Community evacuation from wildfire events

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Executive summary: Wildfire evacuation events were examined to demonstrate their complexity. As part of the wider project, data from a US wildfire exercise was used to configure a macroscopic evacuation model – to simulate evacuation scenarios and capture some of the complexity present. To complement this, this case study explores complexity by identifying event dynamics and examining how they unfold to form a narrative – given events/evacuee decisions compiled from real-world incidents.

Tags: Fort McMurray, Roxborough Evacuation Exercise, pedestrian evacuation, traffic evacuation, community vulnerability, emergency planning, wildland urban interface, evacuation modelling, simulation, North America

Section 1: Background and introduction

According to the NFPA (National Fire Protection Association), a wildland fire is defined as an: 'unplanned and uncontrolled fire spreading through vegetative fuels, at times involving structures.' Where these begin to affect urban areas, these events are termed 'wildland urban interface' fires (WUI fires), as depicted in **Figure 1**. We tend to hear about these more – as they directly affect people, as depicted in **Figure 2**. Wildfires are an important safety issue in many regions of the world.

Such fires can threaten both rural and urban areas – affecting the short-term (life safety, infrastructure and the economy) and long-term (the environmental conditions, community health and well-being, tourism, etc,) status and viability of a community.

Wildfires increasing in frequency and severity

The frequency / disruption and severity / damage of wildfires affecting communities is increasing – for instance, the number of evacuations required because of a wildfire threatening a community. For example, as shown in **Figure 3**, those occurring in Western Canada and in California are of particular concern. Two examples demonstrate the complexity and cost of such events and the need for improved situational awareness and understanding of such events.

The Fort McMurray wildfire spanned 10 weeks in 2016, costing approximately US$10billion, producing disruption to local communities (an evacuation of 88k+ people) and industry (interruption to nearby tar sands refineries). The incident was marred by challenges in assessing the movement of the wildfire and its impact on evacuation routes – and on public communication efforts. As a result, command centres and refuges had to be repositioned during the response (given the unanticipated movement of the fire and evacuee response). The only deaths occurred during the evacuation itself.

More recently, Paradise (California) was subject to a catastrophic wildfire event (affecting a population of 26k). Paradise had an evacuation plan, with four evacuation routes for the population. Residents were familiar with these routes and preparatory exercises had previously been conducted. However, during the incident, two of the routes were blocked by the fire, requiring responders to focus their efforts on supporting the evacuation rather than addressing the incident. Delays in the evacuation meant residents were forced to take refuge in stores wetted by firefighters. Critical infrastructure (e.g., hospitals) were affected requiring ad hoc transportation plans. Personnel from surrounding areas were requisitioned to assist, having a knock-on impact on those areas. 85 people died. So what?

Properties of wildfire evacuation

A wildfire evacuation has several properties that add to its complexity:

- Involves multiple domains (e.g., a fire, land topography, infrastructure, human response, etc.).
- It is highly coupled (the fire can affect the roads available and the behaviour of the citizenry, which might affect the responders reaching the incident).

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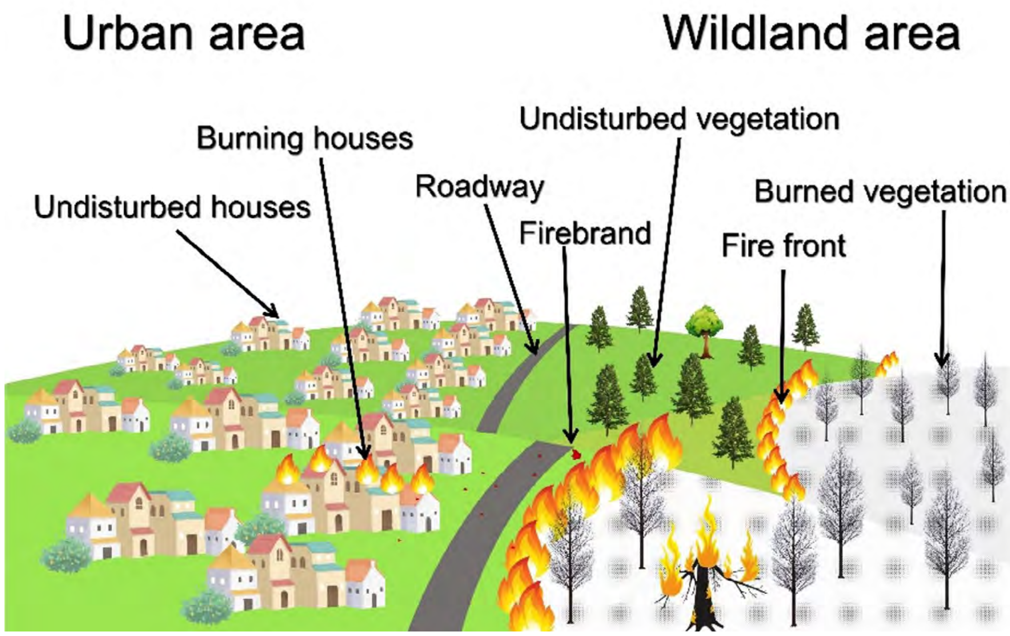


Figure 1: The interface between a wildfire and urban settlements, highlighting the ways in which the fire might affect the surrounding areas (courtesy of Dwi Purnomo).

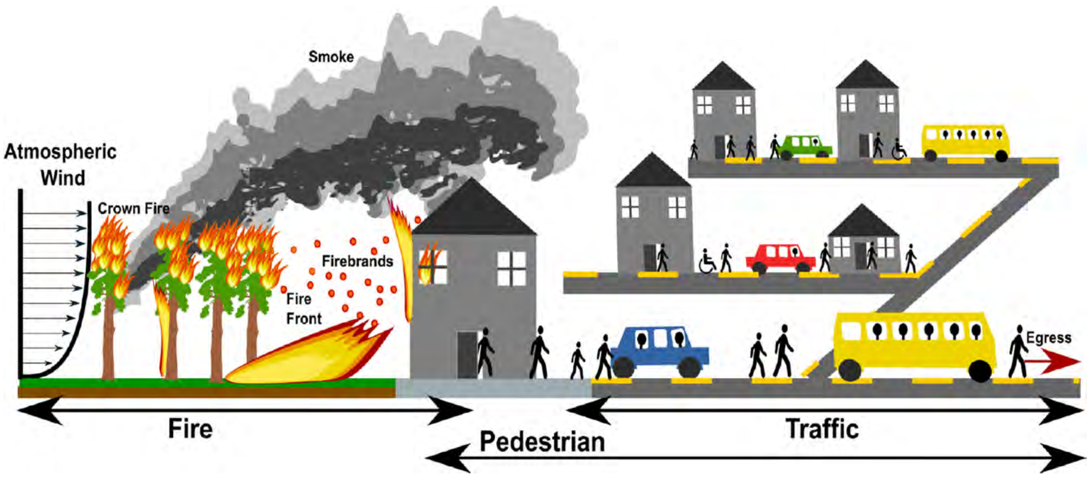


Figure 2: Fire, exacerbated by wind, impacting infrastructure and people (courtesy of Harry Mitchell).

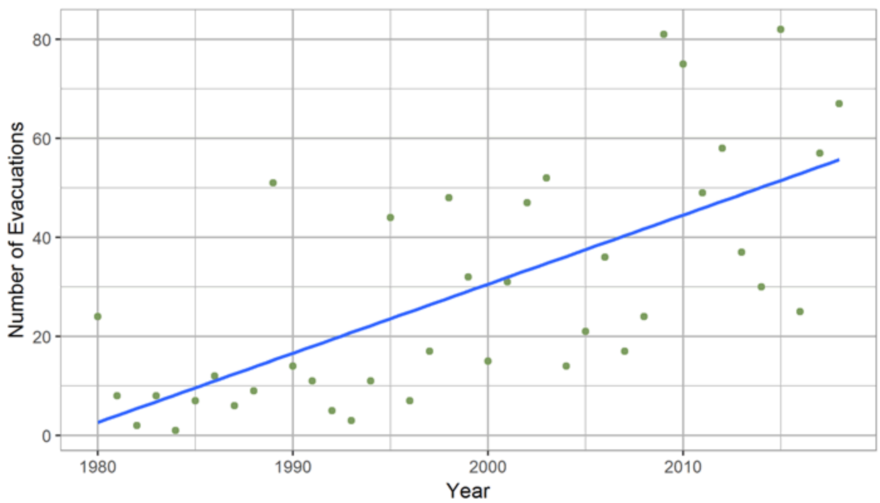


Figure 3: Example of Canadian evacuations (Source: Government of Canada, 2020).

- Involves large-scale (it may cover tens of square kilometres and reach communities hundreds of kilometres from the source).
- Involves multiple organisations / actors (individuals, businesses, communities and government agencies) over a long period of time.
- May involve many modes of movement, information sharing and intervention (e.g., access to social media, formal notification, individuals interacting).
- Potentially multiple incidents (a fire front can produce embers that then start secondary fires).

These actors/ factors interact, producing emergent conditions. These differ over time and the area affected. These affect the information available, perceived risk and actions performed by those involved.

It is possible to gain a clearer insight by accounting for these interactions and the aggregate outcomes – seeing the whole process as a complex system, as depicted in **Figure 4**.

When a fire develops, the location, severity and spread of this fire will be sensitive to the vegetation / fuel present, the topography, and the weather.

Planning and intervention efforts are employed. These affect the public activities prior to the incident, the emergency procedures and resources to intervene during the incident. The intervention performed will be sensitive to the situational awareness of emergency decision-makers, the resources available for this intervention, and the planning in place – along with the actions of the public.

The members of the public subjected to the incident and those sharing resources involved in the evacuation. The public's response will depend on the community size and demographics; the understanding of the existence, location and severity of the wildfire incident; and the resources available (social, physical, experiential, technological, etc.) to the community. This will influence the decision-making process and the action taken. This will be constrained by the available infrastructure, along with the social grouping within which a resident finds themselves.

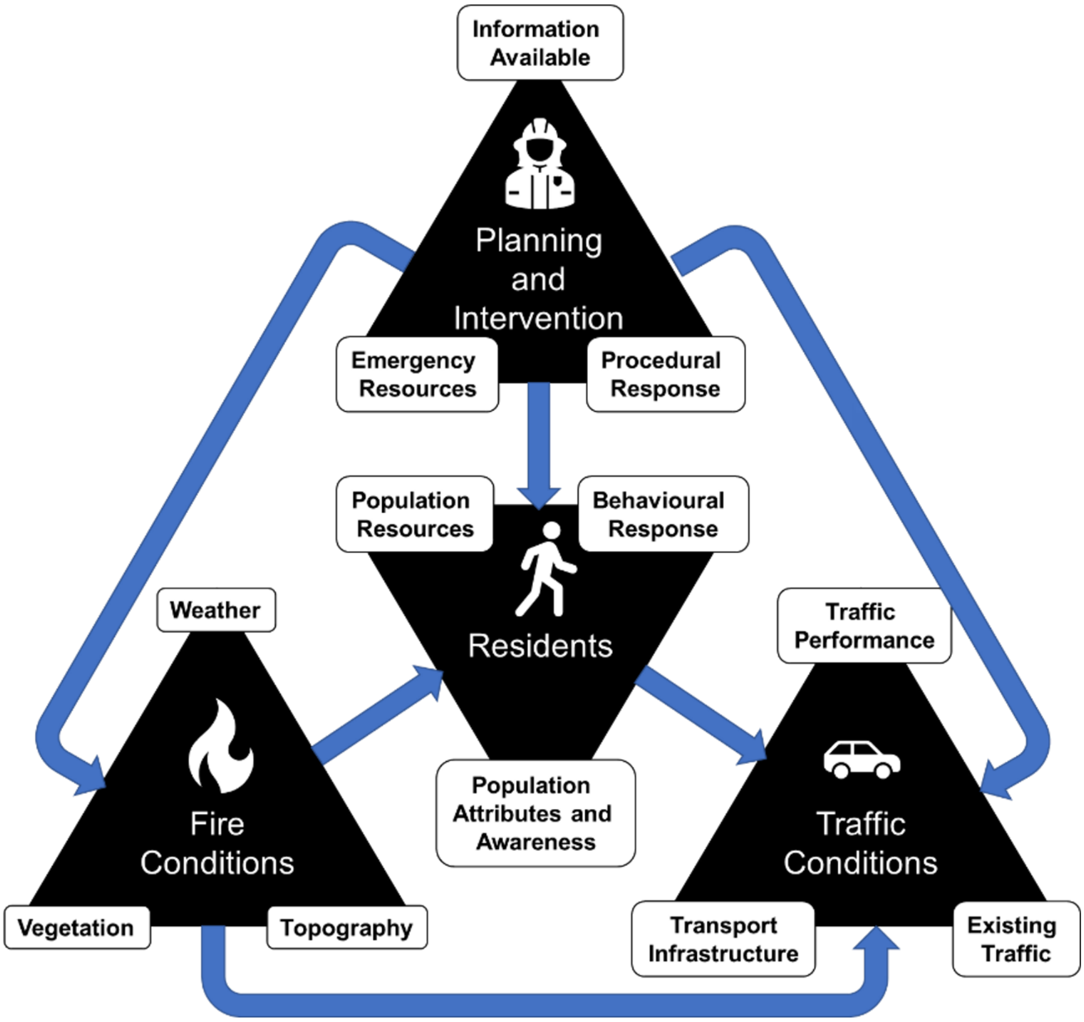


Figure 4: Some of the key properties of wildfire evacuation interacting as a complex system.

Community evacuation timeline

Initially, evacuation might involve pedestrian movement – walking to a local place of safety or moving to a vehicle. As such, one of the outcomes of the citizen movement might be an input into the traffic system and the local conditions produced within it.

The traffic conditions produced during the evacuation are initially influenced by the demand produced by the arriving evacuees into the system and the traffic already there, given the network capacity. The conditions will be shaped by the configuration and capacity of the traffic infrastructure in place, efforts to manage the movement of the traffic and the demand placed on the route capacity available.

These elements interact to produce conditions over the timeline of the incident. At the scenario level, the event can be viewed as unfolding across several distinct stages (see **Figure 5**). It is apparent that the coupling between the incident, the evacuating citizenry and attempts to manage and mitigate the incident are embedded within this timeline.

Evolving scales and conditions

The actions taken by the community and emergency responders during the wildfire will produce conditions that evolve – over space (e.g., kilometres) and time (e.g., weeks), as depicted in **Figure 6**.

The initial fire may develop spawning new fires remote from the original source through the transport of firebrands.

Fires may spread rapidly (faster than most people can run) with fire fronts extending kilometres in length. Smoke may affect communities located tens of kilometres away.

Similarly, multiple communities may be affected by a single fire and be subject to different information and guidance and may fall within different jurisdictions.

Therefore, both the fire conditions and the evacuation process will vary over space and time, be extremely dynamic in nature and be sensitive to changes in one of the influential domains (e.g., the land, the weather, the fire, emergency interventions, public actions, etc.).

This is starkly different from building fires (and associated planning)– where typically timescales are shorter, fires are localised, and the event occurs within one jurisdiction.

Why this matters

Given the above (and the results presented in the long version of this report) we make the following assertions:

- Wildfires pose a serious threat to community safety.
- This threat is expanding and increasing given environmental issues, as depicted in **Figure 7**.
- New communities are becoming vulnerable to this threat as it affects new locations.
- New communities are also becoming vulnerable to this threat as people choose to move to wildland urban interface locations.
- Communities historically threatened by wildfires are facing new and unfamiliar conditions – testing their understanding and resources.
- Given new locations and severity, wildfire conditions are diverging from the conditions faced in the recent past. This makes it harder to estimate the outcomes of new fires directly from historical fires.
- Wildfires are formed from various elements (social, physical and environmental) that interact in complex ways.

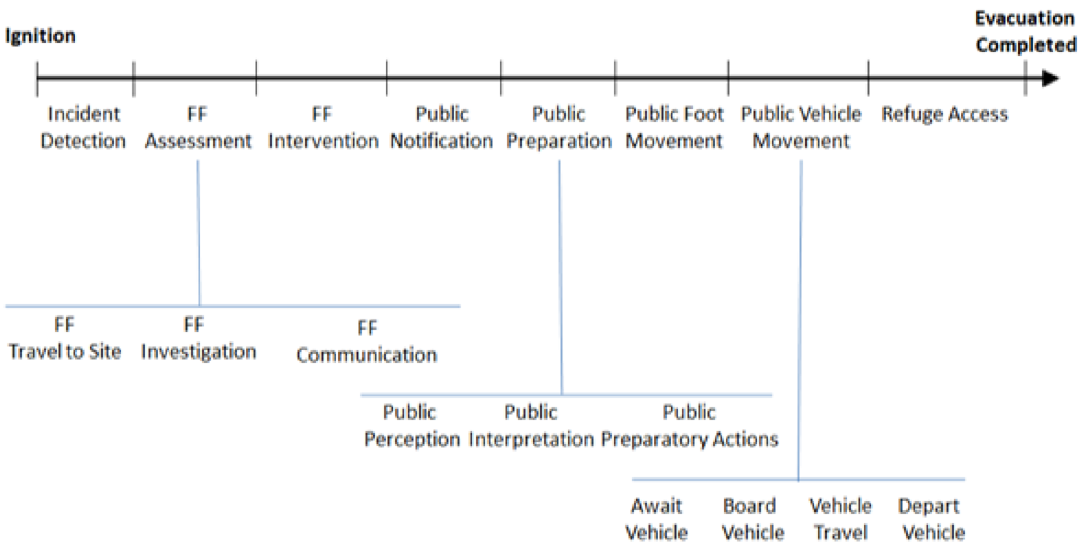


Figure 5: An example of a community evacuation timeline. FF=Fire-fighter(s). (Source: Initini et al (2020), Ronchi et al (2017), Wahlqvist et al (2020))

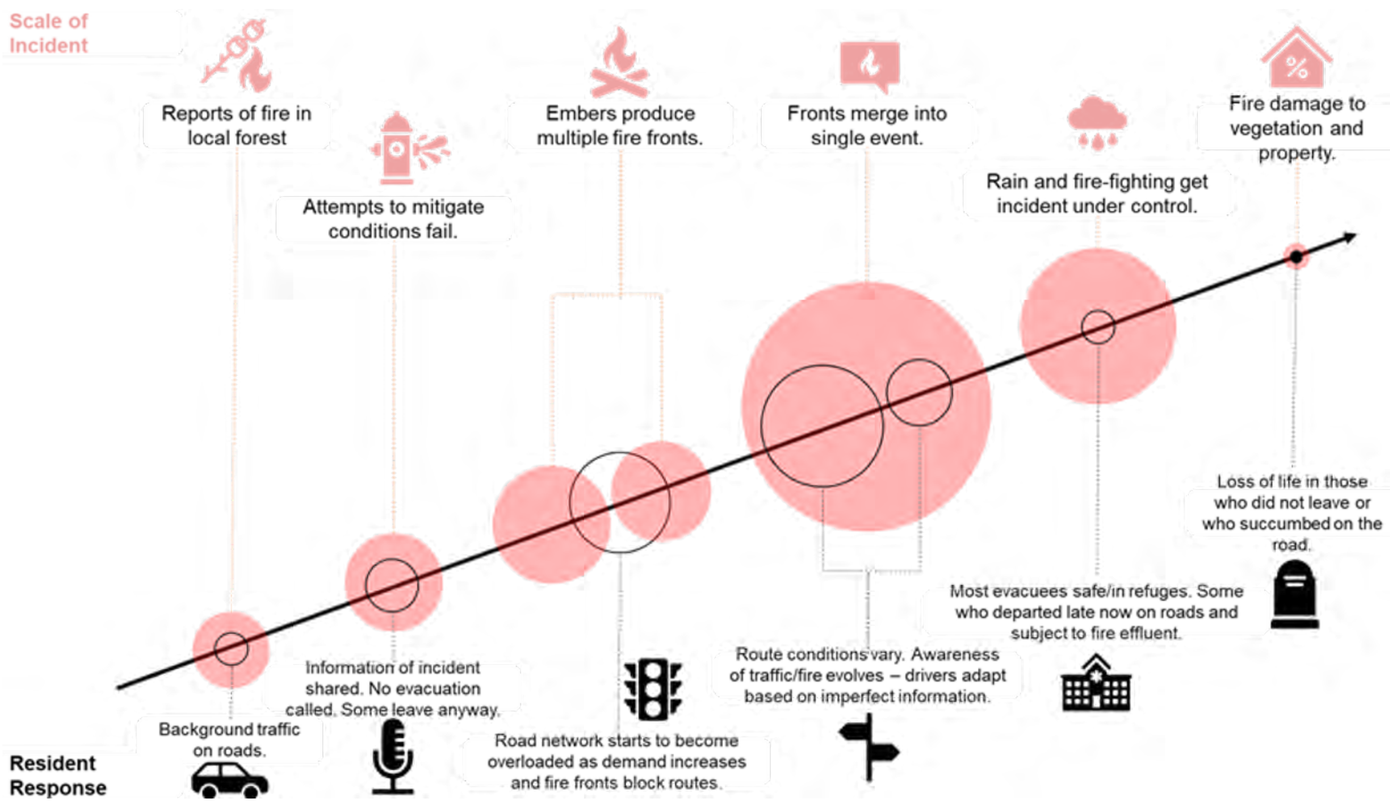


Figure 6: A depiction of the evolution, scale and condition of a wildfire evacuation given the fire conditions faced.

- To understand the threat posed, it is necessary to understand a community's capacity to cope with the conditions faced.
- New means to quantify community evacuation might be needed – to capture interactions between key elements and to cope with challenges in deriving projections from historical events.
- Modelling might assist in this endeavour.
- Such models would also be needed to support performance-based regulations or inform the development of prescriptive approaches.

Granularity of wildfire evacuation

Individuals affected by a wildfire may become aware of a wildfire through different means (e.g., official communications, direct exposure to fire cues, informal conversation with a neighbour, unreliable source on social media, etc.). Prior to this awareness they will have been involved in a range of routine activities.

These individuals will process this information and either individually or collectively determine when and how to respond. Assuming that they are in a household, the residents may discuss the situation, prepare and decide upon a response (i.e., whether they choose to evacuate and when they choose so to do). If they are part of a social group, then this response will likely involve assessing the capabilities of those with them (e.g., preparatory requirements, movement abilities, etc.).

They might eventually walk to their vehicle (or shared vehicle or public transport). Depending on their location, they may interact with other residents inside their building (e.g., in a multi-occupancy structure) with resultant congestion/interactions emerging in a staircase or interact when moving to shared parking areas. This admittedly seems like a trivial example here – not affecting overall performance. However, if this is transposed on to the evacuation of a 50-storey office block or a hospital then these interactions and resultant delays can become extremely serious indeed, as depicted in **Figure 8**.

Emergent conditions might arise from the pedestrian evacuation (e.g., queuing on stairs, boarding a public vehicle, etc.). Or, on the streetscape outside of their building, evacuees may encounter others moving to a local place of safety or to their vehicles.

If they are not at home (e.g., at work), then before evacuating residents may need to return home – potentially moving away from safety on foot or by vehicle. This has implications for traffic congestion, road management and on the delays incurred prior to their movement to a place of safety.

Assuming that evacuation to a remote location is necessary,

Figure 7: Wildfires reported in the media – 2017-2021. In areas where, historically, such events have been both expected (e.g., California) and unexpected (e.g., Sweden).

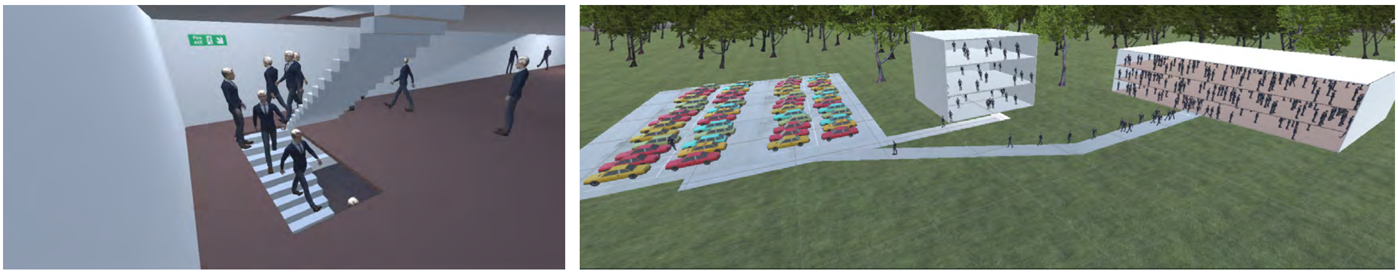


Figure 8: Example simulation (represented within the WUI-NITY model) of people evacuating downstairs and then transitioning from pedestrian to vehicle movement from a multi-occupancy location (Source: Ronchi et al (2017), Wahlqvist et al (2020)).

evacuees will likely board a vehicle and move off, joining the wider traffic system. If this involves public transport, then the capacity of the vehicle might limit the individual's/group's ability to board and move off – forcing them to wait for the next available berth.

The vehicle will eventually be the basic 'unit' of evacuation – possibly hosting several individuals – that then becomes the locus of their agency (their response). The entry of this vehicle into the traffic system is effectively the connection between the pedestrian evacuation and the traffic evacuation. As such, the resident's initial decision-making, preparation and movement to the vehicle might generate local emergent conditions of interest; these in turn provide input into the higher-level traffic evacuation. As such, a wildfire evacuation might reasonably be depicted as a system of multi-layered complexity, as in **Figure 9**.

Agency operates at multiple levels within the wildfire evacuation 'system': individual, residence, street, community, local, regional, national and international, etc. These may all affect the conditions produced and the eventual outcome (both local and general).

Several of these levels might be active at the same time – given different capabilities, objectives and opportunities.

The mode of this agency will change according to the conditions faced and the resources available.

This complicates the evacuation dynamics produced, but also increases the number of 'levers' available to influence the evacuation outcome. The management 'levers' might be available before or during the incident.

They might require different levels of resources, be available to different organisations and may be targeted at the levels of agency present (individuals, groups /

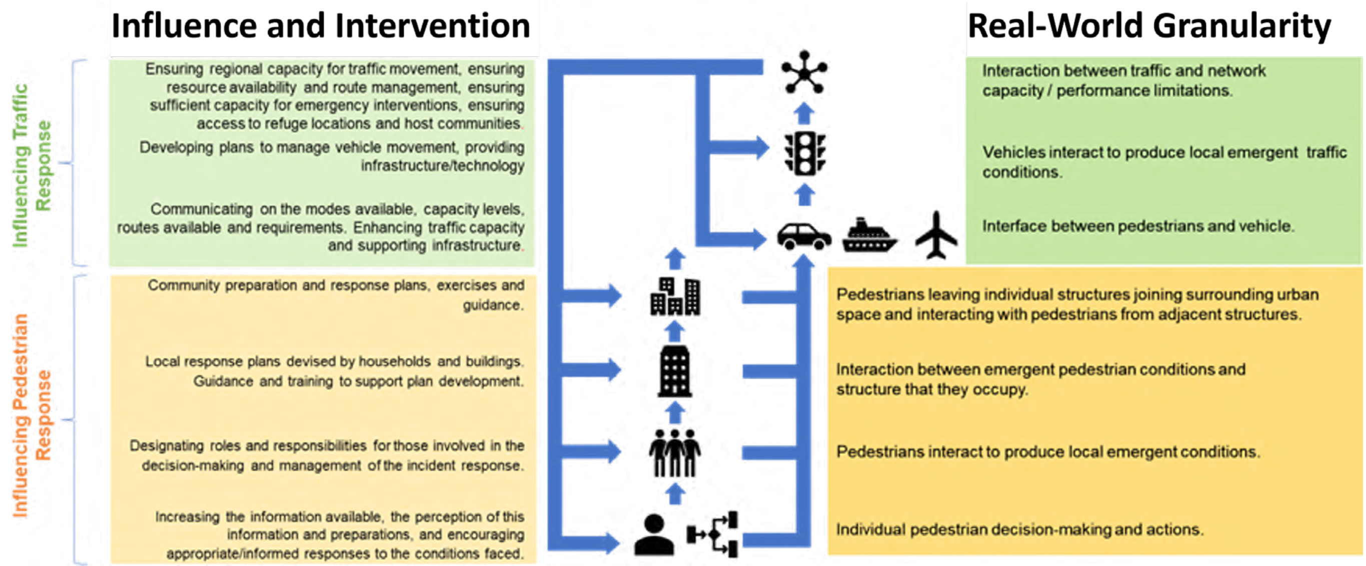


Figure 9: A wildfire evacuation as a system of multi-layered complexity.

vehicles, buildings, communities, regions, etc.). These might include education / outreach, regulation and guidance, emergency planning, exercises, incident notification, incident management, responder intervention, traffic management, etc. The complexity of a wildfire evacuation makes it sensitive to many different factors that operate at many scales. Their interaction can be outcomes out of proportion to the underlying change. Understanding this complexity allows for more interventions (at various levels and points in time); however, it also requires understanding the impact of these interventions as otherwise they can have unintended consequences that quickly get out of control or do not address underlying issues.

Section 2: Analysis and insights

Several cases were described in the long version of this study as the evacuation conditions were reasonably well documented, demonstrating at least some of the complexity described, and showed both that conditions evolve and that human performance can be a key aspect in this evolution.

The dynamics of a wildfire evacuation vary – depending on the scenario. The Fort McMurray wildfire evacuation is selected to demonstrate several aspects of wildfire evacuation and related community safety (with the attributes of complexity identified previously):

1. The evolving incident conditions (weather, fire development, remote fire locations, fire weather);
2. The response of the affected population (e.g., pedestrian movement, traffic movement), reflecting the diversity and vulnerability of the affected population and effectiveness of their decision-making (affected by information available);
3. Attempts at managing the outcome and the conditions faced (notifying people, fighting the fire, managing traffic, deciding to evacuate the community), given the organisations and groups present, emergency procedures employed at the local and regional levels and deployment of emergency resources;
4. Outcomes / consequences (loss of life, loss of property, loss of routes, traffic conditions, local/ national impact, etc.).

The following text is labelled with superscripts (in-line with the numbered list shown above, e.g. (1) reflects incident conditions, (2) reflects population response, etc.) to highlight where these factors are mentioned in the cited material. This is simply to demonstrate that the factors were at play, rather than assigning weight to the significance of their impact on the outcome.

Historical case study: Fort McMurray, Alberta, 2016

At 16:00 on 1 May 2016 a 0.02 km^2 wildfire was spotted in the Wood Buffalo area deep in a forest – 15-20km southwest of Fort McMurray (Alberta, Canada), depicted in **Figure 10**.[1]

Wood Buffalo has a population of more than 125,000 people including rural and urban communities. Of these, approximately 35% are temporary residents and 10% are First Nation communities; i.e., they have different levels of familiarity with the local area and different relationships with local authorities.

Strong winds (>70km/hr) and high temperatures (daily temperatures >30°C and humidity <12%) promoted the development of the fire.[1]

The immediate emergency response included water bombers being deployed, followed by

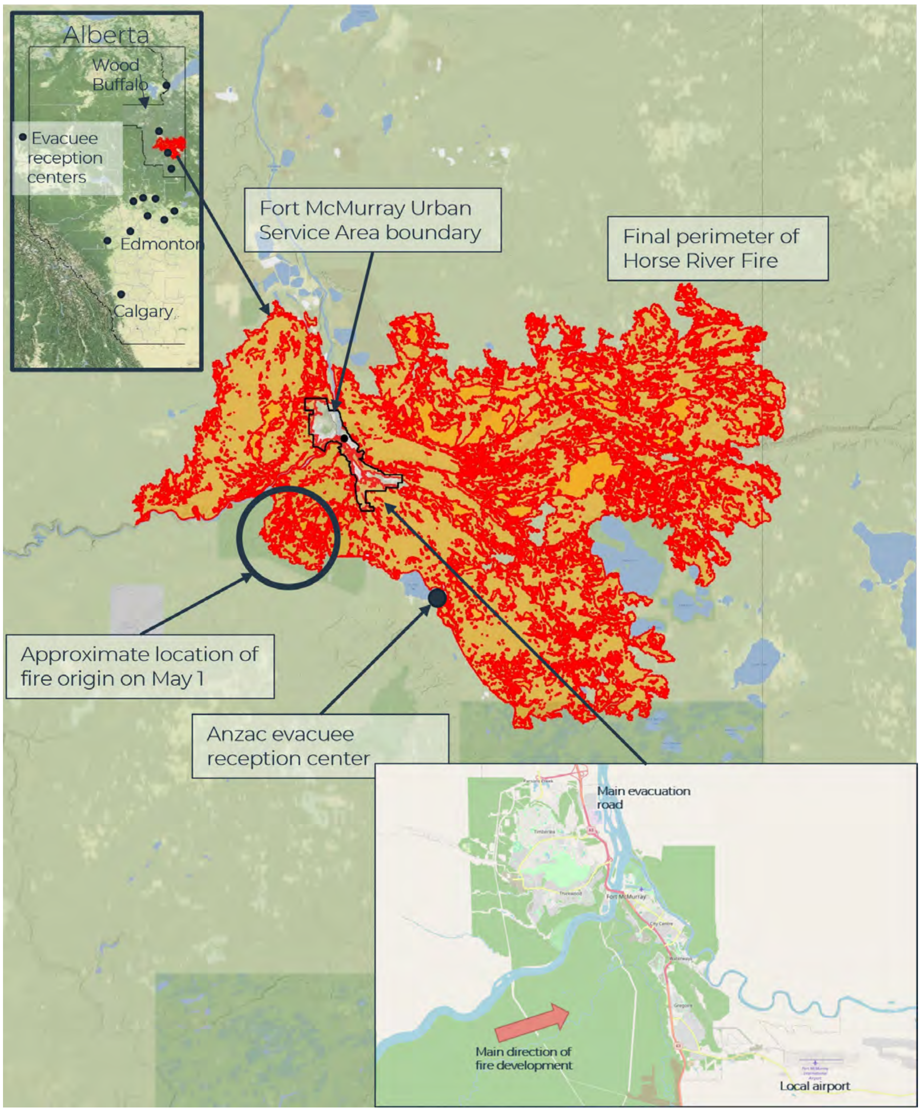


Figure 10: Fort McMurray (2016) case study. (Source: Alberta Agriculture and Forestry (2021), Institute for Catastrophic Loss Reduction (2019), OpenStreetMap (2021), Ronchi et al (2017)).

warnings issued to nearby campgrounds of the possibility of an upcoming evacuation.[2]

Within six hours of the fire initially being spotted, an evacuation centre was opened on MacDonald Island and a local state of emergency declared.[3] However, the next day warning levels were reduced[3] given that wind conditions improved and appeared to be blowing the fire away from the city.[1]

On 3 May conditions changed again and the fire entered Fort McMurray[1] leading to tens of thousands of people evacuating in short order to refuge centres in various locations.[2] Some of these evacuation centres were affected by changing fire conditions requiring them to eventually be evacuated themselves.[3]

During this (re)evacuation, two people were killed in a car accident (i.e., not directly by the fire itself).[4]

By the end of the day, more than 60,000 residents had evacuated, including all 105 patients at the Northern Lights Regional Health Centre.[4]

Highways were quickly overloaded with traffic.[4] To cope with this, convoys were formed.[2]

By 4 May, 1,600 structures had been destroyed with 100 km^2 of wildland involved.[4]

A provincial state of emergency was declared with 80,000 people instructed to leave.[3]

By 5 May, there were 49 separate fires burning and 1 4,000 people had to be airlifted from work camps north of Fort McMurray.[3]

Firestorm conditions were reported, and spot fires ignited new fires more than 1km away from the original source.[1]

On 6 May, 8,000 workers were evacuated from 19 oil sites as the fire spread north.[3]

Most people who fled the region did not have short-term contingency plans in place other than getting away from the immediate danger.[2] Local industry and residents, communities, post-secondary institutions and parks offered to host evacuees.[3] Reception centres were quickly put up across Alberta in numerous locations.[3]

On 6 May, the Alberta Premier announced emergency evacuation funds.[3]

The deployment and use of firefighting resources peaked on 3 June, with approximately 2,197 firefighters actively engaged.[3] The Government informed Albertans of the evolving situation with news conferences, information bulletins, social media, websites, call centres, emails, telephone town halls, etc.[3] Across the incident, more than 88,000 people were evacuated.[4] This primarily involved private vehicles, although public buses and aircraft were also involved.

Smoke generated by the fire affected the evacuee capacity to drive along the routes still available.[4] The incident lasted during May, June and July of 2016, affecting nearly 6,000km^2 of land.[4] Over 2,400 structures were destroyed in the fire, gas, electricity and water supplies were disrupted and the local airport closed.[4]

Management and evacuee decision-making were conducted continuously throughout the response, as depicted in **Figure 11**. These occurred at various organisational levels. There are numerous examples where these decisions (and outcomes) might have benefitted from more timely, accurate and complete information:

- Downgrading of 'evacuation status'
- Use of evacuation routes
- Allocation of evacuees to refuge camps
- Traffic management
- Refinery evacuation
- Community evacuation
- Re-entry management

This is not to criticise the response – only to suggest that during a wildfire event the decisions made are enormously sensitive to the information available and that the selection of a response might be sensitive to an estimation of the potential effectiveness of that response.

Hypothetical case (HC): Tale of the TAILs

A simple hypothetical example is now presented, across 12 inset tiles, to explore incident complexity. It is not based on any one case. Instead, the conditions faced, information available, actions performed, and the organisation responses are representative of those seen elsewhere in previous incidents. The intention is to capture a compilation of the factors and responses seen – but in one incident. This example is characterised by several timelines:

- Government: Those who regulate, guide and coordinate resources and actions beyond the site of the incident;
- Non-Government: Actors who are affected by the incident, but who have organisational responsibility in the private, non-profit, or commercial sectors;
- Emergency Response / Incident Management: Those intervening to affect the conditions produced by the wildfire incident or the incident itself;
- Incident: The evolving fire conditions;
- Population (traffic or on foot): The citizenry affected by the incident who might respond.

Each of the timelines hosts a number of 'episodes' representing key events. Episodes appear along each timeline. These reflect the changing conditions and their potential impact. Other actual incidents might also be similarly represented using this approach.

Actor response is described using up to three panes (see **Figure 12** for the generic format):

- Description. Overview of the situation described.

Figure 12: Three pane generic template describing actor response used in the 12 tiles depicting the Hypothetical Case Study.

- Graphic. A simple schematic of the conditions outlined.
- Status Pane. This includes a description of this population / person's Target (their objective at that point in time); Action (the behaviour exhibited to meet that target); Information (the situational awareness of those involved); and Location (the position of this population and the surrounding conditions).

This is included where decisions of interest are made. Elsewhere episodes are only described using Graphic and Description panes, to indicate condition changes.

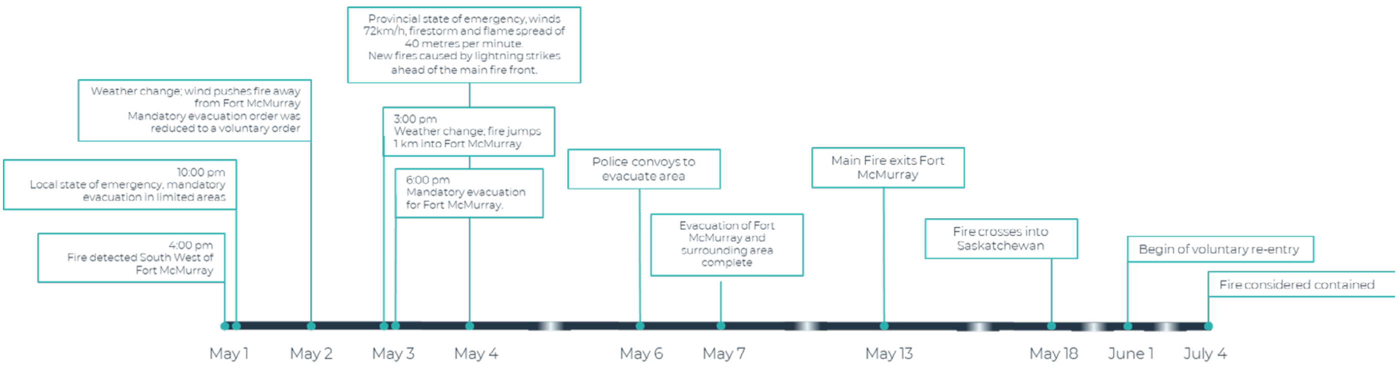
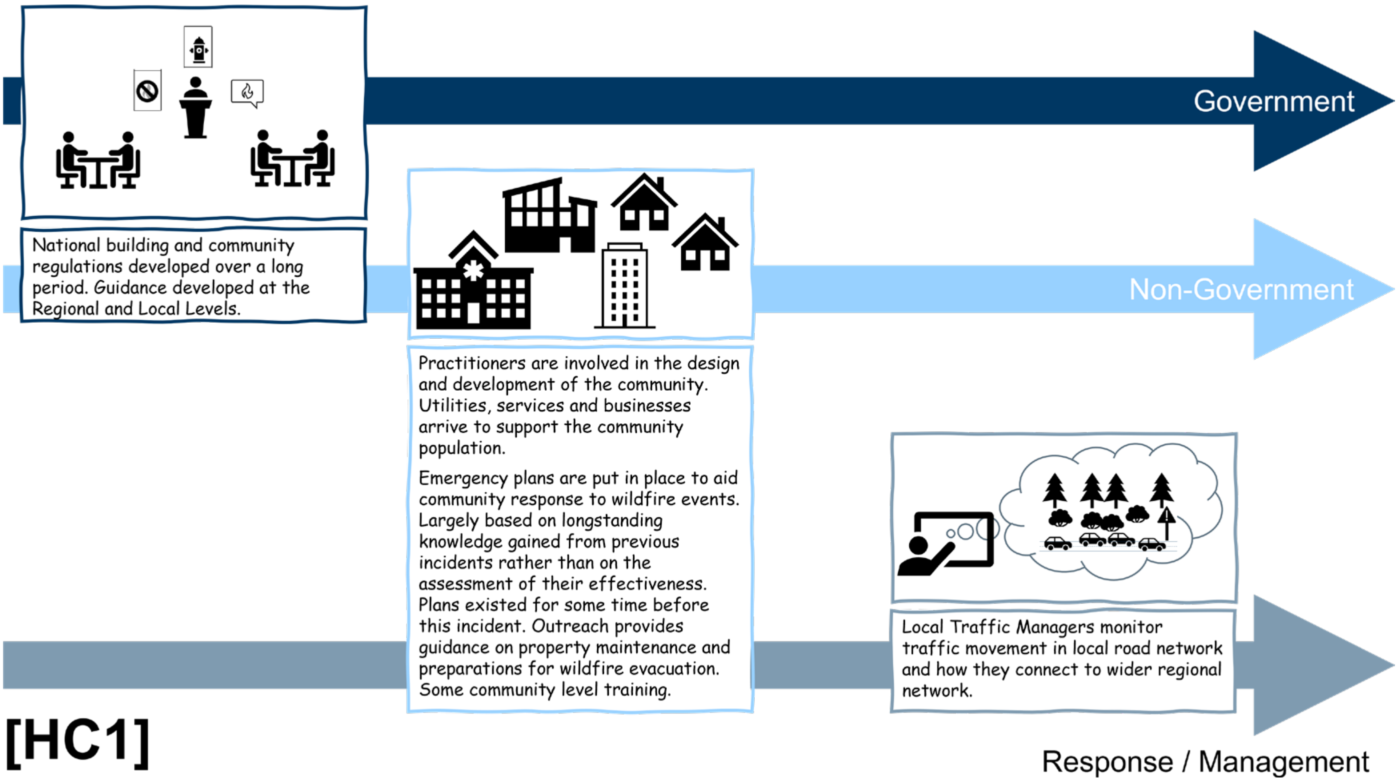
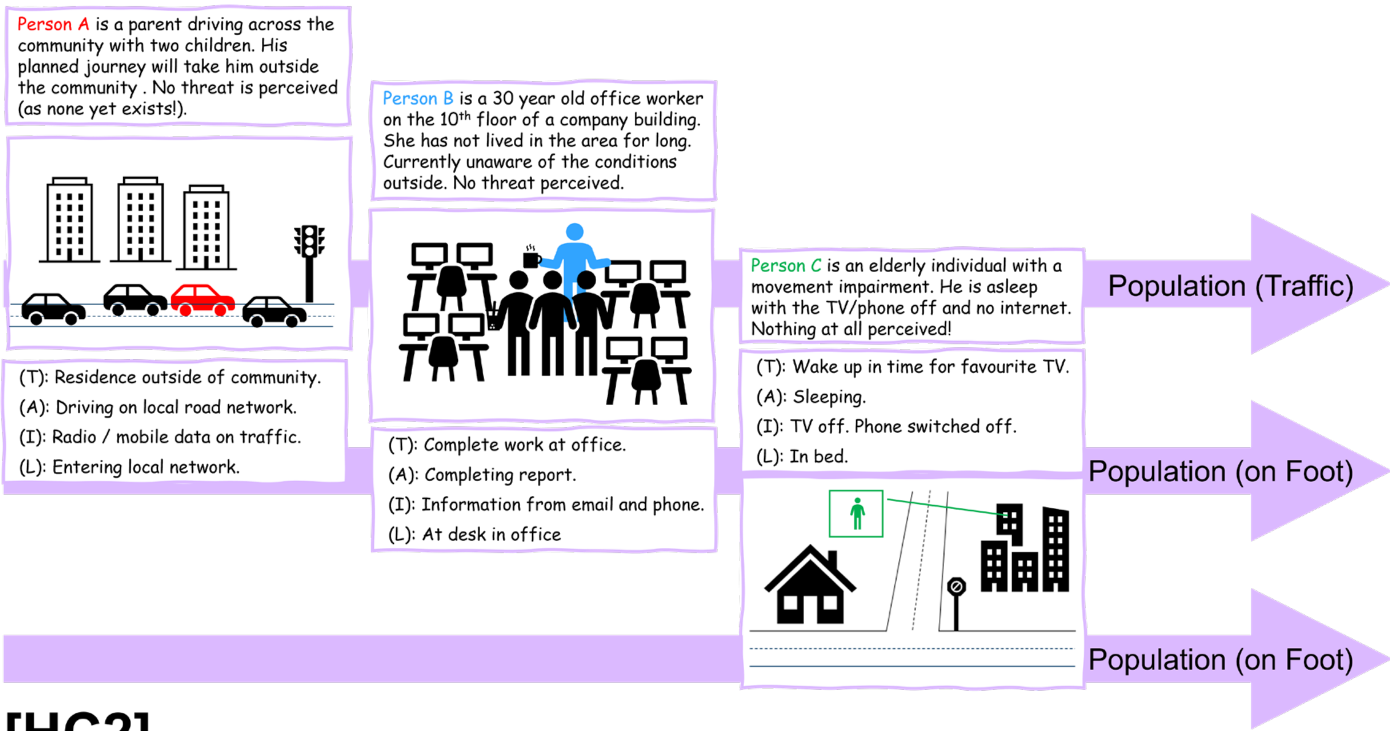


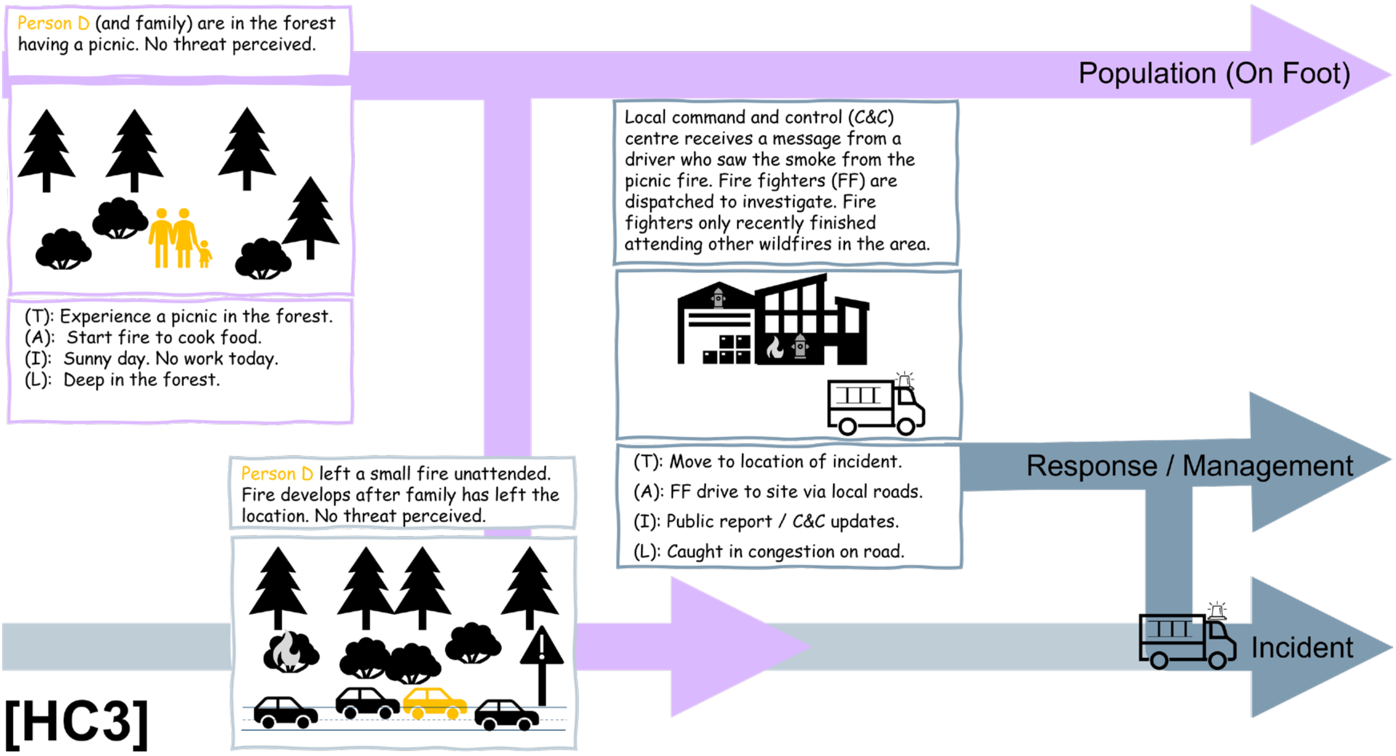
Figure 11: Management and evacuee decision-making timeline of the Fort McMurray (2016) case study.

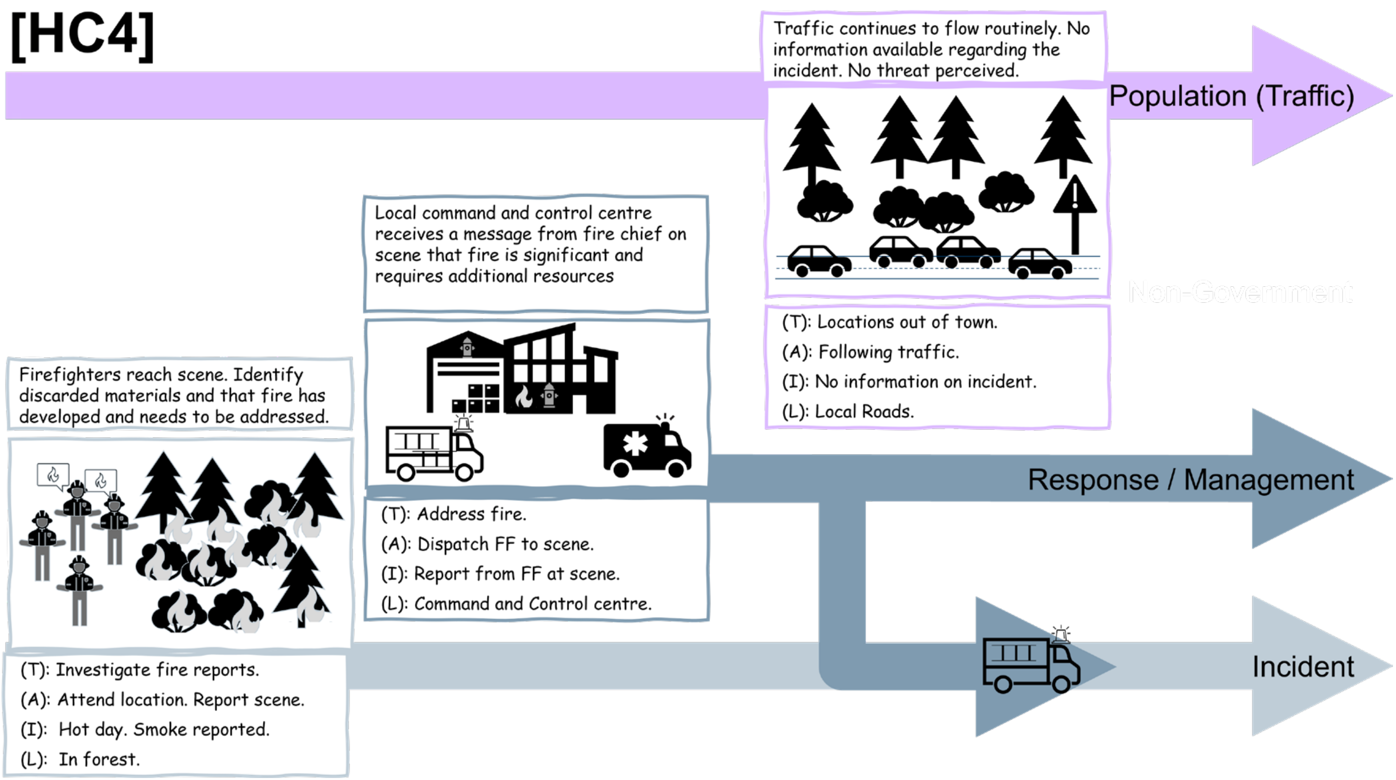

National building and community regulations developed over a long period. Guidance developed at the Regional and Local Levels.
Government
Practitioners are involved in the design and development of the community. Utilities, services and businesses arrive to support the community population.
Emergency plans are put in place to aid community response to wildfire events. Largely based on longstanding knowledge gained from previous incidents rather than on the assessment of their effectiveness. Plans existed for some time before this incident. Outreach provides guidance on property maintenance and preparations for wildfire evacuation. Some community level training.
Non-Government
Local Traffic Managers monitor traffic movement in local road network and how they connect to wider regional network.
Response / Management

[HC1]

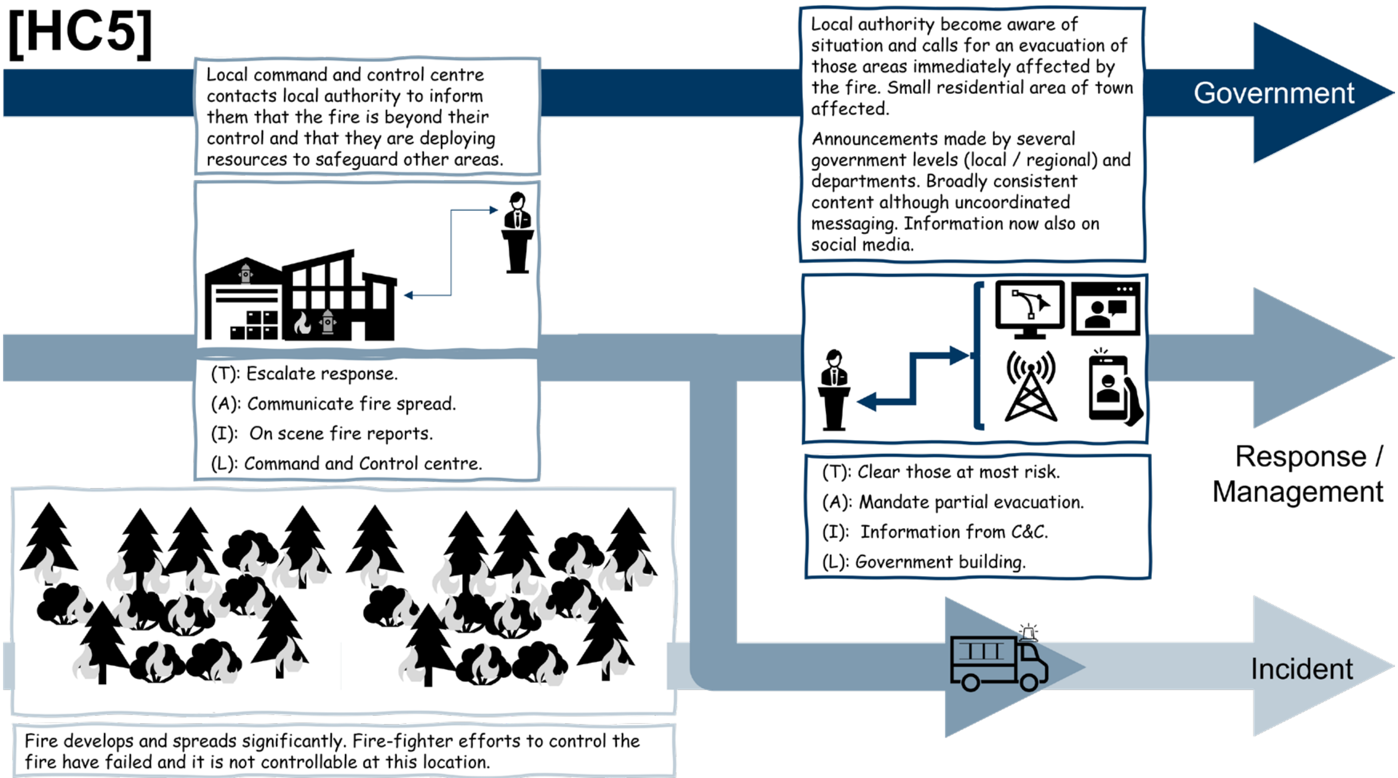

Person A is a parent driving across the community with two children. His planned journey will take him outside the community . No threat is perceived (as none yet exists!).
(T): Residence outside of community.
(A): Driving on local road network.
(I): Radio / mobile data on traffic.
(L): Entering local network.
Person B is a 30 year old office worker on the 10th floor of a company building. She has not lived in the area for long. Currently unaware of the conditions outside. No threat perceived.
(T): Complete work at office.
(A): Completing report.
(I): Information from email and phone.
(L): At desk in office
Person C is an elderly individual with a movement impairment. He is asleep with the TV/phone off and no internet. Nothing at all perceived!
(T): Wake up in time for favourite TV.
(A): Sleeping.
(I): TV off. Phone switched off.
(L): In bed.
Population (Traffic)
Population (on Foot)
Population (on Foot)

[HC2]

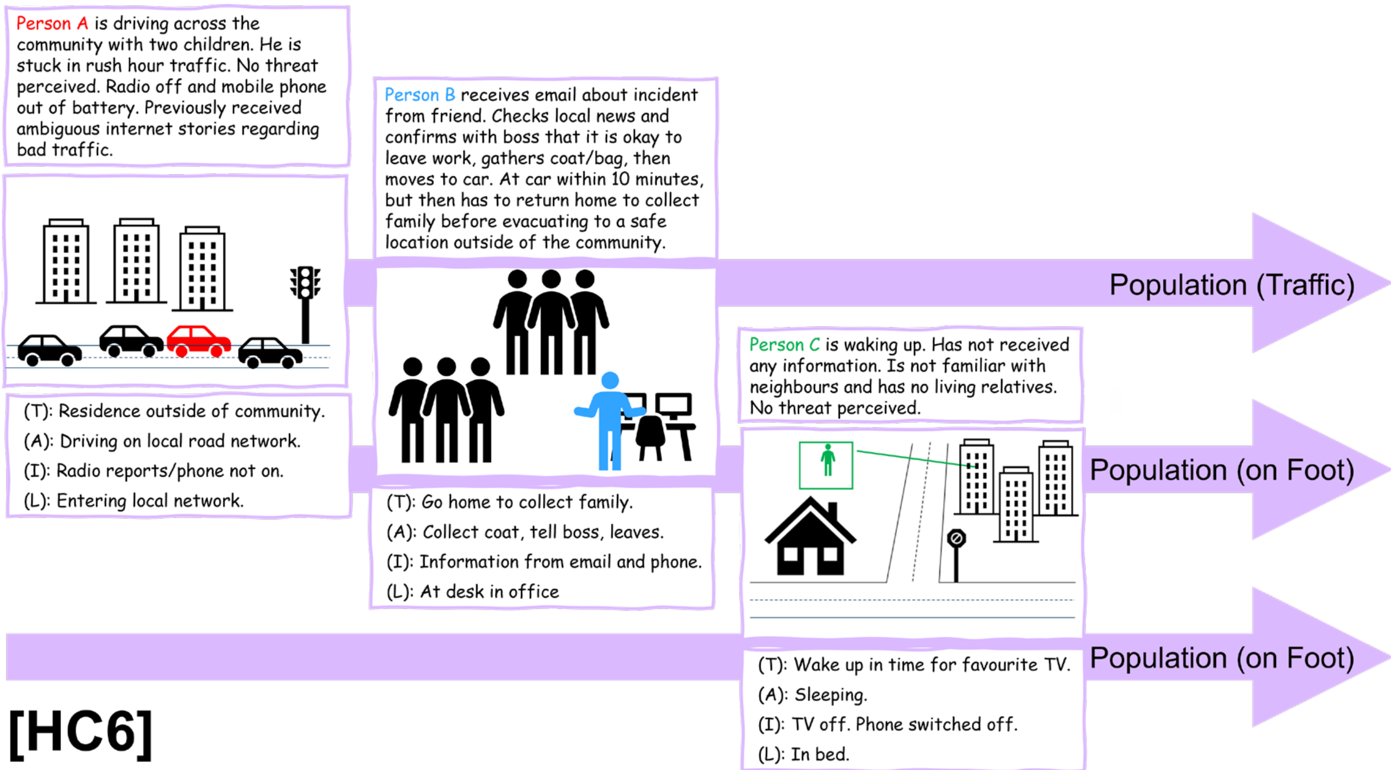

Person D (and family) are in the forest having a picnic. No threat perceived.
Population (On Foot)
(T): Experience a picnic in the forest.
(A): Start fire to cook food.
(I): Sunny day. No work today.
(L): Deep in the forest.
Local command and control (C&C) centre receives a message from a driver who saw the smoke from the picnic fire. Fire fighters (FF) are dispatched to investigate. Fire fighters only recently finished attending other wildfires in the area.
(T): Move to location of incident.
(A): FF drive to site via local roads.
(I): Public report / C&C updates.
(L): Caught in congestion on road.
Response / Management
Person D left a small fire unattended. Fire develops after family has left the location. No threat perceived.
Incident
[HC3]

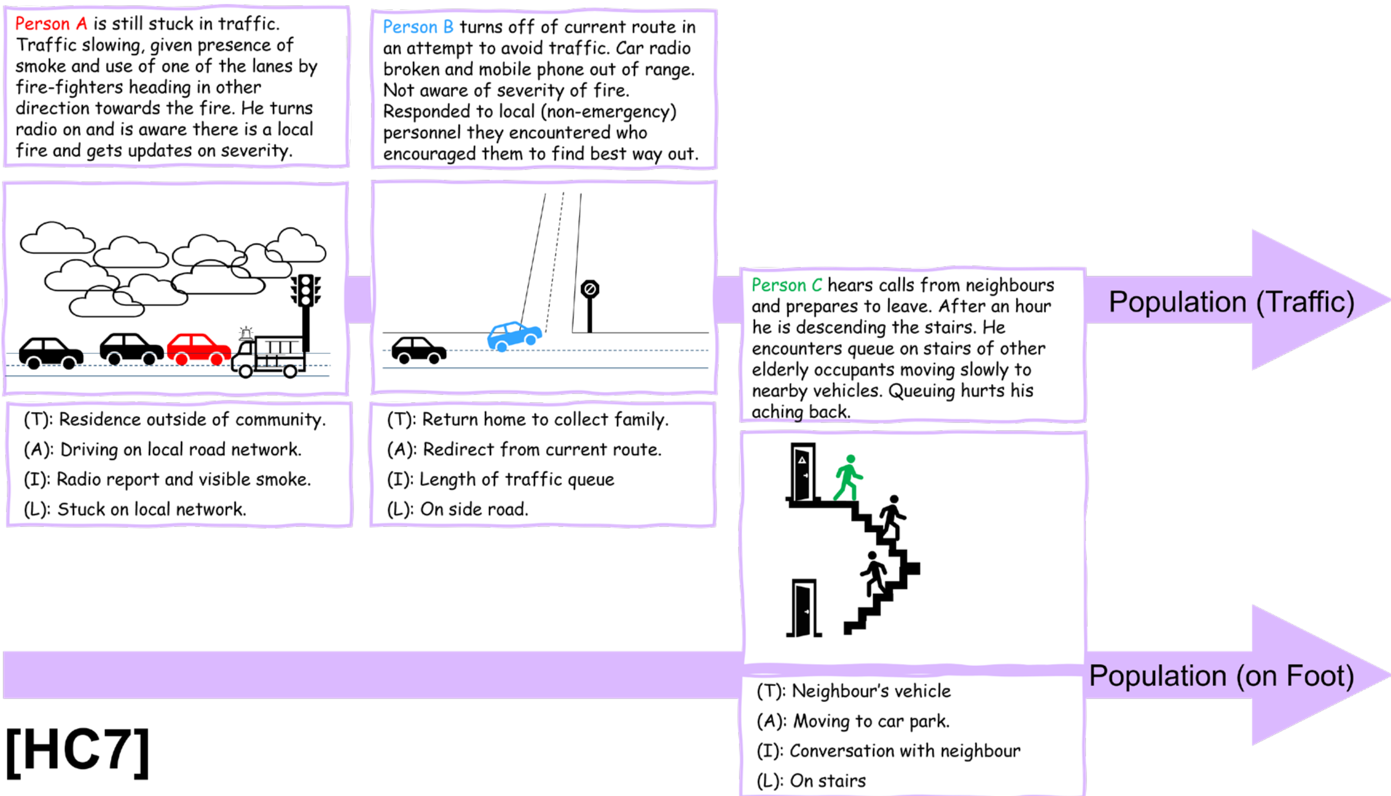

[HC4]
Traffic continues to flow routinely. No information available regarding the incident. No threat perceived.
Population (Traffic)
(T): Locations out of town.
(A): Following traffic.
(I): No information on incident.
(L): Local Roads.
Local command and control centre receives a message from fire chief on scene that fire is significant and requires additional resources
(T): Address fire.
(A): Dispatch FF to scene.
(I): Report from FF at scene.
(L): Command and Control centre.
Response / Management
Firefighters reach scene. Identify discarded materials and that fire has developed and needs to be addressed.
(T): Investigate fire reports.
(A): Attend location. Report scene.
(I): Hot day. Smoke reported.
(L): In forest.
Incident

[HC5]

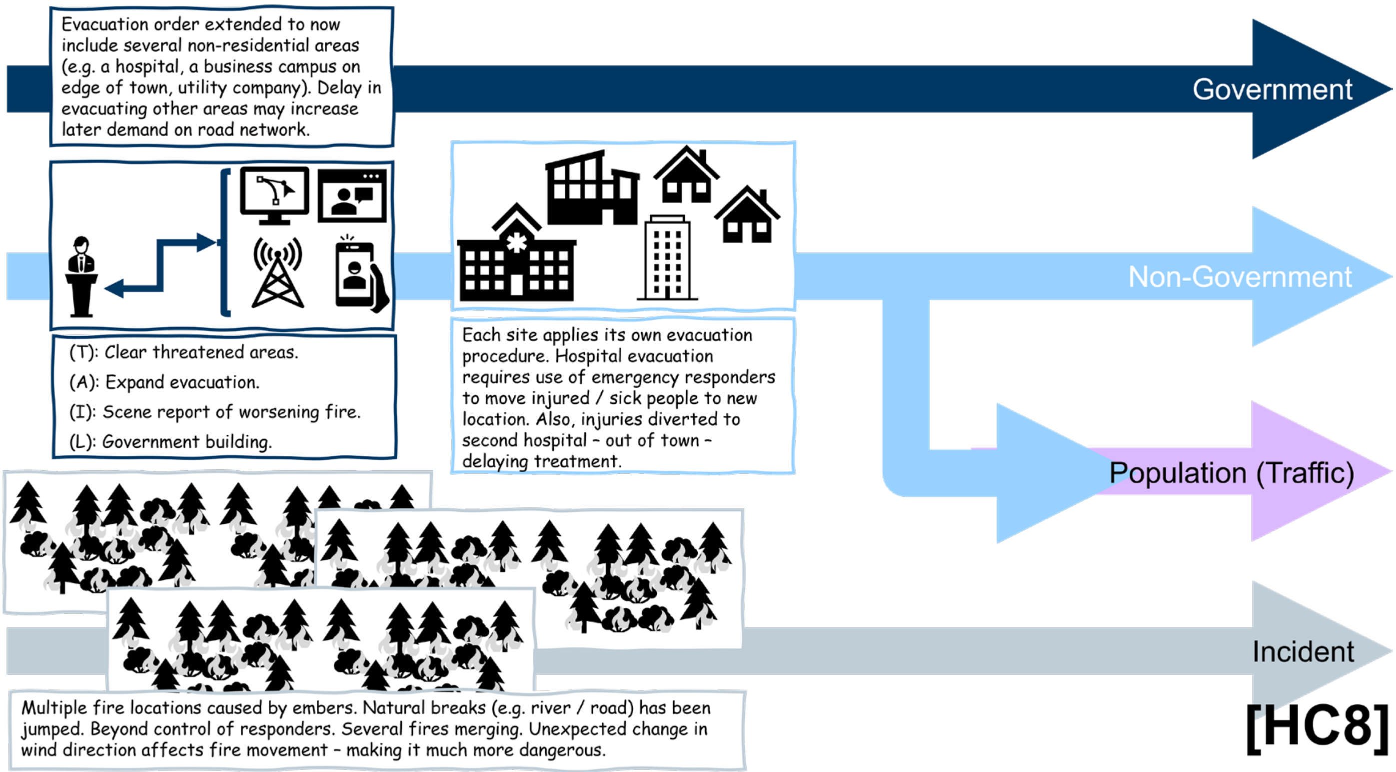

Local command and control centre contacts local authority to inform them that the fire is beyond their control and that they are deploying resources to safeguard other areas.
(T): Escalate response.
(A): Communicate fire spread.
(I): On scene fire reports.
(L): Command and Control centre.
Local authority become aware of situation and calls for an evacuation of those areas immediately affected by the fire. Small residential area of town affected.
Announcements made by several government levels (local / regional) and departments. Broadly consistent content although uncoordinated messaging. Information now also on social media.
(T): Clear those at most risk.
(A): Mandate partial evacuation.
(I): Information from C&C.
(L): Government building.
Government
Response / Management
Incident
Fire develops and spreads significantly. Fire-fighter efforts to control the fire have failed and it is not controllable at this location.

[HC6]


Person A is driving across the community with two children. He is stuck in rush hour traffic. No threat perceived. Radio off and mobile phone out of battery. Previously received ambiguous internet stories regarding bad traffic.
(T): Residence outside of community.
(A): Driving on local road network.
(I): Radio reports/phone not on.
(L): Entering local network.
Person B receives email about incident from friend. Checks local news and confirms with boss that it is okay to leave work, gathers coat/bag, then moves to car. At car within 10 minutes, but then has to return home to collect family before evacuating to a safe location outside of the community.
(T): Go home to collect family.
(A): Collect coat, tell boss, leaves.
(I): Information from email and phone.
(L): At desk in office
Population (Traffic)
Person C is waking up. Has not received any information. Is not familiar with neighbours and has no living relatives. No threat perceived.
(T): Wake up in time for favourite TV.
(A): Sleeping.
(I): TV off. Phone switched off.
(L): In bed.
Population (on Foot)
Population (on Foot)

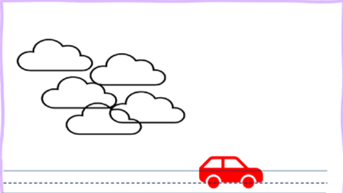

Person A is still stuck in traffic. Traffic slowing, given presence of smoke and use of one of the lanes by fire-fighters heading in other direction towards the fire. He turns radio on and is aware there is a local fire and gets updates on severity.
(T): Residence outside of community.
(A): Driving on local road network.
(I): Radio report and visible smoke.
(L): Stuck on local network.
Person B turns off of current route in an attempt to avoid traffic. Car radio broken and mobile phone out of range. Not aware of severity of fire. Responded to local (non-emergency) personnel they encountered who encouraged them to find best way out.
(T): Return home to collect family.
(A): Redirect from current route.
(I): Length of traffic queue
(L): On side road.
Person C hears calls from neighbours and prepares to leave. After an hour he is descending the stairs. He encounters queue on stairs of other elderly occupants moving slowly to nearby vehicles. Queuing hurts his aching back.
(T): Neighbour's vehicle
(A): Moving to car park.
(I): Conversation with neighbour
(L): On stairs
Population (Traffic)
Population (on Foot)

[HC7]


Evacuation order extended to now include several non-residential areas (e.g. a hospital, a business campus on edge of town, utility company). Delay in evacuating other areas may increase later demand on road network.
(T): Clear threatened areas.
(A): Expand evacuation.
(I): Scene report of worsening fire.
(L): Government building.
Each site applies its own evacuation procedure. Hospital evacuation requires use of emergency responders to move injured / sick people to new location. Also, injuries diverted to second hospital – out of town – delaying treatment.
Multiple fire locations caused by embers. Natural breaks (e.g. river / road) has been jumped. Beyond control of responders. Several fires merging. Unexpected change in wind direction affects fire movement – making it much more dangerous.
Government
Non-Government
Population (Traffic)
Incident

[HC8]

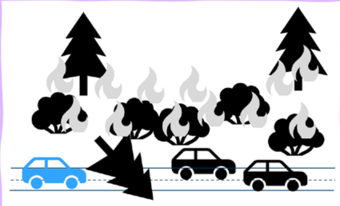
Person A eventually clears local road network and heads off to intended target out of town.



(T): Residence outside of community.
(A): Driving on regional road network.
(I): Radio report and visible smoke.
(L): Moving freely out of town.

Person B route home blocked by fallen tree. This was caused by an earlier car crash as smoke reduced visibility leading to a driver veering off the road.

Route back into town blocked for emergency access. Unable now to reach own house. Difficulty calling home given mobile network demand.



(T): Return home to collect family.
(A): Try to contact home.
(I): Blocked route.
(L): On side road.

Person C gets to car park to find neighbours have left (they did not know they had to pick him up). Forced to wait for emergency responders who are sweeping area for those yet to evacuate. Subject to smoke and anxiety given delayed movement to safety.

(T): Rescue.
(A): Waiting for assistance.
(I): No information on rescue time.
(L): In car park.

Population (Traffic)

Population (on Foot)

[HC9]

Unknown to Person B, (a) his family has already been picked up by neighbours and are on their way out of town and (b) emergency responders are on route to clear blockage.

Person B continues to try and get back home for some time. Person B is exposed to deteriorating environmental conditions and has to pull over. Eventually rescued by paramedics and taken to hospital for smoke inhalation.

(T): Return home to collect family.
(A): Try to contact home.
(I): Blocked route.
(L): On side road.

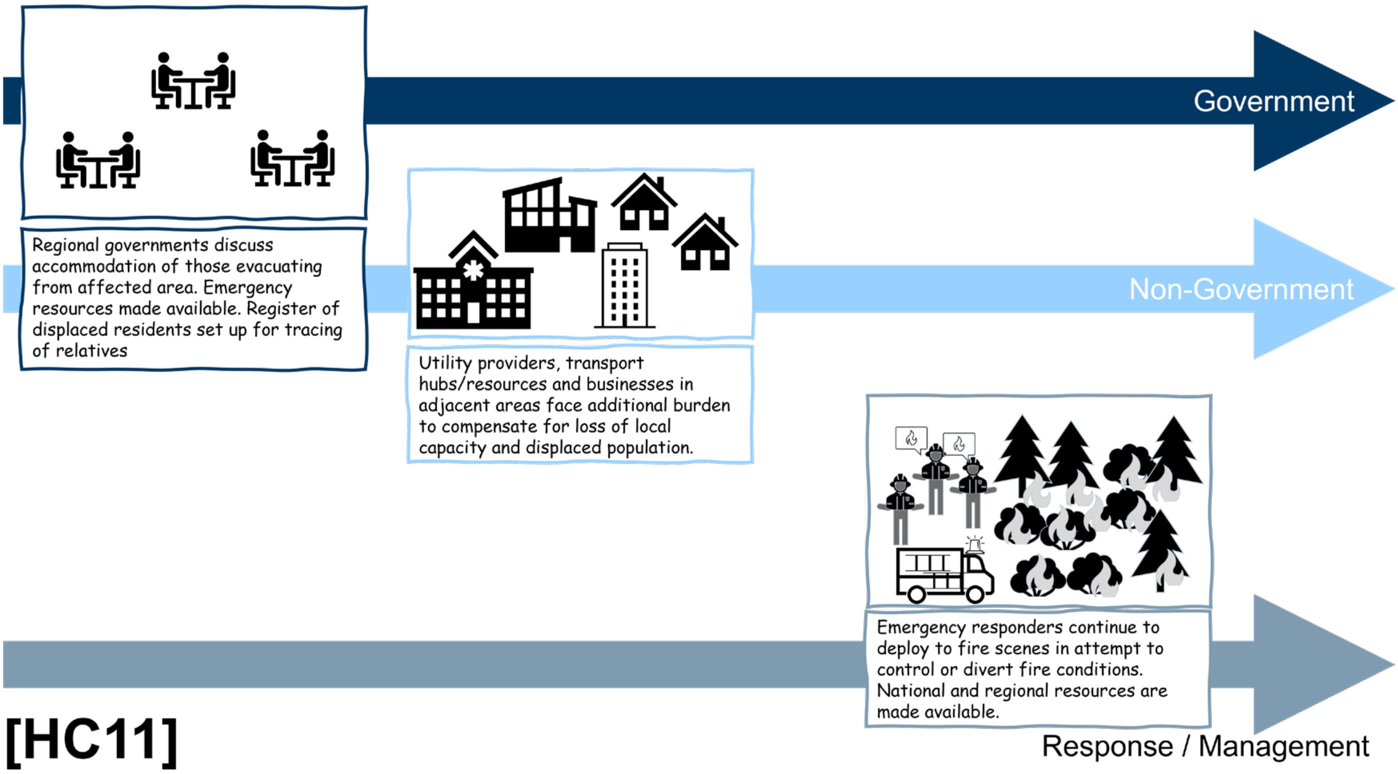
Person C is eventually evacuated although is subjected to smoke inhalation (made worse by existing health conditions) and anxiety given the delayed movement to safety. In addition, on reaching the designated refuge, they have to evacuate again as the refuge location is threatened by approaching wildfire conditions – further increasing their anxiety.

(T): Safety.
(A): Conveyed to hospital.
(I): Information from medics.
(L): On way to hospital.

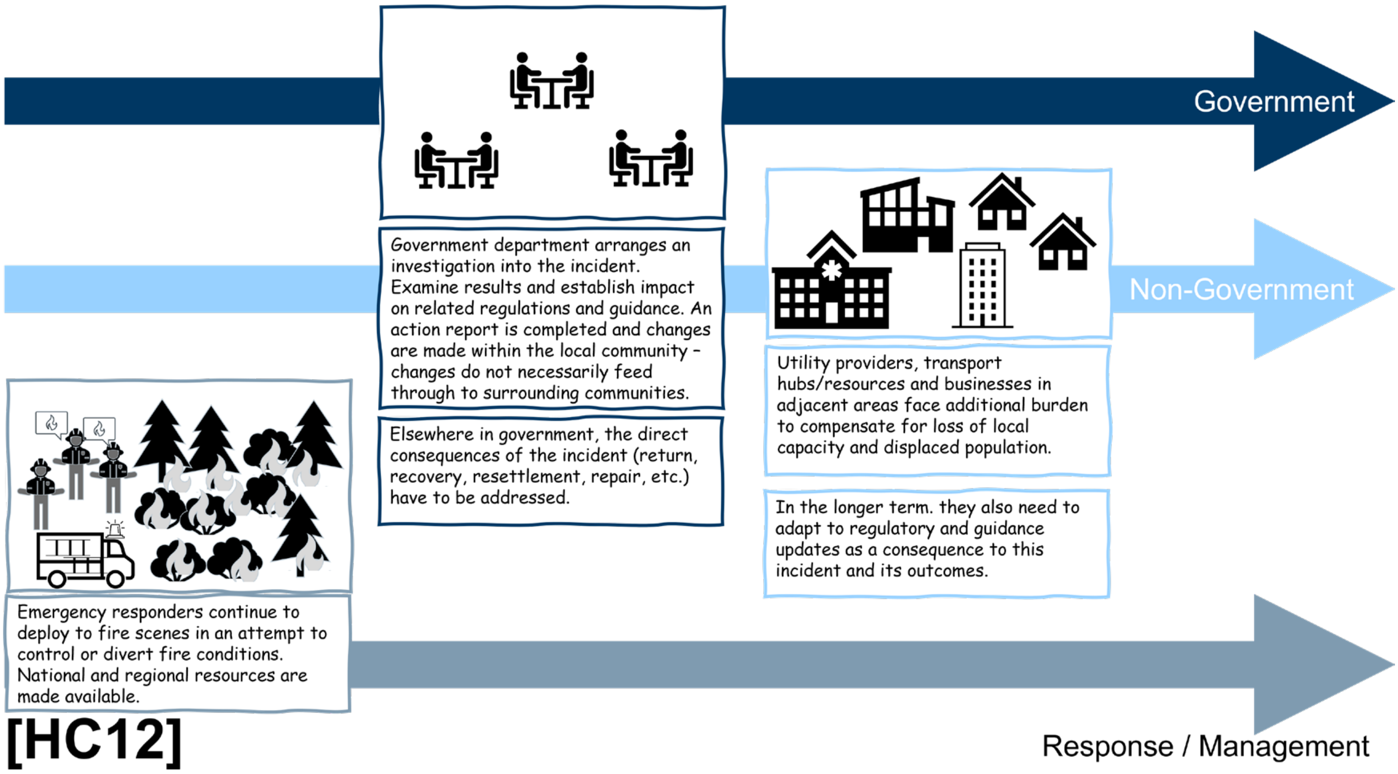
Population (Traffic)

Population (on Foot)

[HC10]


Regional governments discuss accommodation of those evacuating from affected area. Emergency resources made available. Register of displaced residents set up for tracing of relatives
Government
Utility providers, transport hubs/resources and businesses in adjacent areas face additional burden to compensate for loss of local capacity and displaced population.
Non-Government
Emergency responders continue to deploy to fire scenes in attempt to control or divert fire conditions. National and regional resources are made available.
Response / Management

[HC11]


Government department arranges an investigation into the incident. Examine results and establish impact on related regulations and guidance. An action report is completed and changes are made within the local community – changes do not necessarily feed through to surrounding communities.
Elsewhere in government, the direct consequences of the incident (return, recovery, resettlement, repair, etc.) have to be addressed.
Government
Utility providers, transport hubs/resources and businesses in adjacent areas face additional burden to compensate for loss of local capacity and displaced population.
In the longer term. they also need to adapt to regulatory and guidance updates as a consequence to this incident and its outcomes.
Non-Government
Emergency responders continue to deploy to fire scenes in an attempt to control or divert fire conditions. National and regional resources are made available.
Response / Management

[HC12]

Section 3: Discussion and transferable learnings

Impact and regulatory response

The case studies (real and hypothetical) have shown that (1) large-scale wildfire evacuations are complex, (2) conditions evolve over time/place from interactions between social, physical, procedural and environmental factors, (3) seemingly local actions can have broader implications, (4) numerous agents/organisations are involved, and (5) information is likely inconsistent and perceived differently affecting the decision-making of those involved. Given the changing conditions, it is not possible to directly determine the effectiveness of designs and plans from historical incidents.

Complex systems involve the interaction of many actors and factors. To assess the evolution of complex systems typically requires the examination of this interaction – to establish the underlying dynamics of the system and the conditions produced. Similarly, wildfire evacuations might benefit from the application of models that capture key elements to explore the vulnerability of communities to wildfire events (where vulnerability represents the capacity of the community to cope with the conditions faced).

In the more mature building regulatory system, there are typically two approaches to fire regulations:

- Prescriptive approaches embed the knowledge and expertise gathered into a set of regulations that practitioners must follow within the scope of the regulatory framework. Given that the regulations are applied, a building design is deemed to be sufficiently safe for its intended use.
- Performance-based approach that requires an expert practitioner to quantify the evacuation performance achieved and compare it with projected fire conditions for a representative set of scenarios. Safety levels, in this context, must be demonstrated.

This performance-based approach (if it was applied to community evacuation) (a) allows for the effectiveness of different design solutions and emergency procedures to be compared for given scenarios, (b) allows for a variety of community designs to be addressed (given that they do not have to be previously accounted for within the scope of a prescriptive framework), and (c) provides an opportunity to diagnose where issues arise and suggest remedial actions.

Given the challenges posed by wildfire evacuation (in terms of changing conditions, evolving scenarios undermining historical insights, and multiple interacting components), future regulatory efforts may benefit from a performance-based approach. This is no panacea and requires robust engineering tools that capture core evacuation and fire dynamics, sufficient guidance on the use of these tools and oversight of this use. However, given the complexity of wildfire evacuation, performance assessment may be one of the only ways of identifying challenges, suggesting remedial actions and of determining the vulnerability of a community to the conditions that might arise.

Complexity of wildfire evacuations

Given the complexity of wildfire evacuations, we will likely need to use a model as a proxy – to simulate the evolving conditions. Imperfect though this may be, it may allow interactions and emergent conditions to be charted, key vulnerabilities to be identified, different scenarios / response to be explored and these to be prioritised and ranked accordingly – in terms of the threat posed.

Conditions evolve quickly and are sensitive to the factors present. Importantly, different communities are not equally vulnerable to the same incident, a single community's vulnerability evolves over the lifetime of an incident and that community may be subject to multiple scenarios. It is important for regulators and practitioners to have a means to quantify evacuation performance – to identify when and where problems arise and what are the most effective means of addressing them. Of course, this is not trivial – all models are simplifications. But it is important to shape best modelling practice – especially should we accept the complexity of such events and the need to assess performance on a case-by-case basis as a regulatory approach given the speed with which conditions change.

An example demonstration of modelling benefits – not available to a purely prescriptive approach – is described below with reference to **Figure 13**. In **Figure 13** (top row), the blue site has a built-up well-resourced population with some mid-rise structures and offices. The green site (**Figure 13** bottom row) is more rural – with fewer resources. Otherwise, the community footprint is the same shape and size in each case. The three versions of the blue and green sites have the same population, with different road connections – e.g., number, location and size of roads. Comparing horizontally, the same population may have a different evacuation potential given the different road networks available – even when exposed to the same fire. If we now compare vertically – across different site populations for the same road network design – the evacuees will exploit the same road network differently, given their capabilities, awareness and resources, e.g., decision-making, access to vehicles, etc. Quantifying evacuation performance helps determine the extent of these differences and their impact on the outcome. Quantifying these facts helps inform our design, planning and response decisions.

Modelling wildfire evacuations

Models will be necessary for the development of a performance-based approach to wildfire planning

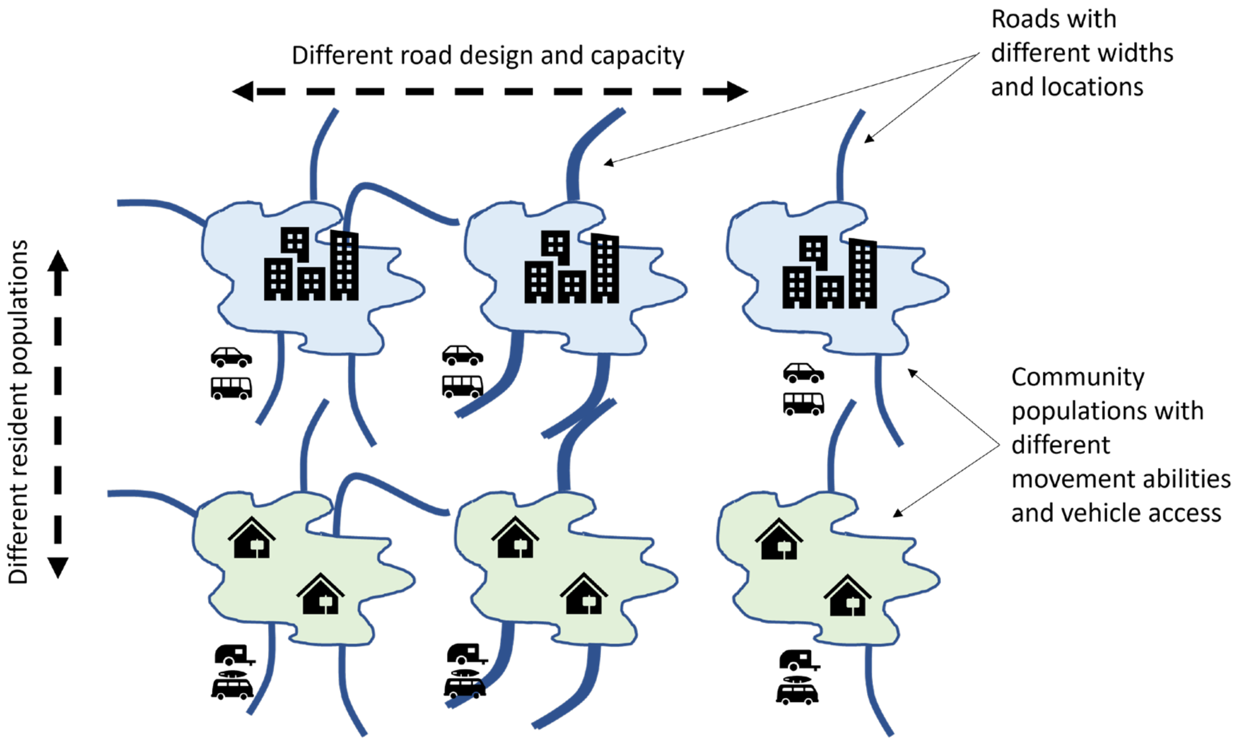


Figure 13: Depiction of comparative modelling utility.

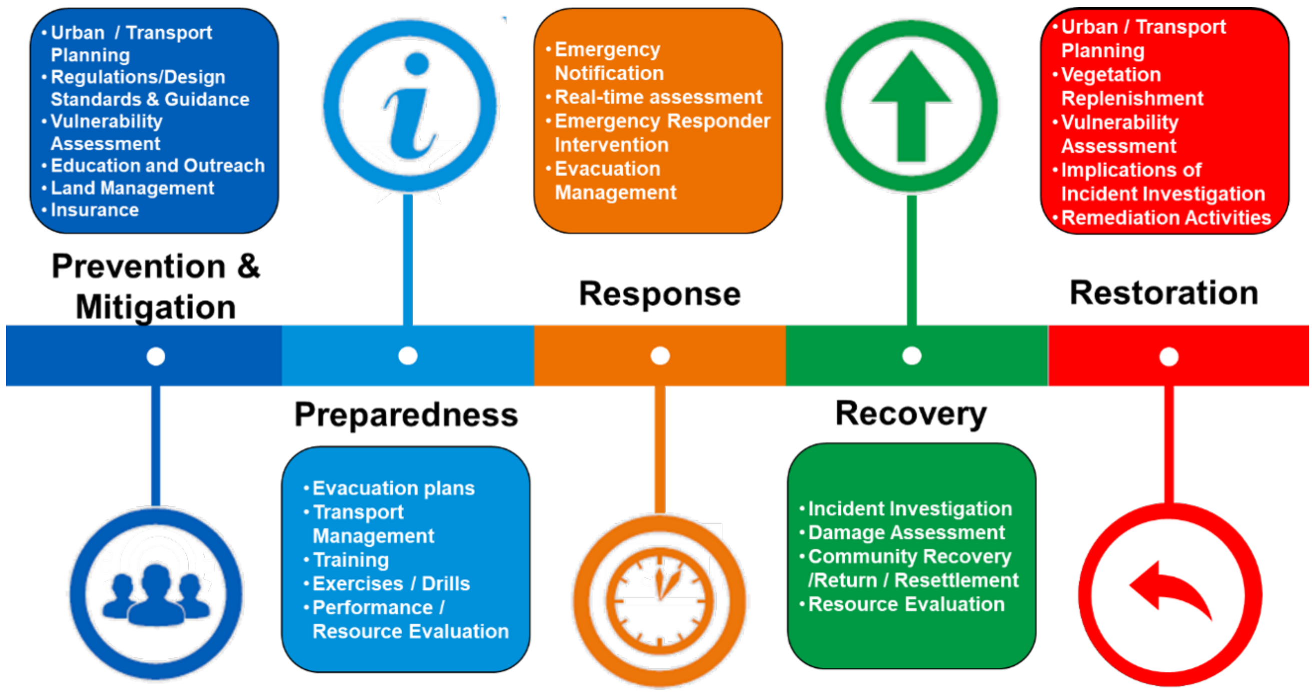


Figure 14: Models will be necessary to support a performance-based approach to wildfire planning.

to function, supporting community safety over time (see **Figure 14**).

They will also help communicate to the public and practitioners:

- The complexity of such events
- The sensitivity of outcomes to decisions made by those involved – public, responders, organisations
- How conditions can quickly and dramatically change
- How effective different measures might be
- How vulnerable different communities are to minor changes in conditions beyond their control.

These will help in community planning, outreach and education.

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