2023 Burgers Program and Combustion Institute -- Summer School on Fire Safety Science - Wildland/WUI Fire Behavior

RMIT UNIVERSITY

Human Behaviour in WUI Fires

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What's next...

Some context…before I begin

- What do I mean by …***human behaviour in WUI fires***?
  - When? Phase(s) of EM: (prevention, mitigation, preparedness, initiation/**response**, recovery)
  - Who? **Public** (individual/household, community), emergency responders, decision-makers
- **Positionality**: this topic is informed by many disciplines, but what is my background/expertise?
- 1.5-hr lecture – a higher-level discussion with references for additional reading. Consider this – *the beginning of a conversation*.

Outline

- Why is an understanding of HB necessary to protect people in WUI fires?
- What do we know about human behaviour in WUI fires?
  - Evacuation decision
  - Evacuee movement to safety
- How can we use that knowledge to protect people in fires, e.g., evacuation planning?
- Key take-aways

- Places around the world are experiencing extreme fire conditions due to ***climate change***, expanding the WUI, and fire exclusion (Kolden)

- Places around the world are experiencing extreme fire conditions due to ***climate change***, expanding the WUI, and fire exclusion (Kolden)

- “And it is clear that we should expect fire seasons like 2019/20, or potentially worse, to happen again” (NSW Bushfire Inquiry)*

- Common goal of response agencies: evacuate households before the fire reaches the community

https://naturaldisaster.royalcommission.gov.au/

naturalhazards.com.au

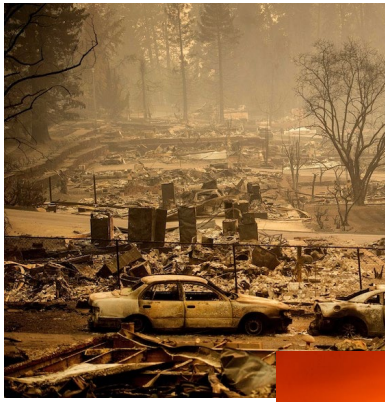
**https://www.dpc.nsw.gov.au/assets/dpc-nsw-gov-au/publications/NSW-Bushfire-Inquiry-1630/Final-Report-of-the-NSW-Bushfire-Inquiry.pdf*

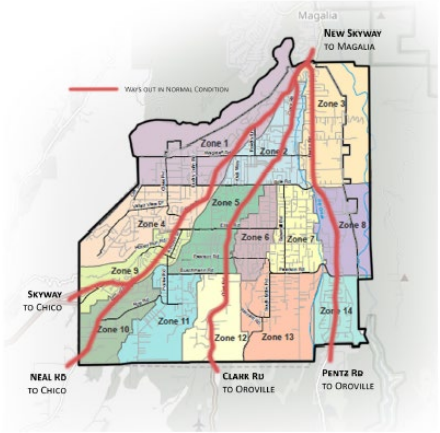
Fire Evacuation can be Challenging!

Bushfire in Gatlinburg, Tennessee (USA) in November 2016

- *"My first warning was my neighbourhood being engulfed in flames."*
- *"… I had no idea how very close the fire was to our home until I saw the pictures on Facebook"*
- *"We drove through flames blowing across the roads three times before reaching the bottom of the mountain. [It was] The most terrifying experience of my life."*

Walpole et al. 2020. Evacuation Decision-Making in the 2016 Chimney Tops 2 Fire: Results of a Household Survey (No. NIST TN 2103)





Wildfire in Paradise, California (USA) in November 2018 causing 85 deaths

- "Perfect storm"
  - Vulnerable population
  - Plan that likely had not been 'stressed'
  - Rapid fire spread/dangerous fire conditions
  - 2 out of 4 routes blocked by fire
  - Difficulties evacuating critical facilities
  - People stranded/trapped within affected area
- *"'The trees to the right of me were on fire, and we were just — dead stop, …, there was no one telling us what to do, anything. We were just sitting there.'"*

https://www.vox.com/the-highlight/2019/10/16/20908291/camp-fire-wildfire-california-paradise-survivors

https://hazards.colorado.edu/quick-response-report/collective-action-in-communities-exposed-to-recurring-hazards

Especially in WUI or Peri-urban Areas

- *Challenges:*
  - higher rates of population growth,
  - infrastructure inadequate to support rapid escape
  - climate change increasing wildfire frequency and intensity, introducing fires to ‘new’ places
- *Consequences*: delays, inaccessible routes, traffic congestion, overcrowded shelters, isolated communities – threatening safety of the (vulnerable) populations

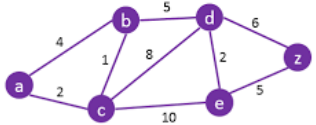
How to Protect Community?

Educate/Prepare

https://www.abc.net.au/emergency/plan-for-emergency-bushfire/12412042

Plan/test plan

Make decisions and communicate them



Dijkstra's Algorithm

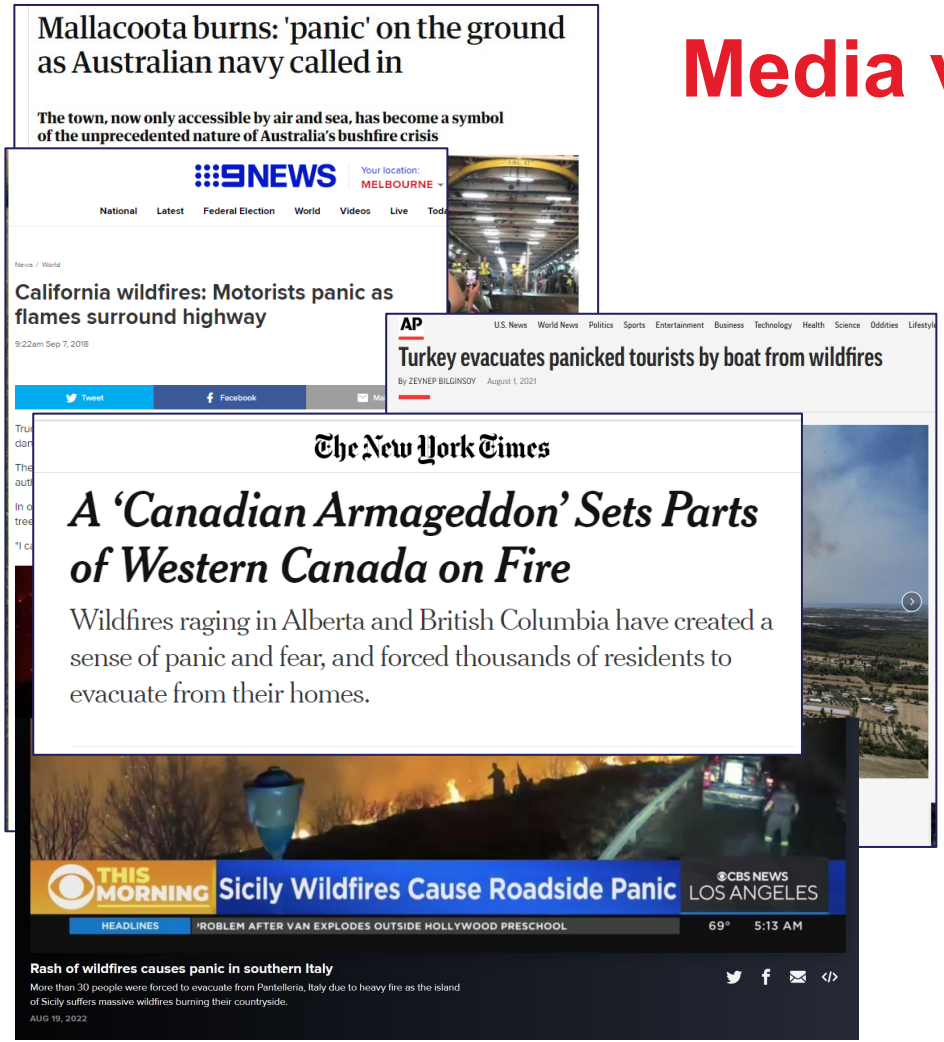
What is the shortest path to travel from A to Z?

Need to understand human behaviour in fire in each step…

Prediction models?

What do we know about HBiF (from the research)?

Media vs. Reality



https://fireadaptednetwork.org/the-panic-myth-what-does-the-research-say-and-what-can-practitioners-do/

FIRE ADAPTED COMMUNITIES
LEARNING NETWORK

The Panic Myth: What Does the Research Say and What Can Practitioners Do?

By: Sarah McCaffrey, Annie Schmidt

Feb 27, 2020 | Research Synthesis, Safety/Evacuation, Tools/Resources

Photo Credit: Forest Service Chief Tony Tooke visits Eagle Creek ICP and recognized FS personnel who helped with hiker evacuations the night of September 2, 2017. Photo by US Fores

The Panic Myth, Part I – What Does the Research Say?

by Sarah McCaffrey

Panic Explained…

- Panic defined: “irrational, nonadaptive, or antisocial behaviour” (McCaffrey and Schmidt 2020)
  - Johnson (1987): “behavior involves selfish competition uncontrolled by social and cultural constraints,” and “breaking of social order, competition unregulated by social forces.”
  - Quarantelli (1979): An acute fear reaction marked by flight behaviour and the panic participant as non-rational in their flight behaviour.
- **Panic is rare in response to natural hazards, including wildfires**
- Not to be confused with heightened fear or anxiety about the situation

Instead…

- Likely behaviour: normalcy or optimism bias (Okabe and Mikami 1982; Tierney 1993)
- People are most often ***rational and altruistic*** actors during times of crisis…
- McCaffrey and Schmidt (2020) asks – why does panic persist?
  - DRAMA! (media)
  - Perspectives from outside observers; and/or Used to explain negative consequences/deaths (Fahy and Proulx 2012)
  - Reinforces existing wildfire governance structures of command and control (Tierney 2003)

Collecting Data on Behaviour

- **Individual-based behaviour:**
  - Traditional: surveys, interviews, (focus groups), travel diaries, experiments
  - Newer tech: VR/AR

Wetterberg, et al. 2020

- **Aggregate/behavioural trends over a population or location:**
  - Traditional: observations, people/traffic flow/counts
  - Newer tech: social media, GPS (big data)

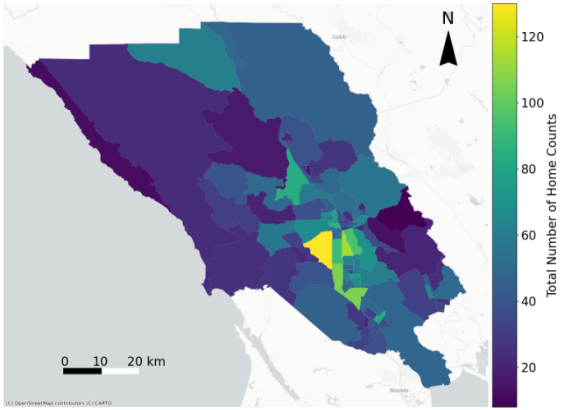


Figure 7: Distribution of Proxy Home Locations at the Census Tract Level

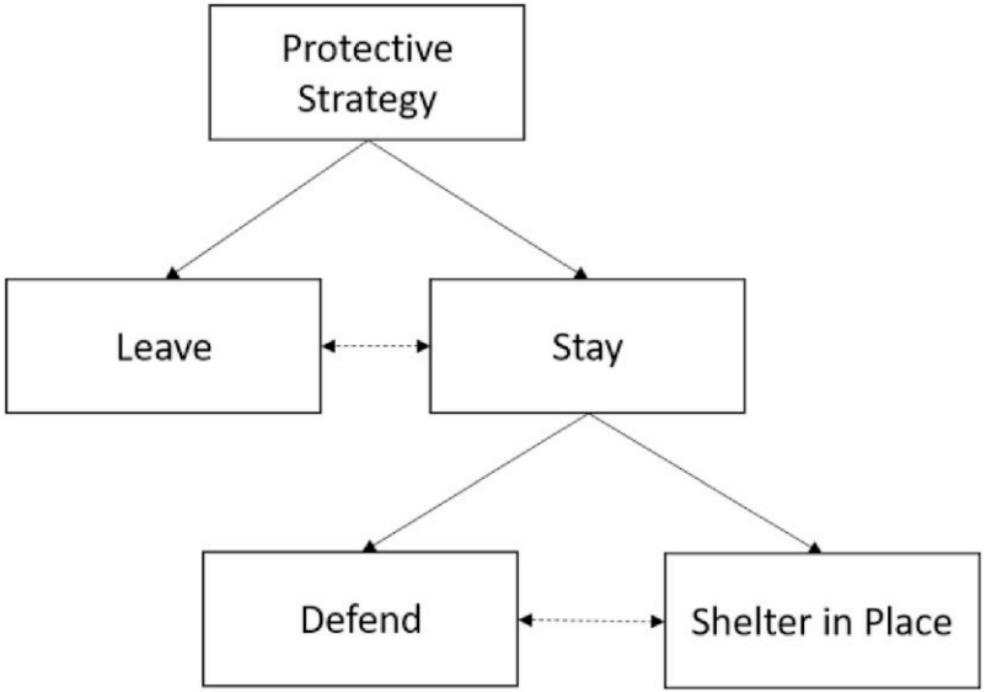
Zhao et al. 2022

Pros and Cons to each Method; e.g.,

Features	Survey data	GPS data
Collection	Active from individuals	Passive from mobile devices (apps)
Data	*Reports* from individuals on experiences, decisions, *behaviours*	Spatio-temporal information (for each ID)
Behaviours	Difficult to capture some types (timing/routes)	Are inferred based on analysis techniques
Modelling	Ability to link behaviours to individual factors (perspectives/ experiences)	Inability to link behaviours at individual level; only Census levels
Sample	Smaller (hundreds of surveys per event)	Large (millions of location signals)
Outputs	Descriptive statistics, mathematical model predicting behaviour	Community-wide trends on decisions/ behaviours

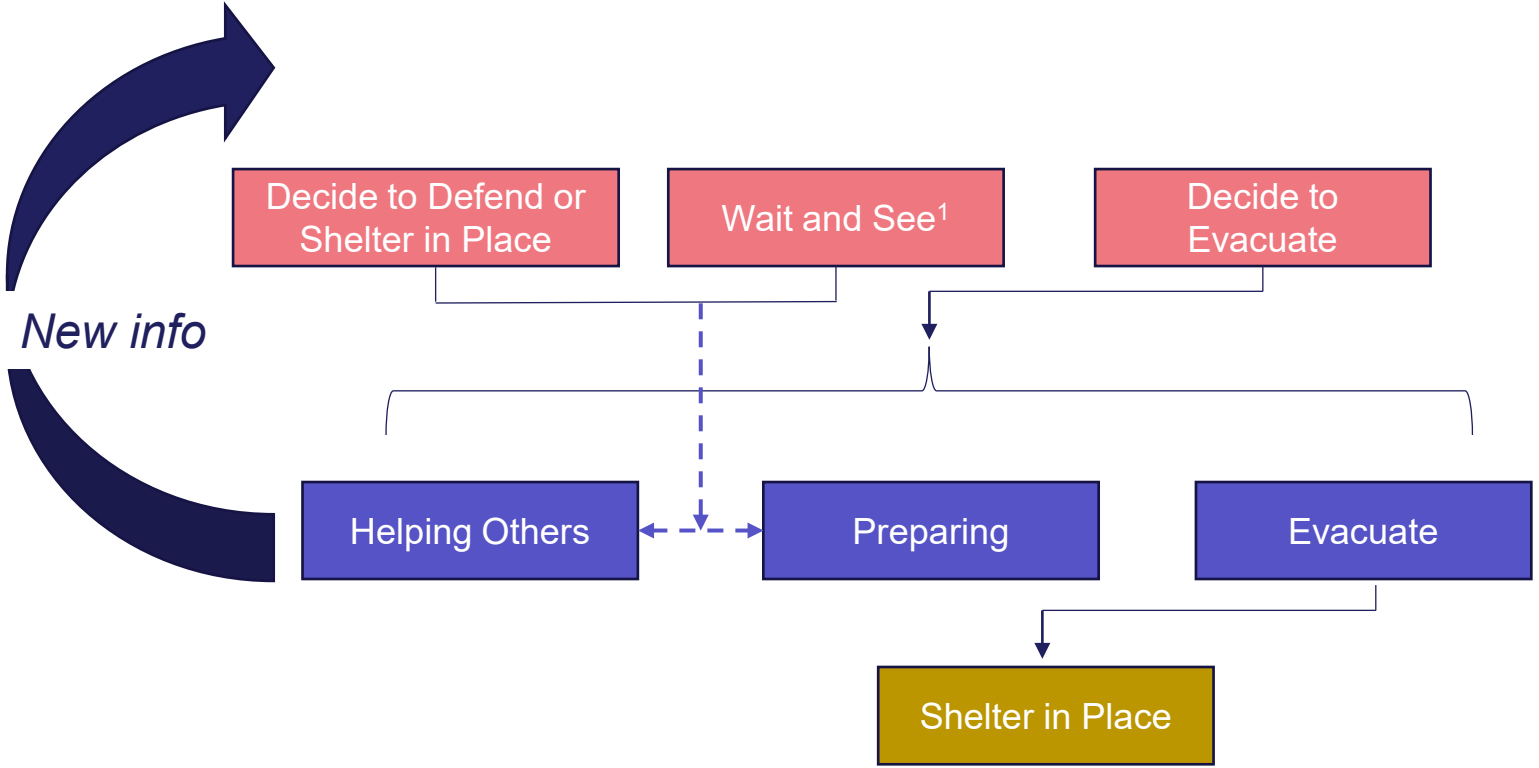
Evacuation Decision

Different Types of Household Response



Lovreglio et al. 2019; Blanchi et al. 2018

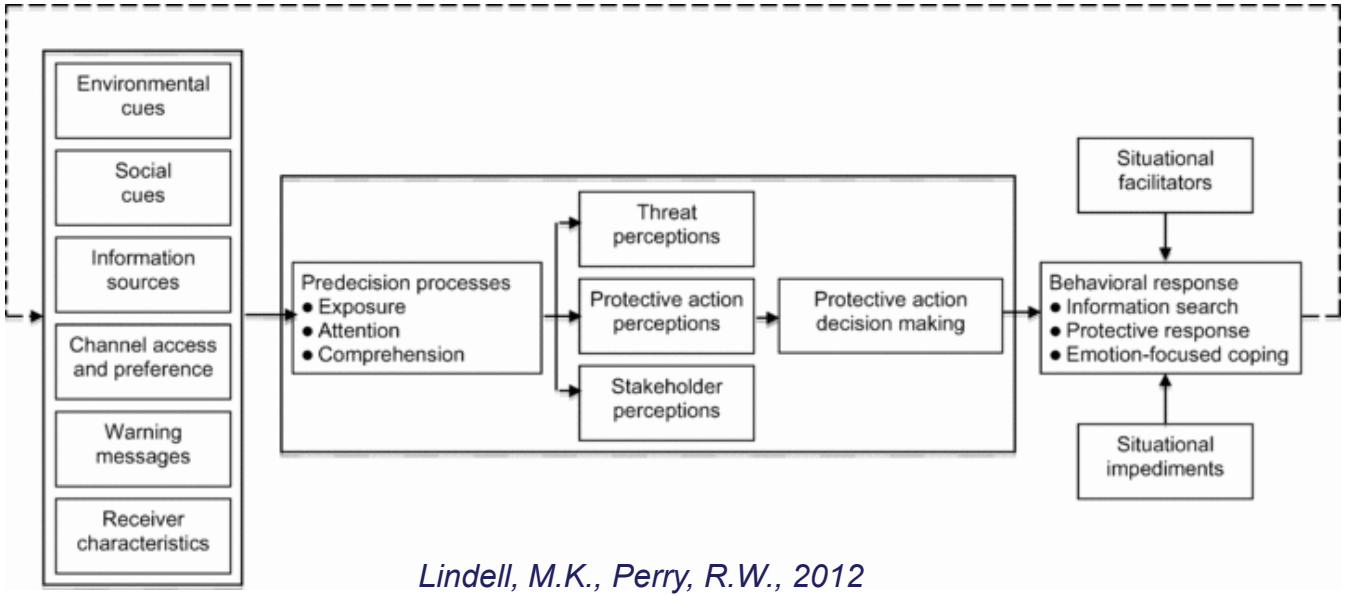
Different Types of Household Response, cont.



[1]*Strahan and Gilbert 2021*

Decision-making in Hazards

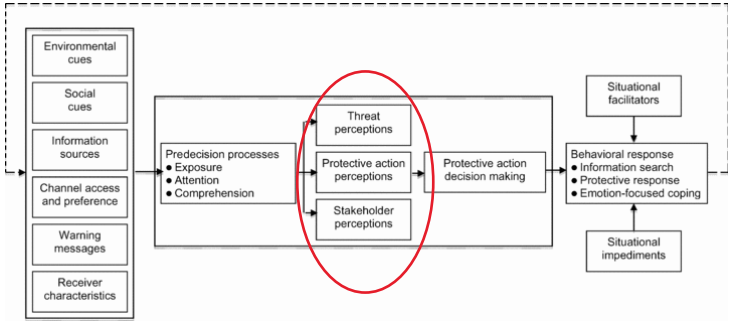
- ***Protective Action Decision Model (PADM)*** (Lindell and Perry 2012) – individuals engage in a decision-making process before deciding to evacuate
- Information seeking behaviours occur during the decision-making process and protective actions after a decision is made



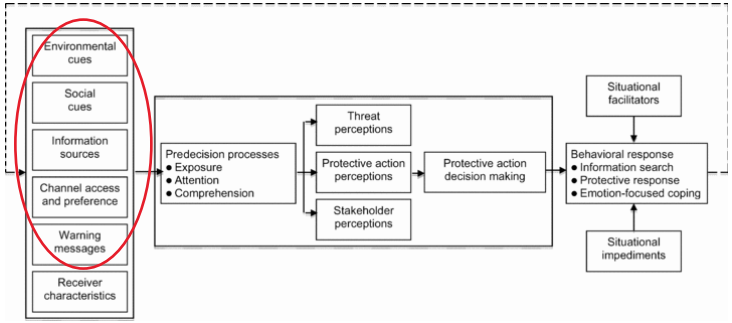
Lindell, M.K., Perry, R.W., 2012

Further Look into Perceptions

- Perceptions of:
  - Threat/Risk
  - Protective actions – effort, skills, knowledge, costs, time
  - Stakeholders/responsibility



External factors



Cues and Policies

- Environmental cues: fire, embers, smoke (varying intensities)
  - Fire/embers have been linked to both higher levels of risk perception (Kuligowski et al. 2020) and the decision to evacuate (McLennan et al. 2012)
  - Smoke – more complicated
  - Consistent/conflicting (Dootson et al. 2022)

- Social cues: e.g., observing others' leaving (Folk et al. 2019); increases risk perception (McLennan et al. 2012)

- Evacuation and warning policies: policies can differ across countries, states and jurisdictions

Warnings

Warning messages

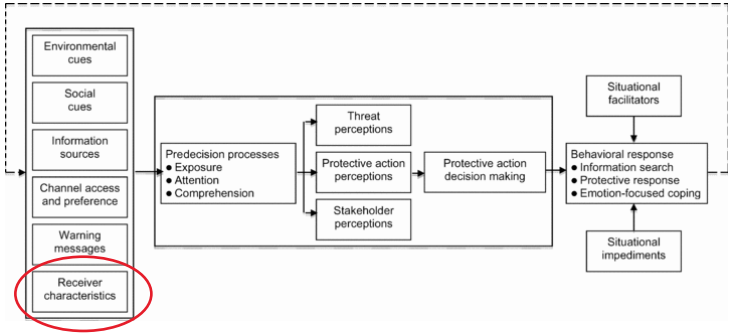
- ***Content***:
  - Source
  - Hazard and consequences
  - Location
  - Actions and why
  - Timing
- ***Style***: Specific, consistent, certain, clear, and accurate
- Repeated more than one time
- Delivered through multiple channels

https://twitter.com/NSWRFS; McCaffrey and Schmidt 2020

Other references:

Doermann et al. 2020
Kuligowski et al. 2023
Sutton and Kuligowski 2019

Receiver factors



Receiver Factors

- Preparation – evacuation planning, home mitigation
- Familial and societal responsibilities (e.g., Tibbits and Whittaker 2007)
- Place/location (and the risks), homeownership, term of residency
- Demographics – age, gender, income

Receiver Factors – Previous Experience

Previous Experience (Ghasemi et al. 2020)

- E.g., injury, personal property damaged/destroyed, evacuated, saw flames/smoke, work affected by fire, worked with fire at their job, experienced discomfort from the smoke, changed plans for a recreation trip, attended a public meeting/class, saw parts of a wildland recently burned/saw regrowth, learned about wildfire in class, etc.

- Outcomes/consequences
- Direct/indirect experience
- *Associated emotions?*
- *Elapsed time?*
- *Frequency?*
- *Knowledge from event(s)?*

For those interested, e.g.,:

- **Weinstein**, N. D. (1989). Effects of personal experience on self-protective behavior. *Psychological Bulletin*, *105*(1), 31–50.
- **Loewenstein** GF, Weber EU, Hsee CK, Welch N. Risk as feelings. Psychol Bull. 2001 Mar;127(2):267-86. doi: 10.1037/0033-2909.127.2.267. PMID: 11316014.
- **Sharma**, U., & Patt, A. (2012). Disaster warning response: The effects of different types of personal experience. *Natural Hazards*, *60*(2), 409–423.
- **Demuth**, J. L. (2018). Explicating Experience: Development of a Valid Scale of Past Hazard Experience for Tornadoes: Explicating Experience. *Risk Analysis*, *38*(9), 1921–1943.
- **Bronfman**, N. C., Cisternas, P. C., Repetto, P. B., Castañeda, J. V., & Guic, E. (2020). Understanding the Relationship Between Direct Experience and Risk Perception of Natural Hazards. *Risk Analysis*, *40*(10), 2057–2070.

Influential factors	Factor	Direction of relationship with evacuation
External	Sensory env. cues	+ (flame/embers) +/- (smoke)
	Social cues	+ (observing others evac)
	Warnings / policy	+ (consistent, content, > channels, mandatory, trusted source)
Receiver	Preparation	+ (evacuation plan); - (mitigation)
	Familial/social responsibilities	- (pets/livestock; concern for prop.); + (children; concern for family's safety)
	Place/location	+ (home owner); - (long-term resident)
	PE/knowledge	+/- (nuances are important)
Receiver's perceptions of:	Threat/risk	+ (expectations of personal impact; intrusiveness of hazard thoughts)
	Stakeholders	+ (perceived responsibility of protecting themselves)
	Protective actions	- (effort, skills, knowledge, time, cost)

Evacuation Decision

Further reading:
McLennan et al. 2019
Folk et al. 2019

Archetypes

- Archetypes developed from cluster and discriminant function analysis of survey data from 457 householders in Australia (Strahan et al. 2018)
- Clustered individuals into 7 archetypes: characterised by differing attitudes and behaviours related to protective action/evacuation in bushfire, e.g.,

Table 2
Description of archetypes.

Archetype	Key characteristics	Evacuate or Remain
Responsibility Denier	Believe they are not responsible for their personal safety or for their property	Highly committed evacuators but expect others to direct and assist
Dependent Evacuator	Expect the emergency services to protect them and their property because they are incapable of taking responsibility for themselves	
Considered Evacuator	Having carefully considered evacuation, are committed to it as soon as they are aware of a bushfire threat	Committed to self-directed evacuation
Community Guided	Seek guidance from neighbours, media and members of the community who they see as knowledgeable, well informed and providing reliable advice	Committed to evacuation on community advice
Worried Waverer	Prepare and equip their property and train to defend it but worry they lack practical experience to fight bushfire putting their personal safety at risk	Wavering between evacuating and remaining
Threat Denier	Do not believe that their personal safety or property is threatened by bushfire	Committed to remain as perceived lack of threat makes evacuation unnecessary
Experienced Independent	Are highly knowledge, competent and experienced and are responsible and self-reliant fighting bushfire	Highly committed to remaining because they are highly experienced and well prepared

Aggregate Findings on Decisions

- Compliance rates can be obtained from different data types: e.g., survey data, mobile device GPS data or social media data with geotags
- 2 studies of the 2019 Kincade fire (US)[1] found differences in rates (80% evacuated via survey data vs. 46% via GPS data analysis)

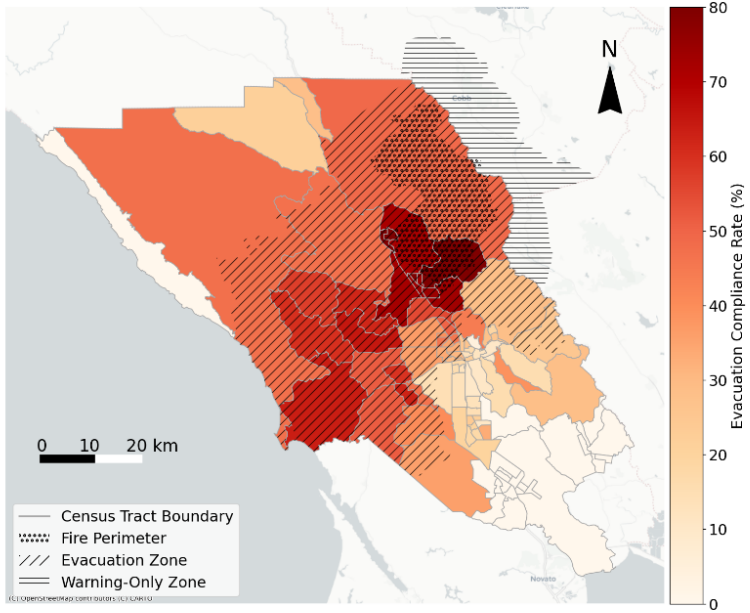
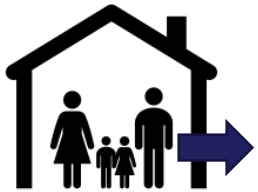


Figure 11: Distribution of Census-Tract-Level Evacuation Compliance Rates

[1]*Kuligowski et al. 2022 (Kincade fire survey); Zhao et al. 2022 (Kincade GPS data study)*

Evacuee Movement to Safety

Household Wildfire Evacuation Process…



Evacuation decision

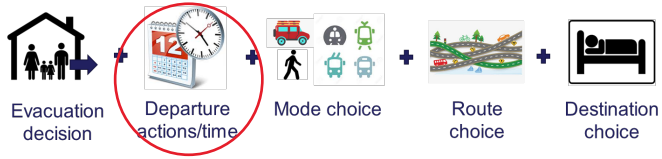
Departure actions/time

Mode choice

Route choice

Destination choice

Factors that Influence Departure Time



- Reasons for ***delaying their decision*** (Strahan and Gilbert 2021)
  - Equally desirable: protect property and household
  - Equally undesirable: risk on the road, exposure to fire
  - Perceive lower risk, safer choice; Belief - can safely leave if necessary
  - Avoidance of potential costs, time, effort, risks of evacuation
  - Lack of knowledge on how to safely evacuate
  - Engagement in lengthy information-based processes; the need for confirmation (Whittaker et al. 2020)
- Other factors (***longer preparation times***): gender (male), having home insurance, longer-term resident, receiving an evacuation notice (Grajdura et al. 2021)
- Higher number of BI actions: +gender (female); +household size (Vaiciulyte et al. 2021)

Aggregate Findings on Departure Time

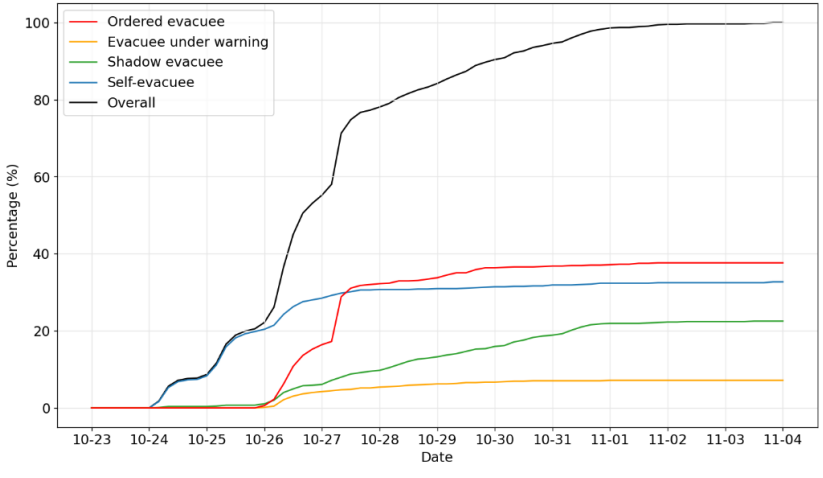


Figure 10: 12-Day Cumulative Evacuation Response Curves of Overall Evacuees and Four Different Evacuee Groups

Zhao et al. 2020 – 2019 Kincade fire

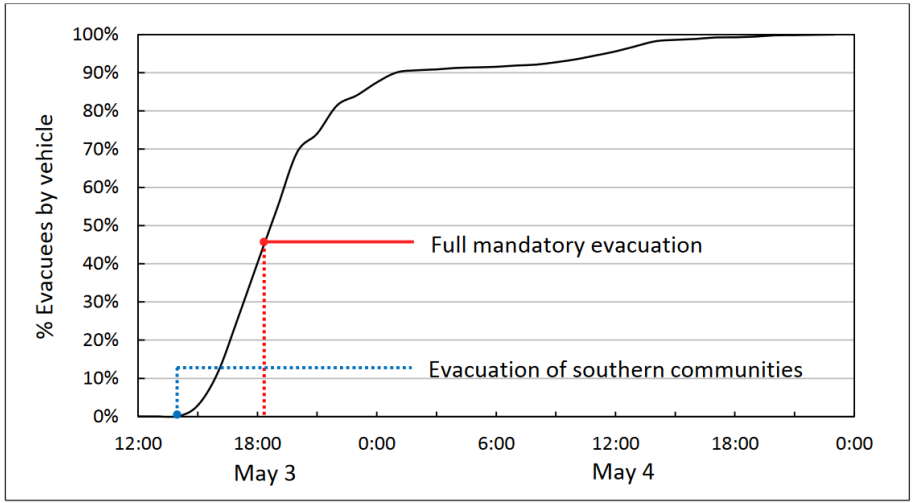
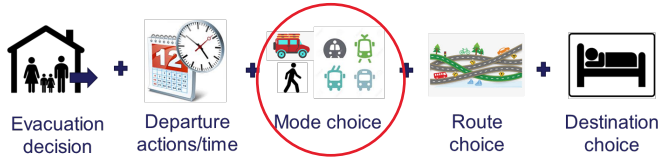


FIGURE 5 Cumulative curve of vehicles leaving Fort McMurray, May 3-4 (counters 1 & 2).

Woo et al. 2017 – Fort McMurray fire

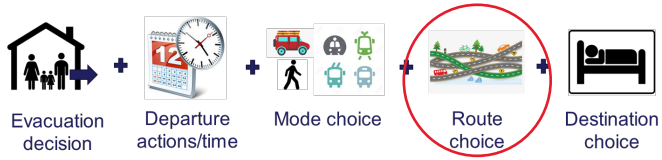
Mode Choice



- Behavioural Trends
  - A few fire studies: preference for personal vehicles (Toledo et al. 2018; Wong et al. 2020; Katzilieris et al., 2022); in some cases, on-foot
  - (Few) fire and hurricane studies show that multiple vehicles per household can be used for evacuation (including trailers for livestock, recreational vehicles, trucks, etc.)
  - Studies found engagement in intermediate trips;
    - Average of 1.10 intermediate trips (Toledo et al. 2018)
    - 50% to pick up or meet household members (Auld et al. 2012)
  - Factors influential to mode choice: original location at receipt of evacuation order, availability of modes*, intention to drive under certain conditions (Katzilieris et al., 2022)

Kuligowski 2021

Routing Choice



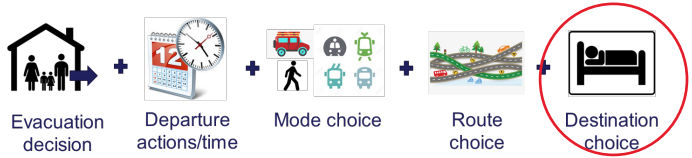
- Behavioural Trends
  - Households prefer certain route types (e.g., highways, backroads, etc.)
  - ***A few wildfire studies***:
  - Highway and non-highway route preferences (Wong et al. 2020);
  - Smaller percentage (~30%) used shorter/faster routes (Brachman et al. 2019)

  - ***Hurricane research***: preference for familiar routes over shortest or quickest routes, influenced by factors, such as, previous experience, en-route information, accessibility of route, road type, perceived service availability along route

https://www.bloomberg.com/news/articles/2019-06-17/new-google-maps-features-help-users-during-crises

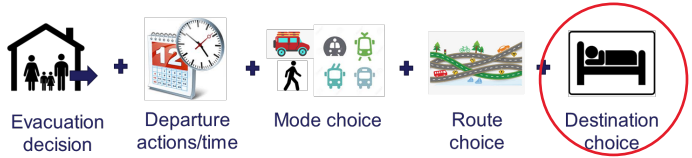
Kuligowski 2021

Destination Choice



- Community-scale trends for destination type
  - Higher percentage selecting relatives' or friends' home, then hotel/motel, other locations (campground, vacation home), and then public shelter (Sorensen 2009; Wong et al. 2020)
  - Hurricane studies document a similar trend; identify other types of destinations (churches, workplaces)
- Trends in distance travelled – other hazards
  - Longer distances for hurricane vs tsunami (<10 km drive, Chen et al. 2022)
  - Support from family/friends → shorter travel distances, within county/state (Na and Grace, 2022)

Destination Choice, cont.



- Individual-based influential factors on destination type choices (wildfire/hurricanes)
  - Income (higher SES → hotels over shelters, if homes not available)
  - Age (older → unlikely to stay with friends)
  - Other demographics (race, education, disability)
  - Home type, household size (larger size → hotels more likely)
  - Evacuee's knowledge of the area
  - Responsibility for pets (including larger animals) → family/friends, campground, cars
  - Social ties/network → family/friends [Newer or part-time residents → shelter]

Example refs: Mesa-Arango et al. 2013; Wu et al. 2012; Kuligowski 2021

How can we use HBiF knowledge/ research to protect people?

Gwynne, Kuligowski and McGee. forthcoming. "Evacuation and Emergency Management in WUI Fires", 6th Edition of the SFPE Handbook

E.g., Planning to Protect our Communities

- Strategies for planning for evacuation at the community-scale (Lindell et al. 2019)
  - **Managing demand and capacity** – public education, warning messages/strategies, identifying evacuation zones, developing phasing strategies
  - **Managing supply** – increasing roadway capacity, road/ramp closures, providing additional transportation, contraflow lanes, retiming traffic signals, police traffic control, advisory information on shelter locations, etc.


Fire
Traffic
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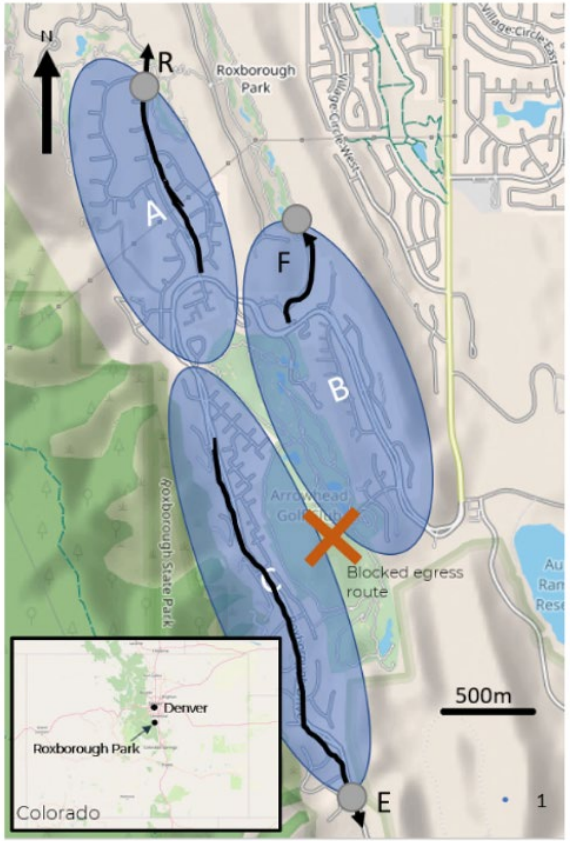
Pedestrians

Spectrum of Planning Development

- No plan
- Basic plan – e.g., shortest routes (best case)
- Plan developed from previous experience/knowledge
- Plan developed from survey data/community data collection; evacuation drills
- Plan developed based on results from evacuation models



Gwynne et al. 2023

Approaches to Modelling Evacuation

- Pedestrian models/tools
- Traffic models/tools
- Integrated models/tools (incl. fire models)

- Benefits of evacuation models
  - Ability to explore outcomes of ‘what if’ scenarios (performance-based analysis); WASET > WRSET
  - Quantify performance and identify mitigation strategies for different scenarios to safely and effectively manage demand and supply
- There are limitations!

Review of models: Ronchi et al. 2017

Pedestrian Models

- Used to simulate the decisions and movement of resident/ pedestrian population (e.g., to vehicle) – WUI or settlement fires*
- Key element – granularity
  - ***Macroscopic*** – movement controlled by network capacity and population density; constrained by physical performance; implicit representation of actions via delay time curves
  - ***Microscopic*** – can reflect individual movement (with local interactions) and even enable decision-making that reflects individual experiences and attributes (ABM)
- Key output – who evacuates and when their (traffic) movement begins

**FT article (proofs stage) "Simulating Evacuation of Humanitarian Settlements" (Kuligowski et al. 2023)*

Traffic Models

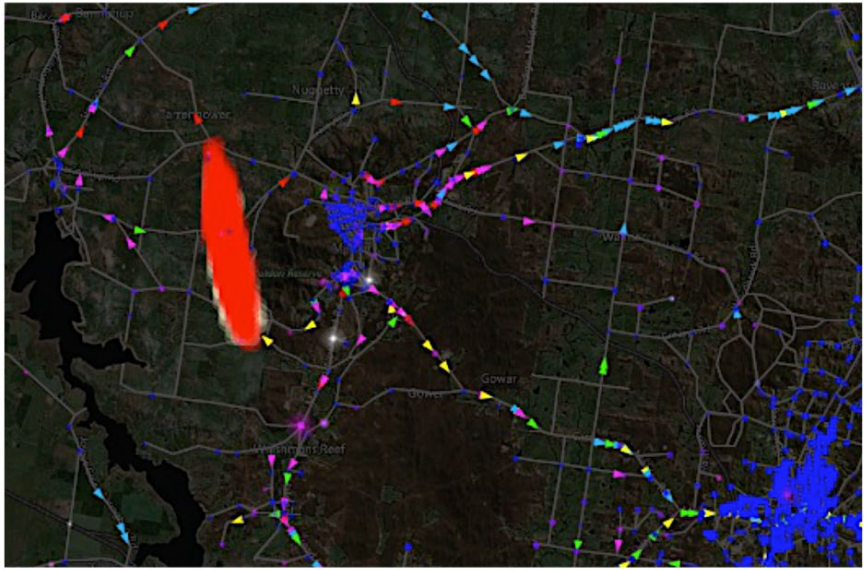
- Quantify vehicle movement on the road network via the 4-step model
- Intini et al. (2019) – reviewed 22 traffic models according to a set of features required by a WUI fire evacuation model:
  - Model availability, level of granularity, capability to simulate dynamic processes, and representation of demand-, supply-, driver-, and dynamic-based variables
  - None were developed specifically with WUI fire in mind
- Macro/micro differences (similar to pedestrian models, but with vehicles/road network)[1]
- Key outputs: Total evacuation time, flows on routes and at destinations, etc.

[1]*Rohaert et al., 2023: non-emergency relationships may not always hold for evacuation*

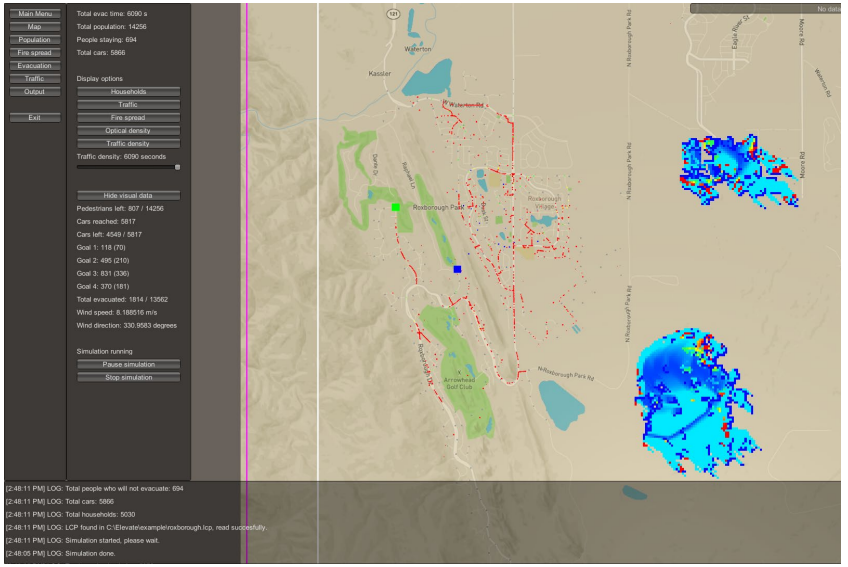
Integrated Simulation Tools

- Integrated models exist for evacuation planning in WUI communities (Ronchi IFSC Webinar)
  - Most simulate 2 layers, and a few 3 layers (fire, pedestrian, traffic)
  - Most focus on movement (and implicitly simulate behaviour)
  - Operate at different levels of granularity – macroscopic, mesoscopic, and microscopic

Examples of Integrated Models for WUI Fires

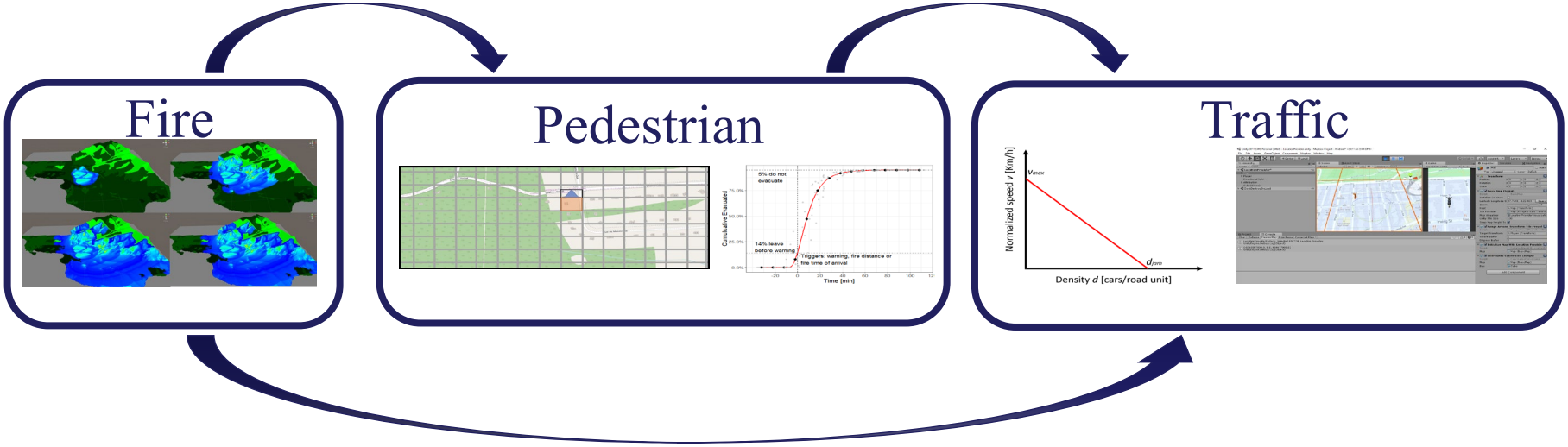


***SEEKER agent-based evacuation model (RMIT-CSIRO)**: Singh et al. 2021*



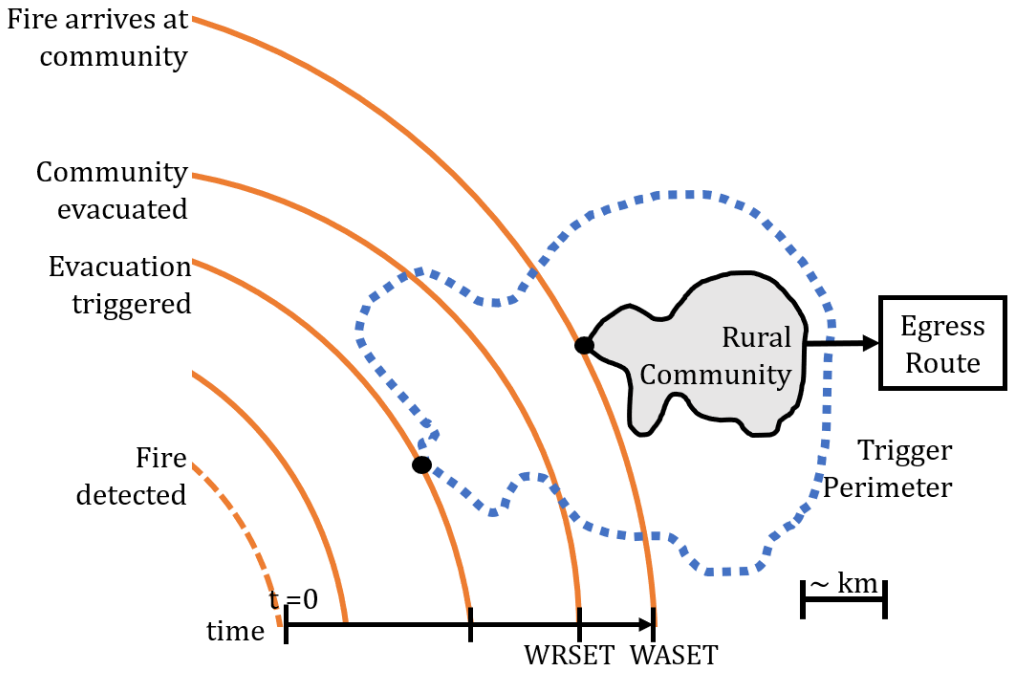
***WUI-NITY evacuation platform (NIST-funded)**: Wahlqvist et al. 2021*

WUI-NITY Introduction



Outputs: Clearance time; evacuation (arrival) time curves and flow at destinations; # of vehicles in locations along road network (traffic density); # of remaining residents, evacuees, and those located in refuge, etc.

WUI-NITY's Added Features



PERIL trigger model

(Mitchell et al. 2023)

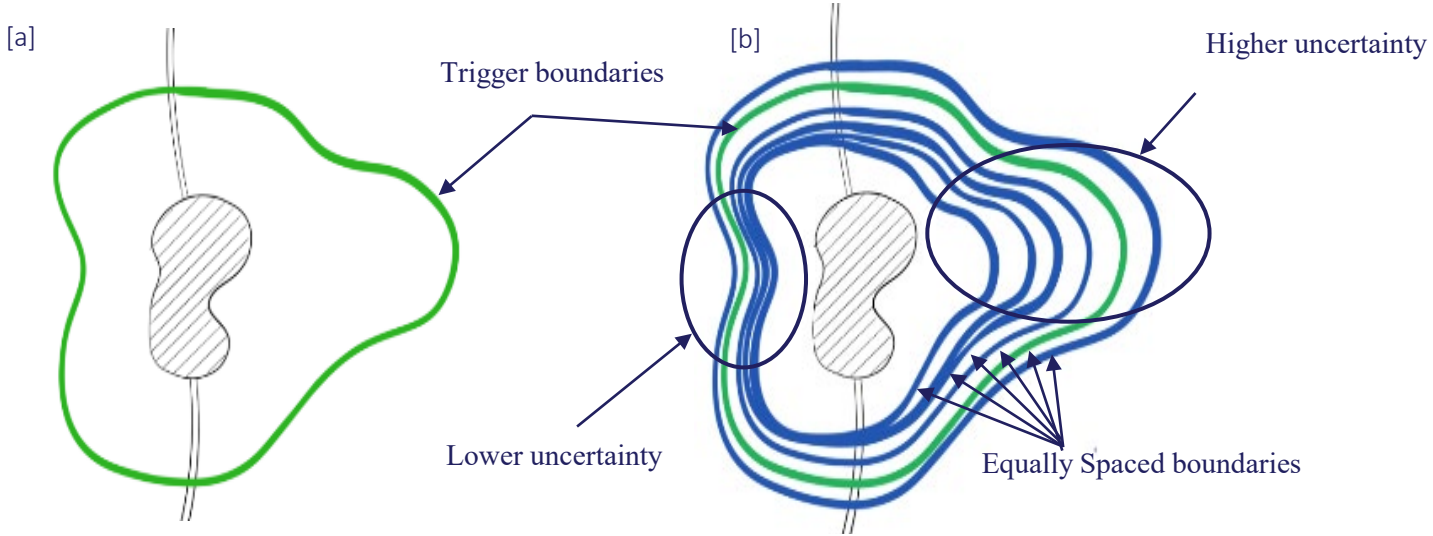


Fig. 3:[a] Example of a deterministic trigger boundary (green) surrounding an urban area (hatched). [b] The same area with stochastic trigger buffers. Stochastic trigger boundaries highlight areas with high or low uncertainty, where the fire behaviour is more or less variable respectively.

K-PERIL trigger model

(Kalogeropoulos et al. 2023 – accepted IAFSS2023)

(Future) Approaches to Assess Planning

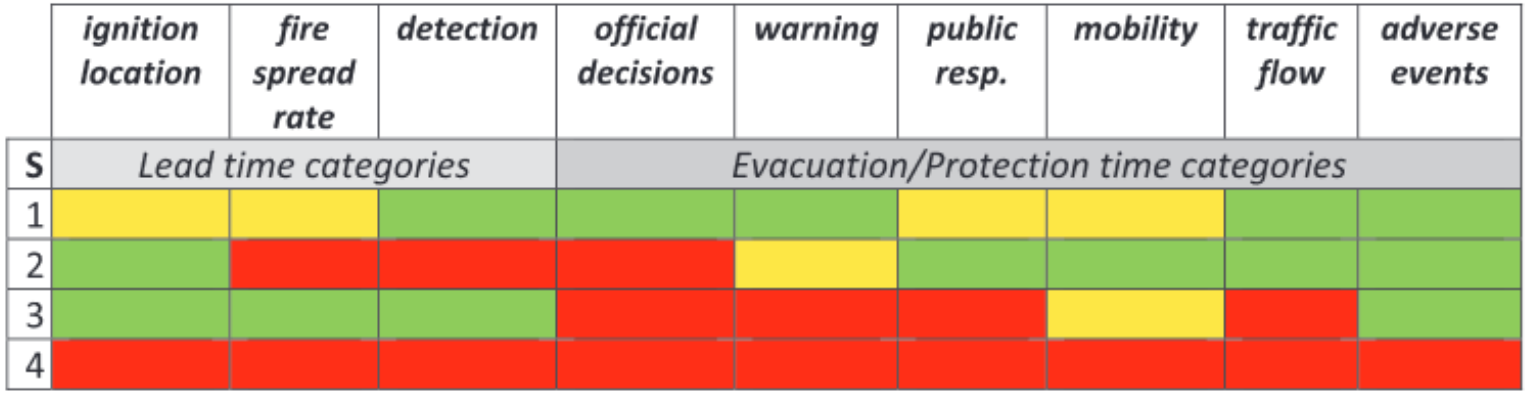
- Prescriptive approach – codified knowledge; if followed – assess safety of design/plan (safe or not)
- Performance-based approach – data are needed; quantifies performance via comparison

	Prescriptive Approach	Performance-based approach
Benefits	Cheaper, less resources	Allows plans to be tested/ stressed (with varied scenarios)
Limitations	Assumes static scenarios	Complex, data dependent

Framework for Developing Dire Scenarios

- Dire scenario → RSET > ASET (e.g., 2018 Camp fire)
- Can be incorporated into planning process (accounting for a range of scenarios) OR during an event if the fire
- Sources of dire fire scenarios:
  - Ignition close to a community
  - Longer detection time
  - Delays in emergency communication or lack of message receipt
  - HB: wait and see; low compliance rates
  - Limited transport capacity (roadways)

Cova et al. 2021 (Natural Hazards Review)



S	Lead time categories			Evacuation/Protection time categories					
	ignition location	*fire spread rate*	*detection*	*official decisions*	*warning*	*public resp.*	*mobility*	*traffic flow*	*adverse events*
1									
2									
3									
4									

Fig. 3. (Color) Dire scenario dashboard where scenarios (rows) progress from routine to extremely dire (1–4) due to varying factor impediment levels (green, yellow, red).

Cova et al. 2021 (Natural Hazards Review)

Summary and Key Take-aways

Summary

- Understanding human behaviour in fires is important to prepare and respond safely to wildfire events
- **Panic is rare**; instead, people are rational, altruistic and are more likely to help others in times of need
- Using the PADM as our framework, there are a number of factors that influence protective action decisions.
- Additional behaviours performed by evacuees after deciding to evacuate -- data are lacking for wildfires

Summary, cont.

- Various models exist to assist with evacuation planning (as well as real-time decision-making, etc.)
  - All are limited – important to understand assumptions/defaults
  - A few – WUI-NITY, SEEKER are developed for WUI fires
  - These tools allow for performance-based analyses … to ‘test’ or ‘stress’ the evacuation plan or strategy at hand
- Knowledge about HBiF is essential for the protection of people before, during and after fires! Additional data/research are needed to further develop, validate AND use evacuation models.

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