Mozumder et al., 2008), holding a belief that their home did not provide safety in a wildfire, and perceiving higher levels of perceived threat (i.e., higher beliefs that their home or neighborhood would be damaged or destroyed by fire)

Table 1
Factors affecting evacuation decision, risk perception, and delay time in previous studies.

Factor	Evacuation Decision	Risk Perception	Delay Time*
Prior awareness/ knowledge about fire and/or evacuation		+	–
Prior experience	+/-	+**	-**
Plan (to evacuate), with destination	+		–
Pre-event mitigation actions	–		
Longer residence time	–	–	+
Home ownership	+		
Emotional attachment to home	–		
Residence type (single-family)			–
Children in the household	+		–
Perception of home safety	–	–	+
No. of adults in the household		–	+
Having pets/livestock	–	–	
Income (lower)	+/-		
Education (lower levels)	–	+	–
Gender (female)	+		–
Age (older)	–		+
Receipt of warning from official or unofficial source	+		
Received voluntary or mandatory order via a trusted source	+	+	
Environmental cues	+/-	+/-	
Threat assessment		+	
Risk Perception	+/-		
Engaging in preparation activities			+
Families staying together			+/-

Note: "+" indicates a significant factor with an increased probability of evacuating; "-" indicates a significant factor with a decreased probability of evacuating; "+" indicates a higher level of risk perception; "-" indicates a lower level of risk perception; "+" indicates a longer delay time; "-" indicates a shorter delay time.
*Encompasses both wildfire and hurricane data/studies.
**In these cases, "previous experience" refers only to experiencing property damage from a previous fire.

(Kuligowski et al., 2022). Additional factors that have been found to increase risk perception are residence time (i.e., having lived in an area for a shorter period of time), having experienced property damage from a previous fire, and having a higher levels of awareness of (or knowledge about) fires (Benight et al., 2004; Mozumder et al., 2008; Whittaker et al., 2021). Environmental factors such as observing fire cues, which include flames and embers, receiving fire information from a trusted source, learning about the impacts of the fires on friends and loved ones, and observing others evacuating during a fire event can also increase levels of risk perception (Kuligowski et al., 2020; McLennan et al., 2013, 2012; Whittaker et al., 2021). Observing smoke, however, may have a more complicated relationship with risk perception (Kuligowski et al., 2020). Finally, household factors, including having a higher number of adults in the household and having pets or other animals at home were linked to lower levels of risk perception during an event (Kuligowski et al., 2022).

2.3. Modelling delay time

Delay time is also understudied within the field of wildfire evacuations. Delay time can be defined as the time between acknowledgement that something out of the ordinary is happening and engagement in protective action behaviors (e.g., evacuation or sheltering/defending in place). However, different definitions have been provided in the literature. For instance, Grajdura et al. (2021) refers to delay time as "preparation time" and introduces terminology to mark its starting and ending points, namely "awareness time" and "departure time", respectively. Other researchers have divided delay time into different phases: decision time and mobilization time, which begins once a decision to evacuate or not is made (Sadri et al., 2013; Sorensen, 1991). In this context, the main behavior performed during decision time would be information-seeking. Mobilization time, often used in hurricane research, refers to the time period after an evacuation decision is made until evacuation travel begins, and this phase often involves engagement in preparation and helping behaviors (Kuligowski, 2021).

In studies of wildfire evacuations, a number of factors have been shown to increase delay time (Folk et al., 2019). A significant factor leading to evacuation delay in many studies was individuals' or households' decisions to 'wait and see' before deciding on evacuation (Paveglio et al., 2014; Strahan and Gilbert, 2021). Research has shown that the tendency to 'wait and see' is related to people's interest in waiting to see how the fire develops and/or spreads, and has been explained as a strategy to improve the chances of both: protecting their property and increasing safety of themselves and their loved ones (Strahan and Gilbert, 2021). In this case, both the act of evacuating and the act of staying in place are equally desirable (McNeill et al., 2015). Other factors that influence the choice to 'wait and see' include: perceiving waiting/staying in place as low risk or a safer choice (Cohn et al., 2006; McLennan et al., 2015b) and a lack of knowledge on how to evacuate the area safety (McLennan et al., 2014; Strahan and Gilbert, 2021). Once a decision to evacuate is made, delay times can be extended by the performance of certain types of preparatory actions, such as, gathering supplies or belongings during the event (Benight et al., 2004) and the tendency for families and/or neighbors to leave together (Cohn et al., 2006). However, other research has found evidence for split evacuation approaches among households (Stasiewicz and Paveglio, 2021; Whittaker et al., 2016). Research has also identified individual or household characteristics that can increase or lengthen overall delay times, and those include gender (men) and residence time (greater than 15 years) (Grajdura et al., 2021).

Due to a lack of delay time studies in wildfire evacuation, research on hurricanes and other hazards has also been consulted to identify additional influential factors (Folk et al., 2019). Examples of additional demographic factors that have been linked to greater delay times were older age, higher education levels, having a larger household size, living in a mobile home, and not having an evacuation destination identified in pre-event planning (Alawadi et al., 2020; Lindell et al., 2011, 2005; Petrolia and Bhattacharjee, 2010). On the other hand, factors linked to shorter delay times included household make-up (i.e., having children living in the household), residence type (detached, single-family dwelling) and previous experience with hurricanes (i.e., those with prior damage experience) (Alawadi et al., 2020; Sorensen, 1991).

2.4. Summary and hypotheses

Table 1 compiles the key factors identified in previous research as

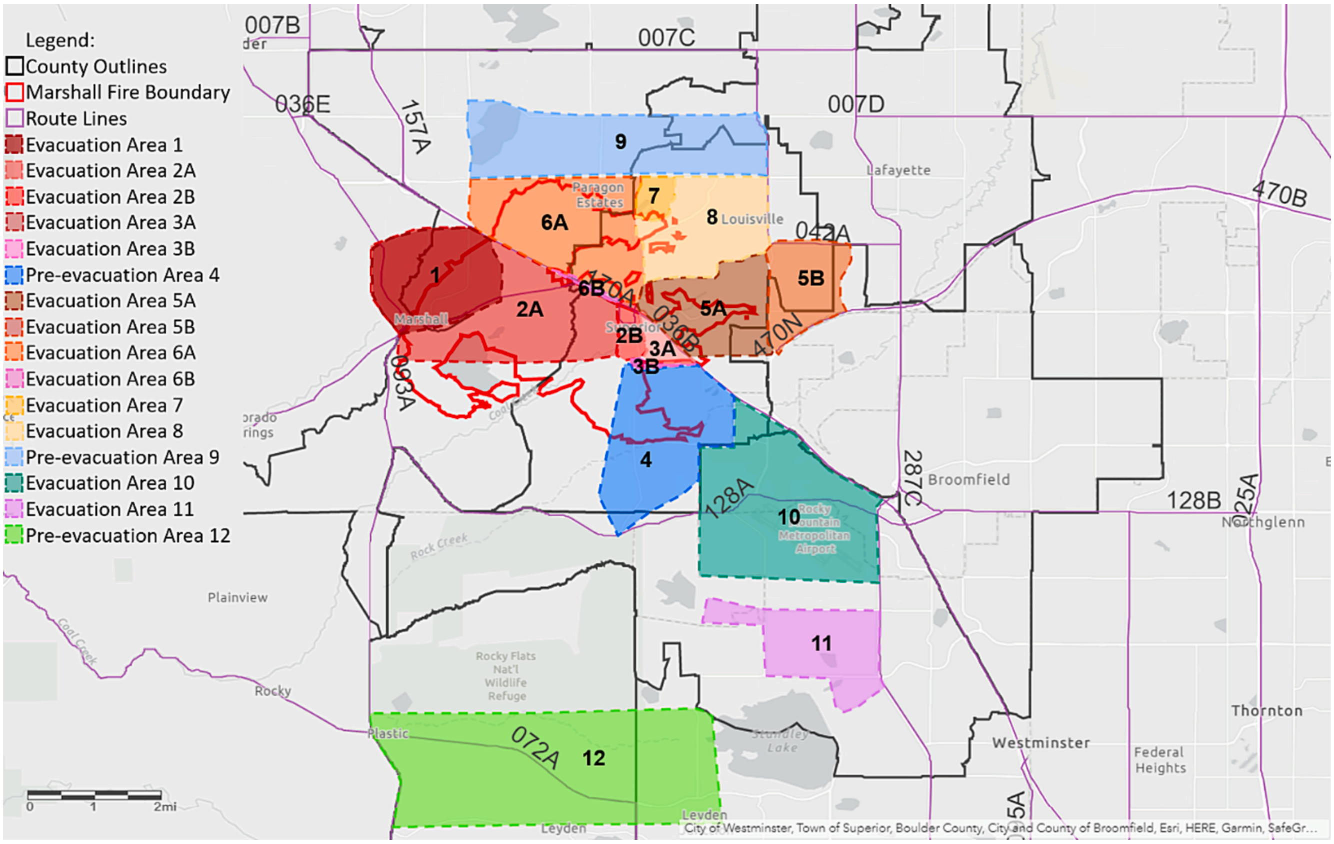

Fig. 1. Evacuation order and pre-evacuation warnings for the Marshall Fire.

influential on evacuation decision, risk perception (at the time of that decision), and delay time, as presented in Sections 2.1-2.3. In Table 1, the findings for evacuation decision and risk perception were taken from wildfire studies only, and the findings for delay time were taken from both wildfire and hurricane studies. In each column, ("+") refers to the factors that led to an increase in the probability of evacuation, an increase in levels of risk perception, and an increase in delay time; while ("-") refers to factors that led to a lower probability of evacuation, a decrease in risk perception levels, and a reduction in delay time. The use of ("+/-") refers to factors where the findings from research disagree. Only the factors relevant to wildfire studies are included in Table 1 and where cells are left blank, no research was found on the relationship between the two variables.

Additional research is needed on residential responses to wildfires, and in particular, the factors that influence individuals' risk perception (at the time of evacuation decision) and the subsequent influence of risk perception along with other variables on the decision to evacuate. Additionally, there is an obvious gap in our understanding of the factors that influence delay times during wildfires. In turn, this research focuses on predicting risk perception, evacuation decisions, and delay time during a wildfire event. The hypotheses of this study are the following:

1. Significant relationships will be found between ***evacuation decisions*** and the following factors: previous experience, pre-event planning and mitigation activities, residence time, perceptions of safety and risk, household characteristics (ownership, emotional attachment, and the presence of children or pets), emergency communication, environmental cues, and demographics (income, education, gender, and age).
2. The following factors will be significantly linked to ***risk perception at the time of evacuation decision***: prior awareness of the fire, previous experience, residence time, perceptions of safety and threat, household characteristics (number of adults and presence of pets), emergency communication, environmental cues, and demographics (education).
3. A number of factors will be significantly linked with ***delay time*** in our case study wildfire event: prior awareness/knowledge of the fire, previous experience, pre-event planning, residence time, perceptions of safety, household characteristics (number of adults and the presence of children), residence type, demographics (education, gender, and age), and engaging in preparation activities. The factor of household evacuation approaches (e.g., together or split evacuation strategies) cannot be tested in this study since we did not collect specific home addresses in our survey (and therefore, in the cases where multiple adults from the same household responded to the survey, we cannot link their responses together).

These hypotheses represent a valuable starting point for the creation of the survey instrument used in this study as well as for the specification of three independent models proposed in this work.

3. Methods

The purpose of this study is to determine the key factors that influenced the decision to evacuate, risk perception, and delay time for those respondents directly affected by the Marshall Fire. This section discusses the methods used in this study, including a discussion of the study context (Section 3.1), the sampling strategy (Section 3.2), the survey instrument (Section 3.3), and data preprocessing (Section 3.4).

3.1. Case study context

The Marshall fire started shortly before 10:30 a.m. on December 30, 2021 in Boulder County, Colorado, and via two ignition points within the County, expanded to a number of suburban areas in Boulder, Jefferson and Adams Counties, including Louisville, Superior, Broomfield,

Table 2
An overview of the timeline of emergency communications for the Marshall fire for December 30, 2021.

County/City	Notification type	Time initiated	Areas in Fig. 1	No. issued[A]	Location specifics, if any provided
Boulder County					
	Order	11:47am	1	215	Highways 93 and Marshall
	Order	12:15pm	2A, 2B	2,588	
	Order	12:46pm	3A, 3B	254	
	Warning	12:49pm	4	4,173	Southern Superior
	Order	1:08pm	5A, 5B	7,251	McCaslin and Highway 36
	Order	1:15pm	6A, 6B	2,509	
	Order	1:25pm	7	276	
	Order	2:51pm	8	4,806	City of Louisville
	Warning	2:58pm	9	2,217	Cherryvale and South Boulder
City of Broomfield					
	Pre-evacuation	2:52pm	10		Apartment complexes in the area
	Order	5:18pm	10		Broomfield, particularly for the Interlocken area and west of Wadsworth Parkway between US 36 and 112th Avenue
	Order (expanded)	6:40pm	10		South of Highway 128 between Simms Street and Indiana Street
City of Westminster					
	Pre-evacuation	7:20pm	11		Westminster Dog Park and Meadow View Community
	Pre-evacuation	7:50pm	11		Meadow View neighborhood
	Order	8:40pm	11		Meadow View neighborhood
City of Arvada					
	Pre-evacuation	7:59pm	12		Areas north of 82nd Avenue between Highway 93 and Standley Lake

[A] The data for the number of messages issued (or the number of people to whom the messages were sent) is not available for all locations.

Lafayette, Arvada, and Westminster. The unusually humid Spring and the following warm and dry Summer and Fall months resulted in dry fuel and favorable conditions for the wildfire. Fire spread was also accelerated due to dry winds in excess of 115 miles per hour (Slevin et al., 2022; Stein, 2022). The fire, which is considered the most destructive in Colorado, burned over 6,200 acres, destroyed 1,084 homes, damaged 149 homes, and caused the deaths of two people (Case, 2022; Fischer et al., 2022; Zialcita, 2022). Estimates for the approximate value of residential damage in Boulder County alone place the total cost at over $513 million (Fischer et al., 2022).

On December 30, 2021, more than 30,000 people were prompted to evacuate in locations within Boulder, Jefferson and Adams Counties due to the Marshall fire (Camero, 2021; Cronin, 2022). Fig. 1 displays the corresponding evacuation and pre-evacuation areas for the affected communities and Table 2 provides an overview the timeline of emergency communication for the Marshall fire on December 30, 2021 (Boulder Co Sheriff's Office, 2021; Ivy et al., 2021).

Pre-evacuation notices for Arvada were lifted by 9:15 pm, pre-evacuation notices and orders for Meadow View in Westminster were lifted by 10:56 pm, and all warnings and orders for all other areas in Broomfield and Boulder County were lifted by 11:55 pm on December 30th (Ivy et al., 2021).

3.2. Sampling strategy and final sample

An online survey of individuals affected by the Marshall Fire was conducted from May 18, 2022, to June 12, 2022. This project was approved by the University of Florida Institutional Review Board (#IRB201903432), and all participants gave their consent before participating in the survey. Participants were recruited using two methods. First, social media posts were used to publicize the survey on Twitter and Facebook. Respondents were screened via a question asking for their zip code, and only those who provided a zip code within the impacted area (i.e., 80027, 80303, 80021, 80007, 80026, and 80020) could continue. For the second approach, a survey company, Qualtrics, was employed to recruit an online panel of respondents from the 20 Zip Codes in or close to the impacted area of the Marshall Fire. Incentives were provided to participants regardless of the recruitment method. A total of 294 valid respondents were obtained for this study, comprising 57 from social media platforms and 237 from the Qualtrics panel. Of these, 83 responses were excluded from the analysis as they were not located within or directly adjacent to the study area (i.e., the evacuation warning or order zones). The final sample for this study, collected using a convenience sampling approach, included a total of 191 responses. Fig. 2 displays a heat map of the number of survey responses within each part of the study area by zip code.

Females made up a higher proportion of survey respondents (62 %), and the mean age of the respondents was 38 years with a standard deviation of 13.90. Most respondents (82 %) were employed at the time of the Marshall fire. For the racial makeup, 78 % of the respondents are white, which is similar to the study area (80 %) (US Census Bureau, 2020). Moreover, the household income of our survey respondents appears to be somewhat representative of the median household income levels of the impacted municipalities: Boulder ($72,279), Westminster ($76,378), Lafayette ($85,909), and Arvada ($92,669), Louisville ($116,000), Broomfield ($101,206), and Superior ($126,000). Additionally, a majority of respondents received some level of higher education (21 % 'some college but no degree', 17 % 'associate degree', 27 % 'bachelor's degree', and 22 % 'graduate degree'), resulting in an over-representation of college graduates among our survey participants. Most respondents owned their homes (60 %) and had no medical conditions (75 %).

3.3. Survey instrument

The survey instrument collected data on multiple factors that impact

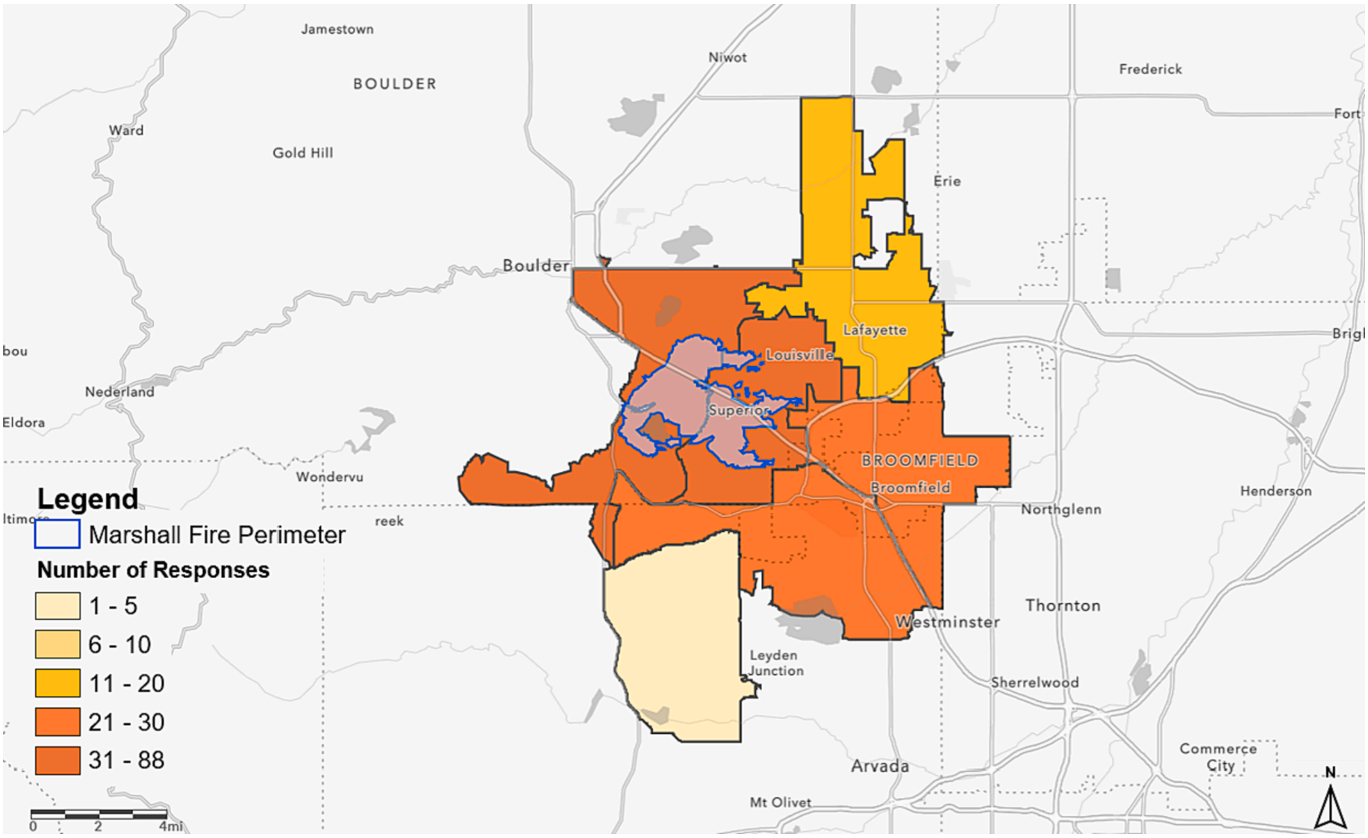

Fig. 2. Marshall Fire Survey Area and Sample Distribution.

risk perceptions, evacuation decisions, and delay time. The survey questions were similar to those used in the studies of the 2016 Chimney Tops 2 fire in Gatlinburg, Tennessee (Kuligowski et al., 2020) and the 2019 Kincade fire in Sonoma County, California (Kuligowski et al., 2022) so that comparisons could be made across fires. All three surveys were designed based on Lindell and Perry's Protective Action Decision Model (PADM) (Lindell and Perry, 2012) and included questions commonly used in prior evacuation studies (Sorensen et al., 2009; Sorensen and Mileti, 2018; Strahan et al., 2018). The PADM outlines people's behavioral responses to natural hazards and disasters, which in this case, was applied to a wildfire event. The model purports that a set of initial factors (e.g., environmental cues, social cues, alerts/warnings, and receiver characteristics) begins a decision-making process. People must engage in a series of pre-decisional processes (exposure, attention and comprehension) and make assessments of the threat, the actions necessary, and key stakeholders. Finally, people decide upon the best course of action by taking into account both situational facilitators and impediments to the behavioral response. The elements of the PADM also formed the basis of our risk perception and evacuation decision models (Lindell and Perry, 2012). The full survey is published on GitHub: https://github.com/EvacuationBehavior/2021-Marshall-Fire-Survey-Study.

Survey responses were entered into R, version 4.2.3. This statistical tool was utilized for data preprocessing, estimating descriptive statistics, and regression analyses.

3.4. Data preprocessing

Data re-coding was conducted before final data analysis could be performed. Table 3 provides a description of the variables analyzed here and links them with the corresponding survey questions. Additional details on data recoding, where necessary are also included in Table 3.

Questions on both threat assessment and risk assessment (at the time of evacuation decision) were included in the analysis. The threat assessment question contained three items (focused on belief about damage to home, neighborhood and town) and risk assessment contained four items (asking about likelihood of injury or death). One score for 'Risk Perception' and one score for 'Threat Assessment' were derived for each participant using a maximum-likelihood factor analysis carried out using the 'Stat' package in R (Bolar, 2019). The analysis generated item weights and combined scores were generated from the four items for 'Risk Perception' and the three items for 'Threat Assessment'.

Among the variables included in the models, missing values existed for 'Preparation' (1.57 %), 'Emergency plan' (1.05 %), 'Gender' (0.52 %), 'Education' (0.52 %), 'Income' (3.14 %), and 'Medical condition' (2.62 %). We replaced missing values (including 'I don't know or don't remember' and 'I prefer not to answer this question' responses) with imputed values. For categorical variables, mode imputation was used and for continuous variables, missing values were replaced with the mean of remaining observations for that variable (Makaba and Dogo, 2019).

4. Results

The results of this work are discussed in this section. First, results from descriptive analyses are presented in Section 4.1, followed by results from the regression models predicting the probability of evacuation decisions, levels of risk perception, and delay times in Section 4.2.

4.1. Descriptive analysis

The descriptive statistics of each variable, their description, corresponding response percentages, and mean and standard deviation are reported in Table 4.

The data shows that over half (61 %) of the respondents had never evacuated from a wildfire before and 43 % of respondents had

Table 3
Variable and corresponding survey questions, response and variable type and additional details on data recoding.

Variable	Survey Question Number	Response Type	Variable Type	Details on data recoding, if necessary
Pre-fire awareness	Q2	Binary	Binary	Others: 0; Aware of wildfire as a community problem: 1
Pre-fire risk perception level	Q3	Multiple	Numeric	Perceived wildfire threat to property - 'Not at all likely': 1 to 'Very likely': 5
Preparation	Q4	Multiple	Binary	'No measures were taken': 0; Others: 1
Emergency plan	Q5a	Binary	Binary	
Prior damage experience	Q6c	Fill-in	Binary	No damage experience: 0; Others: 1
Residence time	Q9a	Multiple	Categorical	'< 5 yrs'; '10 + yrs' Reference category: '5 – 10 yrs'
Own home	Q9b	Binary	Binary	
Residence type	Q9c	Multiple	Categorical	'Detached home'; 'Multi-family home' Reference categories: 'Mobile home' and 'Other home types'
Warning/order: Official/unofficial source	Q10a, Q11a	Binary	Binary	Others: 0; Informed by emergency officials or known person: 1
Warning/order: In person	Q10b, Q11c	Multiple	Binary	Others: 0; Informed in person: 1
Awareness time	Q10c, Q11d, Q12b	Fill-in	Numeric	The earliest time informed by emergency officials, known person and fire cues (converted to minutes after 12 a.m.)
Delay time	Q10c, Q11d, Q12b, Q16e	Fill-in	Numeric	Departure time (Q16e) – Awareness time (converted to minutes after 12 a.m.)
Fire cues	Q12a	Multiple	Binary	Others: 0; Observed flames & ember: 1
Evacuation decision (dependent variable only)	Q13	Binary	Binary	Stay: 0; Evacuate: 1
Threat assessment	Q14	Multiple	Numeric	Calculated using Factor Analysis
Risk perception (at the time of evacuation decision)	Q15	Multiple	Numeric	Calculated using Factor Analysis
Preparation time	Q16d	Fill-in	Numeric	Converted to minutes
Gender	Q19	Binary	Binary	Others: 0; Female: 1
Age	Q21	Fill-in	Categorical	'Below 35 yrs';'55-64 yrs'; '65 + yrs' Reference category:'35-54 yrs'
Education	Q23	Multiple	Categorical	'Bachelor'; 'Graduate' Reference categories: 'High school diploma', 'Some college but no degree', 'Associate degree' and 'Less than high school diploma'
Income	Q24	Multiple	Categorical	'$50,000 - $74,999′;'$75,000 – $99,999′; '> $100,000′ Reference categories: 'Less than $24,999′ and '$25,000 - $49,999′
No. of adults	Q26	Fill-in	Numeric	Adults: 18 years old to 64 years old
Elders in household	Q26	Fill-in	Binary	No elders (above 65 yrs): 0; Has elders: 1
Children in household	Q26	Fill-in	Binary	No children (below 18 yrs): 0; Has children: 1
Animals	Q26	Fill-in	Binary	Others: 0; Pets lived in the household: 1
Household size	Q26	Fill-in	Numeric	No. of adults + No. of children + No. of elders (Above 65 yrs)
Medical condition	Q27a	Binary	Binary	

experienced one or two wildfires prior to the Marshall Fire. While around 65 % of respondents realized that wildfires could be a problem in their community prior to the start of the Marshall Fire, 64 % rated the possibility of a wildfire threatening their property as unlikely and 68 % had no household emergency plan for wildfires in place. Approximately 69 % of the respondents chose to evacuate, while 31 % chose to stay in place during the fire.

When considering the notification of residents during the Marshall Fire, approximately 65 % of respondents received a pre-evacuation notice, an evacuation warning or an evacuation order from an official source (e.g., fire agencies), often between 12:00p.m. and 4:00p.m. on December 30, 2021. The channels used most often when receiving notification from official sources were social media (such as Twitter or Facebook), text message, loudspeaker, or the public address system. Additionally, respondents (56 %) were also alerted or warned to evacuate by someone they knew, often via face-to-face, telephone, and text messaging channels.

4.2. Regression models

We developed three regression models to estimate the factors that influenced individuals' evacuation decisions, risk perception, and delay time: 1) a binary logistic regression for investigating the impacts of different types of factors on evacuation decisions (stay or go), 2) a multivariate linear regression for identifying the factors that influenced respondents' risk perception at the time of the individual's evacuation decision; and 3) a multivariate linear regression for determining the factors which significantly affected respondents' delay time. For each model, multicollinearity was checked by using the variance inflation factor (VIF), and the results show that all VIF values are less than 5, indicating multicollinearity is not of concern for these three models. Note that in order to ensure that all VIF values were less than 5 for all models, threat assessment was not included in the binomial logistic regression model and the linear regression model because of its high correlation with two other independent variables: pre-fire risk perception and fire cues.

The results of the logistic model estimating the probability of evacuation decisions (stay/go) are illustrated in Table 5 The binomial logistic regression model findings with a significant or marginally significant level of 0.10 (i.e., p-value < 0.10) are shown in bold. Being aged 55 to 64 years (compared with the reference age group of less than 35 years) (p =.064), being female-identifying (p =.087), and having increased levels of pre-event wildfire risk (p =.027) increased the likelihood of deciding to evacuate during the Marshall fire. Additionally, higher-income householders (p =.009; p =.054) (those within the income bracket of $75,000 to $99,999 and greater than $100,000, respectively)

Table 4
Descriptive statistics.

Variable	Description	Percent	Mean ± SD
Risk perception level (at the time of evacuation decision)			0.00 ± 0.98
Delay time (mins)			136.59 ± 263.44
Evacuation decision	Stay	30.89	
	Evacuate	69.11	
Pre-fire awareness	Yes	64.92	
	No	35.08	
Preparation	Yes	42.41	
	No	57.59	
Emergency plan	Yes	29.84	
	No	70.16	
Residence time	Less than 5 years	50.79	
	5–10 years	19.37	
	10 or more years	29.84	
Home ownership	Rent	39.04	
	Own	60.96	
Residence type	Detached single family	57.59	
	Mobile or manufactured home	34.03	
	Others	8.38	
Children in household	No	59.69	
	Yes	40.31	
Elders in household	No	79.58	
	Yes	20.42	
Prior wildfire experience	No experience	36.65	
	1–2 experience(s)	42.93	
	More than 2 experiences	20.42	
Prior evacuation experience	No	60.73	
	Yes	39.27	
Prior damage experience	No	80.63	
	Yes	19.37	
Animals (in the household or on the property)	No	65.45	
	Yes	34.55	
Warning/order: Official/unofficial source	No	34.55	
	Yes	65.45	
Warning/order: in person	Warnings received face-to-face	10.29	
	Warnings received other ways	89.71	
Fire cues	No	72.25	
	Yes	27.75	
Medical condition	Household members have no medical conditions	75.81	
	Household member has a medical condition	24.19	
Education level	Bachelor's degree	27.89	
	Graduate degree	22.63	
	Others	49.48	
Income	Less than $50,000	18.92	
	$50,000-$74,999	22.16	
	$75,000-$99,999	18.38	
	More than $100,000	40.54	
Gender	Male	37.70	
	Female	62.30	
Age	Less than 35 years	42.93	
	35–54 years	45.03	
	55–64 years	6.28	
	More than 65 years	5.76	
No. of adults (in the household)			2.08 ± 1.02
Threat assessment level			0.00 ± 0.97
Awareness time (mins)			701.40 ± 200.23
Preparation time (mins)			63.64 ± 84.50
Household size			3.33 ± 1.53
Pre-fire risk perception level			2.29 ± 1.25

Table 5
Binomial logistic regression of evacuation decision (N = 191).

Variable	Estimate	Std. Error	z-statistic	p-value
(Intercept)	−2.362	1.274	−1.854	0.064
Pre-fire awareness	**−1.141**[a]	**0.505**	**−2.261**	**0.024**
Pre-fire risk perception level	**0.470**	**0.213**	**2.205**	**0.027**
Preparation (yes)	−0.319	0.470	−0.679	0.497
Emergency plan (yes)	0.396	0.476	0.832	0.405
Residence time: < 5 yrs[b]	0.127	0.554	0.229	0.819
Residence time: 10 + yrs	−0.496	0.617	−0.803	0.422
Own home	0.042	0.511	0.083	0.934
Residence type (detached home)[b]	0.462	0.711	0.652	0.514
Residence type (multi-family home)	0.216	0.706	0.306	0.760
No. of adults	−0.082	0.229	−0.357	0.721
Children (yes)	0.135	0.498	0.271	0.787
Animals (yes)	0.367	0.459	0.799	0.424
Income: $50,000 - $74,999[b]	0.683	0.591	1.155	0.248
Income: $75,000 - $99,999	**1.943**	**0.749**	**2.594**	**0.009**
Income: >$100,000	**1.312**	**0.681**	**1.927**	**0.054**
Age: 35 – 54 yrs[b]	0.719	0.447	1.607	0.108
Age: 55 – 64 yrs	**2.286**	**1.236**	**1.849**	**0.064**
Age: 65 + yrs	0.786	1.078	0.729	0.466
Gender (female)	**0.776**	**0.454**	**1.709**	**0.087**
Education: Bachelor[b]	−0.399	0.536	−0.745	0.456
Education: Graduate	−0.317	0.686	−0.462	0.644
Medical condition (yes)	0.421	0.517	0.813	0.416
Warning/order: Official/unofficial source	0.704	0.610	1.154	0.249
Warning/order: In person	−0.029	0.411	−0.069	0.945
Fire cues	0.611	0.417	1.465	0.143
Risk perception	−0.275	0.225	−1.221	0.222

Notes: a. Bold font indicates statistical significance at the 0.1 level. We adopted this level of significance due to the small sample size (N = 191).b. the base values for Income, Residence time, Education, and Residence type are Income: 'Less than $24,999′ and '$25,000 - $49,999′, Residence time: 5–10 yrs, Education: 'High school diploma', 'Some college but no degree', 'Associate degree' and 'Less than high school diploma', and Residence types: 'mobile home' and 'other home types', respectively.

Table 6
Linear regression model of risk perception at the time of decision (N = 191).

Variable	Estimate	Std. Error	t-statistic	p-value
(Intercept)	−0.852	0.416	−2.048	0.042
Pre-fire awareness	0.119	0.173	0.684	0.495
Pre-fire risk perception level	**0.192**[a]	**0.068**	**2.816**	**0.005**
Residence time: < 5 yrs[b]	−0.022	0.196	−0.114	0.909
Residence time: 10 + yrs	−0.080	0.217	−0.369	0.713
Own home (yes)	−0.198	0.186	−1.063	0.289
Residence type (detached home)[b]	−0.055	0.276	−0.200	0.842
Residence type (multi-family home)	−0.013	0.269	−0.050	0.960
No. of adults	−0.079	0.078	−1.016	0.311
Animals (pet) (yes)	0.253	0.162	1.568	0.119
Income: $50,000 - $74,999[b]	**0.474**	**0.227**	**2.091**	**0.038**
Income: $75,000 - $99,999	**0.498**	**0.238**	**2.094**	**0.038**
Income: >$100,000	0.196	0.243	0.803	0.423
Education: Bachelor[b]	0.134	0.183	0.730	0.467
Education: Graduate	0.204	0.224	0.910	0.364
Medical condition (yes)	**0.596**	**0.179**	**3.331**	**0.001**
Warning/order: Official/unofficial source (yes)	−0.149	0.214	−0.696	0.487
Fire cues (yes)	**0.495**	**0.146**	**3.384**	**0.001**

Notes: a. Bold font indicates statistical significance at the 0.05 level. We adopted this level of significance due to the small sample size (N = 191).
b. The base values for Income, Residence time, Education, and Residence type are Income: 'Less than $24,999′ and '$25,000 - $49,999′, Residence time: 5–10 yrs, Education: 'High school diploma', 'Some college but no degree', 'Associate degree' and 'Less than high school diploma', and Residence types: 'mobile home' and 'other home types', respectively.

Table 7
Linear regression of evacuee delay time (N = 129).

Variable	Estimate	Std. Error	t-statistic	p-value
(Intercept)	839.934	145.506	5.772	0.000
Awareness time	**−0.724**[a]	**0.109**	**−6.645**	**0.000**
Preparation time	**0.695**	**0.266**	**2.613**	**0.010**
Pre-fire awareness	52.798	47.493	1.112	0.269
Pre-fire risk perception level	−16.165	19.689	−0.821	0.414
Prior damage experience (yes)	**−129.911**	**54.922**	**−2.365**	**0.020**
Residence: < 5 yrs[b]	−71.189	55.373	−1.286	0.201
Residence: 10 + yrs	−7.436	60.968	−0.122	0.903
Own home (yes)	**−167.561**	**55.585**	**−3.014**	**0.003**
Residence type (detached home)[b]	60.595	78.622	0.771	0.443
Residence type (multi-family home)	59.356	77.858	0.762	0.448
Household size	**−53.335**	**19.885**	**−2.682**	**0.009**
Elders in household (yes)	53.258	55.653	0.957	0.341
Children (yes)	**116.571**	**68.911**	**1.692**	**0.094**
Income: $50,000 - $74,999[b]	−32.526	66.194	−0.491	0.624
Income: $75,000 - $99,999	64.222	66.789	0.962	0.339
Income: >$100,000	34.683	62.951	0.551	0.583
Education: Bachelor[b]	33.199	53.084	0.625	0.533
Education: Graduate	10.394	62.281	0.167	0.868
Age: 35 – 54 yrs[b]	−42.719	43.697	−0.978	0.331
Age: 55 – 64 yrs	−8.625	77.909	−0.111	0.912
Age: 65 + yrs	−150.519	122.080	−1.233	0.220
Gender (female)	−22.812	44.211	−0.516	0.607
Medical condition (yes)	5.344	51.662	0.103	0.918
Threat assessment	−20.255	26.939	−0.752	0.454
Risk perception (at the time of evacuation decision)	13.642	26.328	0.518	0.605

Notes: a. Bold font indicates statistical significance at the 0.1 level. We adopted this level of significance due to the small sample size (N = 191).
b. The base values for Income, Residence time, Education, and Residence type are Income: 'Less than $24,999′ and '$25,000 - $49,999′, Residence time: 5–10 yrs, Education: 'High school diploma', 'Some college but no degree', 'Associate degree' and 'Less than high school diploma', and Residence types: 'mobile home' and 'other home types', respectively.

were more likely to evacuate. On the other hand, having a prior awareness of wildfires (p =.024) had a negative impact on the probability of evacuating.

The results of the risk perception model and findings with a significance level of 0.05 (i.e., p-value < 0.05) are shown in bold in Table 6. The R-square of the model is 0.2, indicating a moderate fit. The model shows that the participants with higher levels of perceived risk (p =.005) (prior to the Marshall fire) also had increased levels of risk perception at the time of the evacuation decision. In addition, individuals of middle-income households (p =.038; p =.038) (those with income levels of $50,000 to $74,999 or $75,000 to $99,999, respectively) had higher levels of risk perception when compared with individuals of households within the lowest income category (less than $50,000). Receiving fire cues (p <.001), such as observing smoke or embers, and having a medical condition (p <.001) were also linked with increased levels of risk perception.

Finally, the results of the delay time model and the findings with a significant or marginally significant level of 0.10 (i.e., p-value < 0.10), shown in bold, are presented below in Table 7. The R-square of the model is 0.53, indicating a good fit. Preparation time (p =.010) (i.e., defined as the amount of time that the respondent took to prepare for departure after they had decided to evacuate) was found to be significantly associated with longer delay times. By contrast, we found that those who had prior experience with fire damage (p =.020), owned their homes (p =.003), had larger household sizes (p =.009), and had a later awareness time (p <.001) (i.e., the earliest time that the respondent received notice of a wildfire threat) had shorter delay times. For instance, a one-minute increase in awareness time was associated with a reduction of 0.7 min in delay time; and on average, having prior experience with fire damage reduced the delay time by about 130 min. Moreover, although the result is marginally significant at the 0.1 level, we found that having children within the home (p =.094) was associated with longer delays, adding an average of about two hours to the evacuation delay time.

5. Discussion of results

The analysis performed in this study has identified the factors that influenced the decision to evacuate, risk perception levels, and delay times during the 2021 Marshall fire. Overall, the results of this study only partially support Hypotheses 1, 2 and 3. Discussing the evacuation decision model first, this study found that people with higher incomes (Paveglio et al., 2014) and women were more likely to evacuate (Eriksen et al., 2010; Whittaker et al., 2016), which aligns with previous research. It should be noted; however, that rather than gender itself being the dominant factor, often household or gender roles are the drivers behind these results (Bateman and Edwards, 2002; Chowdhury et al., 2022). Other results were inconsistent with existing literature. While this study found that a specific age group (55–64 years old) were more likely to evacuate, previous research has found that older adults are less likely to do so (Alsnih et al., 2005). However, the authors acknowledge that results showing statistical significance of only one age category rather than showing a particular trend is indicative of a weak or nonexistent relationship.

Results from this model also contribute to new findings, including the linkages between higher levels of prior awareness and a lower likelihood of evacuating and higher levels of risk perception (prior to the Marshall fire) and higher likelihood of evacuating. The former relationship is similar to findings from Kuligowski et al. (2020) which found that people who had prepared for the fire season were less likely to leave the affected areas. In both cases, having higher levels of awareness about fires and/or preparing their homes or properties for the impending season may have given residents higher confidence in their abilities to protect themselves while staying in place. On the other hand, people who perceived higher levels of risk prior to the fire season were already on higher alert when the Marshall fire occurred, potentially expediting their process of confirming the risk and deciding to evacuate (Wood et al., 2018).

It is important to note that risk perception (at the time of evacuation decision) was not found to have a significant influence on the decision to evacuate. This is also counter to a number of studies whose results support this relationship, for example, Katzilieris et al. (2022), Kuligowski (2021) and Wong et al. (2022)). With that said, Kuligowski (2015) in her study of the 2001 World Trade Center evacuation found that a higher level of risk perception was not a necessary condition for evacuation. In some cases, the occupants were alerted or warned to leave by someone they trusted, and in turn, left the building while perceiving lower levels of risk. The same phenomenon could have occurred in the Marshall fire, during which over 50 % of people received alerts or warnings to evacuate from people they knew and potentially trusted.

The regression model predicting levels of perceived risk also confirmed certain results found in current wildfire literature. This study found that witnessing environmental cues from the fire, i.e., embers and/or flames, increased levels of perceived risk, which aligns with Kuligowski et al.'s (2020) study of the 2016 Tennessee fire in the US. With that said, other results from this model provide new insights to the field. First, perceiving a higher likelihood that fires, in general, would threaten their property prior to the Marshall fire led to higher levels of risk perceived at the time of evacuation decision. Upon reflection, it is logical that people who were concerned about wildfires before the Marshall fire would have had higher levels of concern during the actual event. Additionally, people with pre-fire medical conditions also had higher levels of perceived risk during the fire. Certain medical conditions, e.g., temporary mobility impairments or longer-term chronic conditions, like asthma, can render individuals more vulnerable to injuries or death in fire situations where evacuation is necessary (Cutter et al., 2003). Therefore, this result is also a logical one. Finally, certain income brackets had higher levels of perceived risk at the time of evacuation decision. However, since only two categories of income were statistically significant, and no specific trend in perceptions existed among people from lower or higher income households, this indicates a potentially weak relationship between the two variables.

Finally, novel insights were gained from the evacuation delay time model. Consistent with previous literature (Benight et al., 2004; Kuligowski and Mileti, 2009), spending longer amounts of time engaging in preparedness activities led to longer delay times. Evacuees from wildfires can engage in a number of different activities – including attending to pets or livestock (Taylor, 2016; Trigg et al., 2021), preparing their home or property, packing items to take with them, talking or milling with others (Wood et al., 2018) and planning for their evacuation (i.e., identifying routes and destinations) – and many of these can take significantly longer periods of time. Also consistent with current hurricane literature, this study found that experiencing previous fire events, and more specifically, damage to their homes from these events, decreased delay time (Alawadi et al., 2020). Additional research is needed to explore the role that negative experiences during fires and/or evacuation can have on evacuee delay time. Via qualitative analysis, Kuligowski et al.'s (2022) study of the 2019 Kincade fire in California, US discovered that evacuees who had experienced significant traffic congestion during the fire two years prior (2017) evacuated in 2019 even before an evacuation order was issued. The impact of these and other negative experiences in previous fires and their influence on future evacuation decisions and delay times warrants further study.

The delay model also identified results not previously studied in other fire literature. First, household size was linked with shorter delays, while householders with children were linked to longer delays. These findings are inconsistent with findings from other hazards; whereby Sorensen (1991) found that households with children were more likely to engage in early evacuation in a hazardous materials fire event and Lindell et al. (2011) found that larger households took longer to evacuate during hurricanes. These findings require further study, especially in wildfires, since it is unclear whether delay time results from no-notice (i.e., hazardous materials fire) and slow-onset events (i.e., hurricanes) will consistently translate to wildfires (rapid-onset events). In the Marshall fire, it is possible that householders with children took longer to prepare for evacuation, as the adults had to assist not only themselves, but their children in the preparations before leaving. Additionally, it can also be envisioned that householders with higher numbers of adults were more likely to divide the tasks among themselves, as a division of labor, resulting in a lower delay time and an earlier departure time. These trends of division of labor among households in hazards have been seen in previous research (Hung, 2018). Additional new insights include the link between later awareness time and shorter response delays. This is a logical result, since the later the time (on December 30) that people found out about the fire, the shorter the timeframe they had to respond before the fire came closer to their location. Finally, model results showed that if people owned their own home, they had shorter delay times. It is posited that this result may be related to the pre-fire, established social ties among homeowners within the affected communities. As mentioned earlier, over 50 % of the sample were alerted or warned to evacuate by someone that they knew. This potentially demonstrates the pre-fire social network that existed in affected areas prior to the Marshall fire. Aldrich and Meyer (2015) note that strong bridging ties among people in a community can enhance the response and resilience of that community in the face of a hazard event. While further research is needed, especially on the strength of social ties among renters vs. homeowners in WUI and suburban areas and their influence on delay times, this research may provide some foundation for future work.

5.1. Comparison of results across the 2016, 2019 and 2021 fires

Since a similar survey was used to analyze evacuation behavior from the 2016 Chimney Tops 2 fire in Tennessee (Kuligowski et al., 2020), the 2019 Kincade fire in California (Kuligowski et al., 2022) and the 2021 Marshall fire in Colorado (all US fires), a brief discussion is included here to compare results across the three events. The focus of the comparison is predicting risk perception (at the time of the evacuation decision) and the decision to evacuate, since data on delay times were not collected or analyzed for the 2016 and 2019 fires.

The 2016 Chimney Tops 2 fire evacuation occurred when extreme winds combined with exceptional drought and low humidity drove the fire rapidly toward Gatlinburg, Tennessee. The population affected was rural and generally inexperienced with wildfire. Kuligowski et al. (2020) found that official warnings were sparse (less than 20 % received one) and most evacuees made their evacuation decision based on fire cues (75 %). Risk perception (at the time of evacuation decision) was high (3.7 on 5.0 scale) and 87 % of the participants chose to evacuate. Risk perception was found to be correlated with the evacuation decision, and the most common reason stated for evacuating was witnessing fire cues including flames, embers, and smoke. Linear regression analysis revealed that (1) seeing flames or embers and (2) smelling or seeing smoke were significant predictors of risk perception, where the former led to an increase, and the latter led to a decrease. Prior awareness of fire risk decreased risk perception as did receiving a warning from a trusted source. Logistic regression analyses showed that the evacuation decision was influenced by risk perception (at the time of evacuation decision), gender (female), having an evacuation plan, receiving warnings from a trusted source, and refraining from taking home preparation actions.

The 2019 Kincade fire in Sonoma, California resulted in the evacuation of a large suburban and exurban region over several days. County emergency managers and residents had significantly more wildfire experience and preparedness than Gatlinburg in the Chimney Tops 2 fire. Residents received warnings from multiple sources, including text messaging, social media, email, telephone, siren, radio, and face-to-face. In contrast to the Chimney Tops 2 fire, only 13 % reported seeing fire cues prior to making their evacuation decision. Kuligowski et al. (2022) found that 80 % of survey respondents chose to evacuate with moderate risk perception (2.5 / 5.0). Risk perception (at the time of the evacuation decision) was correlated with threat assessment, prior awareness of the threat, and observing fire cues. Linear regression analysis identified significant predictors of risk perception, including pre-fire perceptions of safety, household makeup (adults, pets, livestock), income, education and threat assessment. Logistic regression analyses showed that the evacuation decision was influenced by risk perception, length of residence, household makeup, income, education, evacuation orders, fire cues, pre-fire perceptions of (home) safety, and homeownership.

Differences in the survey results across the Chimney Tops 2, Kincade and Marshall fires highlight challenges in developing a general model for predicting wildfire evacuation behavior. Foremost, the fire events differed significantly regarding the threat, warning, and household contexts. In terms of the threat, the Chimney Tops 2 and Kincade fires offered much more lead time, on the order of days, than the Marshall fire, which was burning structures in less than an hour after detection. The community evacuated in the Chimney Tops 2 fire was a small, relatively inexperienced rural community where 1 in 5 households received an official warning and most decided to evacuate based on informal warnings and fire cues. The Kincade evacuation was a much larger evacuation of more experienced residents, a majority of which received an evacuation notice from multiple channels, both official and informal. The Marshall evacuation was a moderately sized evacuation with a low level of prior experience (between the two prior cases) where most residents received a warning from one or more informal and/or official sources (similar to the Kincade case).

Predictive modeling across the case studies reinforces the degree to which the scenarios vary. For the linear regression model of risk

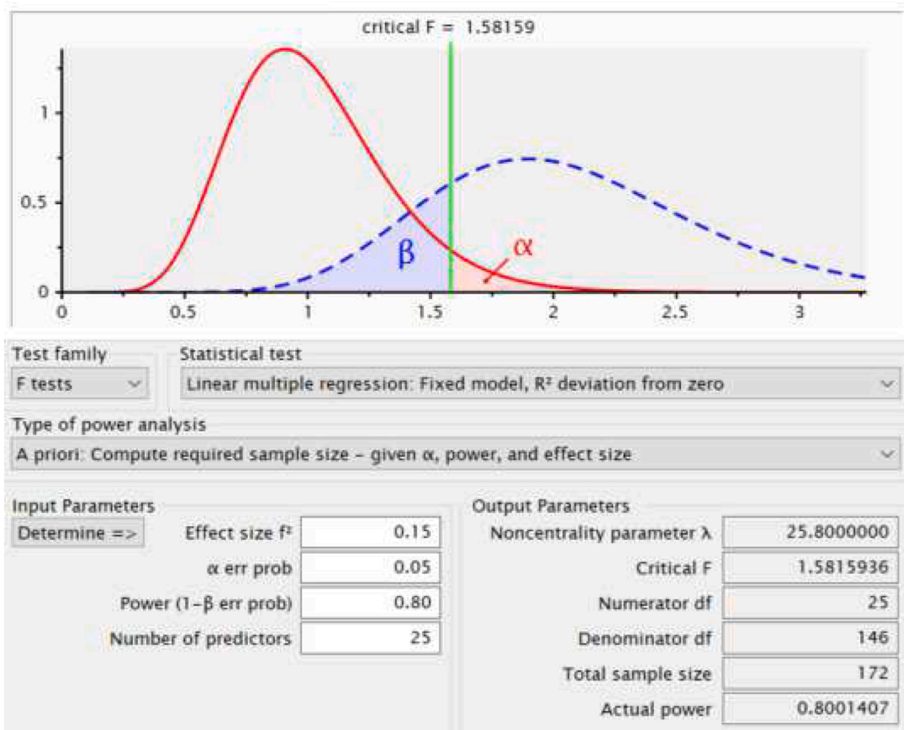

Fig. A1. A priori power analysis.

perception, the significant variables and their coefficients varied. Fire cues (flames and embers) were significant and similar predictors of risk perception for the Chimney and Marshall fires but not in the Kincade fire study. Binomial regression modeling to predict the evacuation decision showed that fire cues were significant for the Kincade case, although in the Chimney Tops 2 case, the presence of fire cues was a significant predictor of risk perception, which was then a significant predictor of the evacuation decision (fire cues to risk perception to decision). For the Marshall case, neither fire cues nor risk perception were significant predictors of the evacuation decision. This may be due to the relative size of the evacuation zone to the fire scar, as only a small percentage of evacuees witnessed fire cues. There are prior wildfire studies that were also unable to find a statistically significant relationships between risk perception and evacuation decisions (McLennan et al., 2014; Paveglio et al., 2014). In general, the stark difference in the scenarios and resulting behavioral models highlights challenges in developing a general predictive model for wildfire evacuation decision making. Developing a database of survey results representative of common wildfire evacuation types is a worthy research goal.

5.2. Policy implications of the Marshall fire results

In the Marshall fire study, it was observed that higher pre-fire risk perception (measured by the perception of wildfire threatening their property) led to an increased probability of evacuation. Additionally, the delay time model showed longer preparation time caused more delays in evacuations. Therefore, local agencies should consider conducting additional wildfire educational campaigns to teach the public about the dangers of wildfires, how wildfires could rapidly damage or even destroy their properties, and how to effectively plan and prepare for future events, aiming to enhance residents' pre-fire risk perception and increase their readiness in case of evacuation. Furthermore, wildfire evacuation drills should also be considered and implemented at the community level to help residents practice evacuating people, animals, and pets and address potential problems and delays in the evacuation process (U.S. Fire Administration, 2022).

It was also observed that evacuees who were aware of the fire early tended to experience shorter delays in their departure time. Hence, local agencies should prioritize timely and effective communication and alert systems. This can be achieved through the use of mobile device alerting platforms and/or the development of mobile applications that deliver real-time updates on fire-related information. In challenging scenarios like power outages or limited signal coverage, agencies also need to utilize traditional, low-tech communication methods for disseminating relevant information (Wong et al., 2020). Besides, fostering community-based networks for fire detection and prompt reporting can further enhance residents' early awareness of fire.

Moreover, according to the delay time model, having children in the household caused more delays in evacuation. Therefore, agencies should consider providing more resources and assistance to households with children in case of evacuation. For example, agencies should provide child care supplies and a safe environment for children in public shelters, and prioritize these households' transportation needs during evacuations; e.g., using Mobility as a Response to assist their evacuation (Xia and Yeh, 2022).

5.3. Limitations and future work

There are limitations associated with this study due to the nature of survey research. The survey data collection strategy used a convenience sample approach, where respondents volunteered to participate in the survey. In these cases, it is possible that people who evacuated were more motivated to participate compared with those who stayed in place. In addition, the number of survey responses that were included in the study (191 responses) was lower than the previous studies deploying a similar survey (2016 Chimney Tops 2 fire & 2019 Kincade fire). However, the sample of this study is larger than the number required (i.e., 172 participants) to investigate a medium effect size (0.15) from linear multiple regression analyses with 16 predictors (see Table 5) and 25 predictors (see Table 6) considering a power of 0.80 (Faul et al., 2007). The readers can refer to the Appendix for a comprehensive overview of the a priori power analysis carried out in this study. We focused on this sample due to their initial location at the start of the fire. This survey expanded upon similar versions to include questions on pre-transport and transport decisions made by the respondents. Questions were added to obtain information on mode, route, and destination choices in the Marshall fire. However, since the survey was unable to collect the complete set of independent variables influential to travel decisions, such as vehicle ownership, traffic and roadway conditions, and gasoline availability (Kutela et al., 2023), future work will further expand the questionnaire to better address transportation needs and decisions in wildfire evacuations. Finally, having similar data from multiple U.S. wildfires allows for an in-depth comparative study to be conducted. Our goal is to conduct a multi-fire comparative analysis to better understand the influential factors on risk perception and evacuation decisions beyond the brief discussion provided in this paper.

6. Conclusions

This study of the 2021 Marshall fire identified the factors that influenced the evacuation decision and levels of risk perception (at the time of evacuation decision). Also identified were the factors that influenced evacuee delay time (defined as the time between first awareness of the fire and the decision to evacuate or stay). Findings from the linear regression analysis showed that pre-fire awareness and pre-fire risk perception level, age, income, and gender were significantly linked with risk perception. Factors that influenced evacuation decision included pre-fire risk perception level, household income level, having a medical condition, and observing fire cues. Finally, the factors that influenced delay time included awareness and preparation time, prior damage experience, home ownership, household size, and having children.

This study can help provide recommendations for future fires in more suburban areas, especially in communities not as familiar with fire events. More informed decisions can be made by evacuation planners and fire officials using the findings from our study to better understand evacuation behavior, and needs before, during, and when communicating with residents in an event. This is especially the case with delay time, which is often less of a focus in existing wildfire studies. Understanding the factors that increase delay time, e.g., households with children or individuals with increasing preparation activities, can help officials target certain households or areas within a community to better prepare for the next fire event. The less time people take to delay, the more time they have to evacuate (as long as the transport infrastructure is sufficient). Along the same lines, understanding the factors that decrease delays, e.g., having previous experiences in fire events, can assist officials in educating and training those without fire experiences about the risks and difficulties that can accompany late evacuation. Technology like virtual and augmented reality are becoming increasingly used to safely and effectively demonstrate the danger associated with delayed action for those more inexperienced with fire events.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was supported by the Natural Hazards Center Quick Response Research Program. The Quick Response program is based on work supported by the National Science Foundation (Award #1635593). This research was also supported by an Early-Career Research Fellowship from the Gulf Research Program of the National Academies of Sciences, Engineering, and Medicine and an ARC Future Fellowship by the Australian Government through the Australian Research Council (Grant No. FT220100618). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of NSF, the Natural Hazards Center, the Australian Government, the Australian Research Council, or the Gulf Research Program of the National Academies of Sciences, Engineering, and Medicine.

Appendix A. – A priori power analysis

A priori power analysis was carried out using G*Power 3.1.9.7 (Faul et al., 2009) to estimate the minimum sample size required for the investigation. To perform this calculation, we consider a medium effect size ($f^2 = 0.15$), a level of significance (α) of 0.05, a power (β) of 0.80 and a number of predictors (i.e., independent variables) of 25. The values selected for this analysis are in line with the one suggested in the seminal paper by Cohen (Cohen, 1992). The results indicate that need for a total sample of 172 as shown in Fig. A1.

References

Alawadi, R., Murray-Tuite, P., Marasco, D., Ukkusuri, S., Ge, Y., 2020. Determinants of full and partial household evacuation decision making in hurricane matthew. Transp. Res. Part D: Transp. Environ. 102313 https://doi.org/10.1016/j.trd.2020.102313.

Aldrich, D.P., Meyer, M.A., 2015. Social Capital and Community Resilience. Am. Behav. Sci. 59, 254–269. https://doi.org/10.1177/0002764214550299.

Alsnih, R., Rose, J., Stopher, P., 2005. Understanding Household Evacuation Decisions Using a Stated Choice Survey - Case study of bush fires 18.

Bateman, J.M., Edwards, B., 2002. Gender and Evacuation: A Closer Look at Why Women Are More Likely to Evacuate for Hurricanes. nat. Hazard. Rev. 3, 107–117. https://doi.org/10.1061/(ASCE)1527-6988(2002)3:3(107).

Benight, C.C., Gruntfest, E., Sparks, K., 2004. Colorado Wildfires 2002 (Quick Response Research Report No. 167). Natural Hazards Center.

Bolar, K., 2019. STAT: Interactive Document for Working with Basic Statistical Analysis version 0.1.0 from CRAN [WWW Document]. R Package. URL https://rdrr.io/cran/STAT/ (accessed 5.18.23).

Boulder Co Sheriff's Office, 2021. Emergency Notifications from Boulder County Communications.

Bowman, D.M.J.S., Kolden, C.A., Abatzoglou, J.T., Johnston, F.H., van der Werf, G.R., Flannigan, M., 2020. Vegetation fires in the Anthropocene. Nature Reviews Earth & Environment 1, 500–515. https://doi.org/10.1038/s43017-020-0085-3.

Camero, K., 2021. What to know about destructive Marshall Fire in Colorado | The Sacramento Bee [WWW Document]. accessed 3.18.23 The Sacramento Bee. https://www.sacbee.com/news/nation-world/national/article256962277.html.

Case, A., 2022. Updated numbers show 1,084 homes destroyed in Marshall Fire [WWW Document]. accessed 3.18.23 Kusa.com. https://www.9news.com/article/news/local/wildfire/1084-homes-destroyed-marshall-fire/73-5fc58914-54ae-4eb2-a368-4a88e6535c5f.

Chowdhury, T.J., Arbon, P., Kako, M., Muller, R., Steenkamp, M., Gebbie, K., 2022. Understanding the experiences of women in disasters: lessons for emergency management planning. AJEM 10 (47389/37), 72–77. https://doi.org/10.47389/37.1.72.

Cohen, J., 1992. A power primer. Psychol. Bull. 112, 155–159. https://doi.org/10.1037/0033-2909.112.1.155.

Cohn, P.J., Carroll, M.S., Kumagai, Y., 2006. Evacuation Behavior during Wildfires: Results of Three Case Studies. West. J. Appl. For. 21, 39–48. https://doi.org/10.1093/wjaf/21.1.39.

Comfort, L., Soga, K., Stacey, M., McElwee, M., Ecosse, C., Dressler, J., Zhao, B., 2019. Collective Action in Communities Exposed to Recurring Hazards: The Camp Fire, Butte County, California, November 8, 2018, Natural Hazards Center Quick Response Grant Report Series, 300. University of Colorado Boulder, Boulder CO, Natural Hazards Center.

Cronin, B., 2022. After the Marshall Fire, Boulder County makes changes to help people get out faster in an emergency | KUNC [WWW Document]. accessed 3.18.23 Kunc.org. https://www.kunc.org/news/2022-10-04/after-the-marshall-fire-boulder-county-makes-changes-to-help-people-get-out-faster-in-an-emergency.

Cutter, S.L., Boruff, B.J., Shirley, W.L., 2003. Social Vulnerability to Environmental Hazards*. Social Science Q 84, 242–261. https://doi.org/10.1111/1540-6237.8402002.

Eriksen, C., Gill, N., Head, L., 2010. The gendered dimensions of bushfire in changing rural landscapes in Australia. J. Rural. Stud. 26, 332–342. https://doi.org/10.1016/j.jrurstud.2010.06.001.

Faul, F., Erdfelder, E., Buchner, A., Lang, A.-G., 2009. Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. Behav. Res. Methods 41, 1149–1160. https://doi.org/10.3758/BRM.41.4.1149.

Fire Administration, U.S., 2022. Wildfire outreach materials [WWW Document]. U.S, Fire Administration https://www.usfa.fema.gov/wui/outreach/ (accessed 11.7.23.

Fischer, E., Wham, B., Dashti, S., Liel, A., Whelton, A., Berty, N., Klingaman, J., Metz, A., Ramos, J., Rose, H., 2022. 2021 Marshall Wildfire, Boulder County, Colorado (No. GEER—075). GEER Association.

Folk, L.H., Kuligowski, E.D., Gwynne, S.M.V., Gales, J.A., 2019. A Provisional Conceptual Model of Human Behavior in Response to Wildland-Urban Interface Fires. Fire Technol 55, 1619–1647. https://doi.org/10.1007/s10694-019-00821-z.
Grajdura, S., Qian, X., Niemeier, D., 2021. Awareness, departure, and preparation time in no-notice wildfire evacuations. Saf. Sci. 139, 105258 https://doi.org/10.1016/j.ssci.2021.105258.
Hung, L.-S., 2018. Gender, Intra-Household Dynamics, and Household Hurricane Preparedness: An Exploratory Study Employing a Dyadic Interview Approach. Int J Disaster Risk Sci 9, 16–27. https://doi.org/10.1007/s13753-018-0158-9.
Ivy, J., O'Donnell, S., Cook, L.L., Rose, A., 2021. Thursday updates: Hundreds of homes destroyed by Marshall Fire, thousands of people evacuated | ABC4 Utah [WWW Document]. abc4.com. URL https://www.abc4.com/news/top-stories/live-updates-superior-louisville-under-mandatory-evacuations-as-wildfires-spread-nearby/ (accessed 5.18.23).
Katzilieris, K., Vlahogianni, E.I., Wang, H., 2022. Evacuation behavior of affected individuals and households in response to the 2018 Attica wildfires: From empirical data to models. Saf. Sci. 153, 105799 https://doi.org/10.1016/j.ssci.2022.105799.
Kramer, H.A., Mockrin, M.H., Alexandre, P.M., Radeloff, V.C., 2019. High wildfire damage in interface communities in California. Int. J. Wildland Fire 28, 641. https://doi.org/10.1071/WF18108.
Kuligowski, E., 2015. Model building: an examination of the pre-evacuation period of the 2001 World Trade Center disaster: AN EXAMINATION OF THE PRE-EVACUATION PERIOD OF THE 2001 WTC DISASTER. Fire Mater. 39, 285–300. https://doi.org/10.1002/fam.2201.
Kuligowski, E.D., 2021. Evacuation decision-making and behavior in wildfires: Past research, current challenges and a future research agenda. Fire Saf. J. 120, 103129 https://doi.org/10.1016/j.firesaf.2020.103129.
Kuligowski, E.D., Mileti, D.S., 2009. Modeling pre-evacuation delay by occupants in World Trade Center Towers 1 and 2 on September 11, 2001. Fire Saf. J. 44, 487–496. https://doi.org/10.1016/j.firesaf.2008.10.001.
Kuligowski, E.D., Walpole, E.H., Lovreglio, R., McCaffrey, S., 2020. Modelling evacuation decision-making in the 2016 Chimney Tops 2 fire in Gatlinburg. TN. Int. J. Wildland Fire 29, 1120–1132. https://doi.org/10.1071/WF20038.
Kuligowski, E.D., Zhao, X., Lovreglio, R., Xu, N., Yang, K., Westbury, A., Nilsson, D., Brown, N., 2022. Modeling evacuation decisions in the 2019 Kincade fire in California. Saf. Sci. 146, 105541 https://doi.org/10.1016/j.ssci.2021.105541.
Kutela, B., Msechu, K.J., Kidando, E., Das, S., Kitali, A.E., 2023. Eliciting the influence of roadway and traffic conditions on hurricane evacuation decisions using regression-content analysis approach. Travel Behav. Soc. 33, 100623 https://doi.org/10.1016/j.tbs.2023.100623.
Lindell, M.K., Lu, J.-C., Prater, C.S., 2005. Household Decision Making and Evacuation in Response to Hurricane Lili. Nat. Hazards Rev. 6, 171–179. https://doi.org/10.1061/(ASCE)1527-6988(2005)6:4(171).
Lindell, M.K., Kang, J.E., Prater, C.S., 2011. The logistics of household hurricane evacuation. Nat Hazards 58, 1093–1109. https://doi.org/10.1007/s11069-011-9715-x.
Lindell, M.K., Perry, R.W., 2012. The Protective Action Decision Model: Theoretical modifications and additional evidence. Risk Anal. 32, 616–632. https://doi.org/10.1111/j.1539-6924.2011.01647.x.
Lovreglio, R., Kuligowski, E., Gwynne, S., Strahan, K., 2019. A modelling framework for householder decision-making for wildfire emergencies. Int. J. Disaster Risk Reduct. 41, 101274 https://doi.org/10.1016/j.ijdrr.2019.101274.
Makaba, T., Dogo, E., 2019. A Comparison of Strategies for Missing Values in Data on Machine Learning Classification Algorithms, in: 2019 International Multidisciplinary Information Technology and Engineering Conference (IMITEC). Presented at the 2019 International Multidisciplinary Information Technology and Engineering Conference (IMITEC), IEEE, Vanderbijlpark, South Africa, pp. 1–7. https://doi.org/10.1109/IMITEC45504.2019.9015889.
McCaffrey, S., Wilson, R., Konar, A., 2018. Should I Stay or Should I Go Now? Or Should I Wait and See? Influences on Wildfire Evacuation Decisions: Should I Stay or Should I Go Now? Risk Anal. 38, 1390–1404. https://doi.org/10.1111/risa.12944.
McKinley, C., 2022. Marshall Fire shows gaps in emergency alert systems [WWW Document]. accessed 3.3.23 Kusa.com. https://www.9news.com/article/news/local/wildfire/marshall-fire-gaps-emergency-alert-systems/73-8046d04f-47e2-46ad-abc0-53212849e072.
McLennan, J., Elliott, G., Omodei, M., 2012. Householder decision-making under imminent wildfire threat: stay and defend or leave? Int. J. Wildland Fire 21, 915. https://doi.org/10.1071/WF11061.
McLennan, J., Elliott, G., Omodei, M., Whittaker, J., 2013. Householders' safety-related decisions, plans, actions and outcomes during the 7 February 2009 Victorian (Australia) wildfires. Fire Saf. J. 61, 175–184. https://doi.org/10.1016/j.firesaf.2013.09.003.
McLennan, J., Cowlishaw, S., Paton, D., Beatson, R., Elliott, G., 2014. Predictors of south-eastern Australian householders' strengths of intentions to self-evacuate if a wildfire threatens: Two theoretical models. Int. J. Wildland Fire 23, 1176. https://doi.org/10.1071/WF13219.
McLennan, J., Paton, D., Beatson, R., 2015a. Psychological differences between south-eastern Australian householders' who intend to leave if threatened by a wildfire and those who intend to stay and defend. Int. J. Disaster Risk Reduct. 11, 35–46. https://doi.org/10.1016/j.ijdrr.2014.11.008.
McLennan, J., Paton, D., Wright, L., 2015b. At-risk householders' responses to potential and actual bushfire threat: An analysis of findings from seven Australian post-bushfire interview studies 2009–2014. Int. J. Disaster Risk Reduct. 12, 319–327. https://doi.org/10.1016/j.ijdrr.2015.02.007.
McLennan, J., Ryan, B., Bearman, C., Toh, K., 2019. Should We Leave Now? Behavioral Factors in Evacuation Under Wildfire Threat. Fire Technol 55, 487–516. https://doi.org/10.1007/s10694-018-0753-8.
McNeill, I.M., Dunlop, P.D., Skinner, T.C., Morrison, D.L., 2015. Predicting delay in residents' decisions on defending v. evacuating through antecedents of decision avoidance. Int. J. Wildland Fire 24, 153. https://doi.org/10.1071/WF12213.
Mehta, A.M., Murray, S., McAndrew, R., Jackson, M., Tippett, V., 2022. Encouraging evacuation: The role of behavioural message inputs in bushfire warnings. Int. J. Disaster Risk Reduct. 67, 102673 https://doi.org/10.1016/j.ijdrr.2021.102673.
Mozumder, P., Raheem, N., Talberth, J., Berrens, R.P., 2008. Investigating intended evacuation from wildfires in the wildland–urban interface: Application of a bivariate probit model. Forest Policy Econ. 10, 415–423. https://doi.org/10.1016/j.forpol.2008.02.002.
Paveglio, T., Prato, T., Dalenberg, D., Venn, T., 2014. Understanding evacuation preferences and wildfire mitigations among Northwest Montana residents. Int. J. Wildland Fire 23, 435. https://doi.org/10.1071/WF13057.
Penman, T.D., Eriksen, C.E., Horsey, B., Bradstock, R.A., 2016. How much does it cost residents to prepare their property for wildfire? Int. J. Disaster Risk Reduct. 16, 88–98. https://doi.org/10.1016/j.ijdrr.2016.01.012.
Petrolia, D.R., Bhattacharjee, S., 2010. Why Don't Coastal Residents Choose to Evacuate for Hurricanes? Coast. Manag. 38, 97–112. https://doi.org/10.1080/08920751003605365.
Radeloff, V.C., Helmers, D.P., Kramer, H.A., Mockrin, M.H., Alexandre, P.M., Bar-Massada, A., Butsic, V., Hawbaker, T.J., Martinuzzi, S., Syphard, A.D., Stewart, S.I., 2018. Rapid growth of the US wildland-urban interface raises wildfire risk. Proc Natl Acad Sci USA 115, 3314–3319. https://doi.org/10.1073/pnas.1718850115.
Sadri, A.M., Ukkusuri, S.V., Murray-Tuite, P., 2013. A random parameter ordered probit model to understand the mobilization time during hurricane evacuation. Transportation Research Part c: Emerging Technologies 32, 21–30. https://doi.org/10.1016/j.trc.2013.03.009.
Slevin, C., Peterson, B., Piepert, T., 2022. Investigators narrow search for origin of Colorado wildfire | AP News [WWW Document]. accessed 5.18.23 AP News. https://apnews.com/article/wildfires-business-fires-environment-and-nature-colorado-73dc5417bd9b1cae15e203f560e7bdb9.
Sorensen, J.H., 1991. When shall we leave - Factors affecting the timing of evacuation departures. Int. J. Mass Emerg. Disasters 9.
Sorensen, J.H., Sorensen, B.V., Smith, A., Williams, Z., 2009. Results of An Investigation of the Effectiveness of Using Reverse Telephone Emergency Warning Systems in the October 2007 San Diego Wildfires (No. ORNL/TM-2009/154). Oak Ridge National Laboratory, Oak Ridge, Tennessee.
Sorensen, J.H., Mileti, D.S., 2018. Warning issuance, diffusion, and public protective action initiation during the Febuary 2017 Oroville Dam event. U.S, Army Corps of Engineers, Davis, California.
Stasiewicz, A.M., Paveglio, T.B., 2021. Preparing for wildfire evacuation and alternatives: Exploring influences on residents' intended evacuation behaviors and mitigations. Int. J. Disaster Risk Reduct. 58, 102177 https://doi.org/10.1016/j.ijdrr.2021.102177.
Stein, A., 2022. Marshall fire explained: Why Boulder County had 100+ mph winds that stoked wildfire [WWW Document]. accessed 3.18.23 Denver Post. https://www.denverpost.com/2021/12/31/marshall-fire-explained-firestorm-colorado-weather/.
Strahan, K., Gilbert, J., 2021. The Wait and See Literature: A Rapid Systematic Review. Fire 4, 4. https://doi.org/10.3390/fire4010004.
Strahan, K., Watson, S.J., 2019. The protective action decision model: when householders choose their protective response to wildfire. J. Risk Res. 22, 1602–1623. https://doi.org/10.1080/13669877.2018.1501597.
Strahan, K., Whittaker, J., Handmer, J., 2018. Self-evacuation archetypes in Australian bushfire. Int. J. Disaster Risk Reduct. 27, 307–316. https://doi.org/10.1016/j.ijdrr.2017.10.016.
Strahan, K.W., Whittaker, J., Handmer, J., 2019. Predicting self-evacuation in Australian bushfire. Environ. Hazards 18, 146–172. https://doi.org/10.1080/17477891.2018.1512468.
Strawderman, L., Salehi, A., Babski-Reeves, K., Thornton-Neaves, T., Cosby, A., 2012. Reverse 911 as a Complementary Evacuation Warning System. Nat. Hazards Rev. 13, 65–73. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000059.
Taylor, M., 2016. Managing Animals in Disasters: Improving preparedness, response, and resilience through individual and organisational collaboration (No. 217.2016). Bushfire and Natural Hazards CRC, Melbourne, Vic.
Trigg, J., Taylor, M., Fountain, L., 2021. Animals in disasters: an updated assessment of Australia's animal related planning for, and response to, disasters: report prepared for World Animal Protection. Macquarie University, Sydney, NSW, Australia.
United Nations Environment Programme, 2022. Spreading like Wildfire – The Rising Threat of Extraordinary Landscape Fires (A UNEP Rapid Response Assessment). Nairobi.
US Census Bureau, 2020. US Census 2020 (5 Yr data) [WWW Document]. accessed 5.18.23. https://www2.census.gov/programs-surveys/acs/summary_file/2020/prototype/.
Whelton, A.J., Seidel, C., Wham, B.P., Fischer, E.C., Isaacson, K., Jankowski, C., MacArthur, N., McKenna, E., Ley, C., 2023. The Marshall Fire: Scientific and policy needs for water system disaster response. AWWA Water Science 5. https://doi.org/10.1002/aws2.1318.
Whittaker, J., Eriksen, C., Haynes, K., 2016. Gendered responses to the 2009 Black Saturday bushfires in Victoria, Australia: Gender and the Black Saturday bushfires. Geogr. Res. 54, 203–215. https://doi.org/10.1111/1745-5871.12162.
Whittaker, J., Haynes, K., Wilkinson, C., Tofa, M., Dilworth, T., Collins, J., Tait, L., Samson, S., 2021. Black Summer - How the NSW community responded to the 2019-

20 bushfire season (No. 651.2021). Bushfire & Natural Hazards Cooperative Research Centre.

Whittaker, J., Taylor, M., Bearman, C., 2020. Why don't bushfire warnings work as intended? Responses to official warnings during bushfires in New South Wales, Australia. Int. J. Disaster Risk Reduct. 101476 https://doi.org/10.1016/j.ijdrr.2020.101476.

Wong, S.D., Chorus, C.G., Shaheen, S.A., Walker, J.L., 2020. A Revealed Preference Methodology to Evaluate Regret Minimization with Challenging Choice Sets: A Wildfire Evacuation Case Study. Travel Behav. Soc. 20, 331–347. https://doi.org/10.1016/j.tbs.2020.04.003.

Wong, S.D., Broader, J.C., Walker, J.L., Shaheen, S.A., 2022. Understanding California wildfire evacuee behavior and joint choice making. Transportation. https://doi.org/10.1007/s11116-022-10275-y.

Wood, M.M., Mileti, D.S., Bean, H., Liu, B.F., Sutton, J., Madden, S., 2018. Milling and Public Warnings. Environ. Behav. 50, 535–566. https://doi.org/10.1177/0013916517709561.

Xia, C., Yeh, A.G.O., 2022. Mobility as a response to environmental hazards in the urban context: A new perspective on mobility and inequality. Travel Behav. Soc. 27, 192–203. https://doi.org/10.1016/j.tbs.2022.01.008.

Zialcita, P., 2022. Identity of final person missing from Marshall fire confirmed as investigators uncover bone fragments | Colorado Public Radio [WWW Document]. accessed 3.18.23 CPR News. https://www.cpr.org/2022/01/19/identity-final-person-missing-marshall-fire-bone-fragments/.