→ **Presented by Steve Gwynne**
GHD/Movement Strategies, Lund University

WUI-NITY 3: Developments

NIST Fire Day 2022

Team Members

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Imperial College London

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movement strategies

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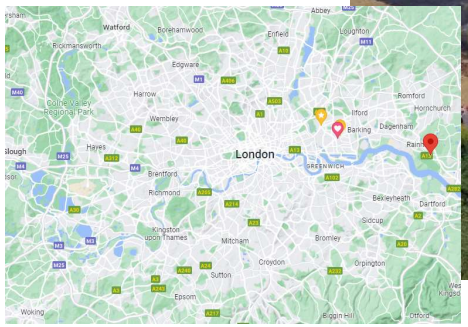
Why this matters?

Wildfires reported in the media – 2017-2021. In historically both expected (e.g. California) and unexpected locations.(e.g. Sweden, UK)



metro.co.uk

Wildfires pose a serious threat to community safety.

Wildfires are formed from various elements (social, physical and environmental) that interact in complex ways.

Threat is expanding and increasing given environmental issues.

- New vulnerable communities - new locations.

- Existing communities facing unfamiliar conditions.

- New vulnerable communities – arriving populations.

Wildfire conditions are diverging from the conditions previously faced.

- Harder to estimate the outcomes of new fires directly from historical fires.

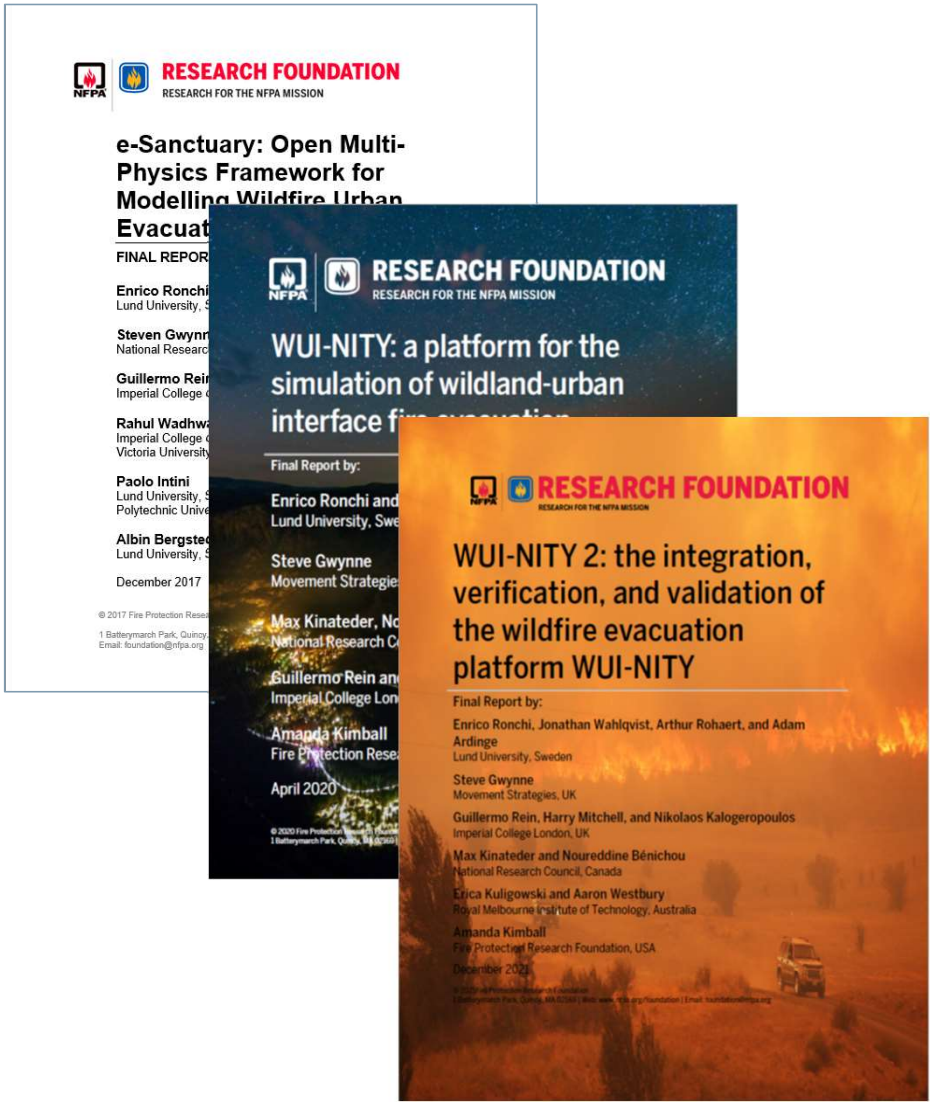
To understand the threat posed necessarily to understand a community's capacity to cope with the conditions faced.

Overview

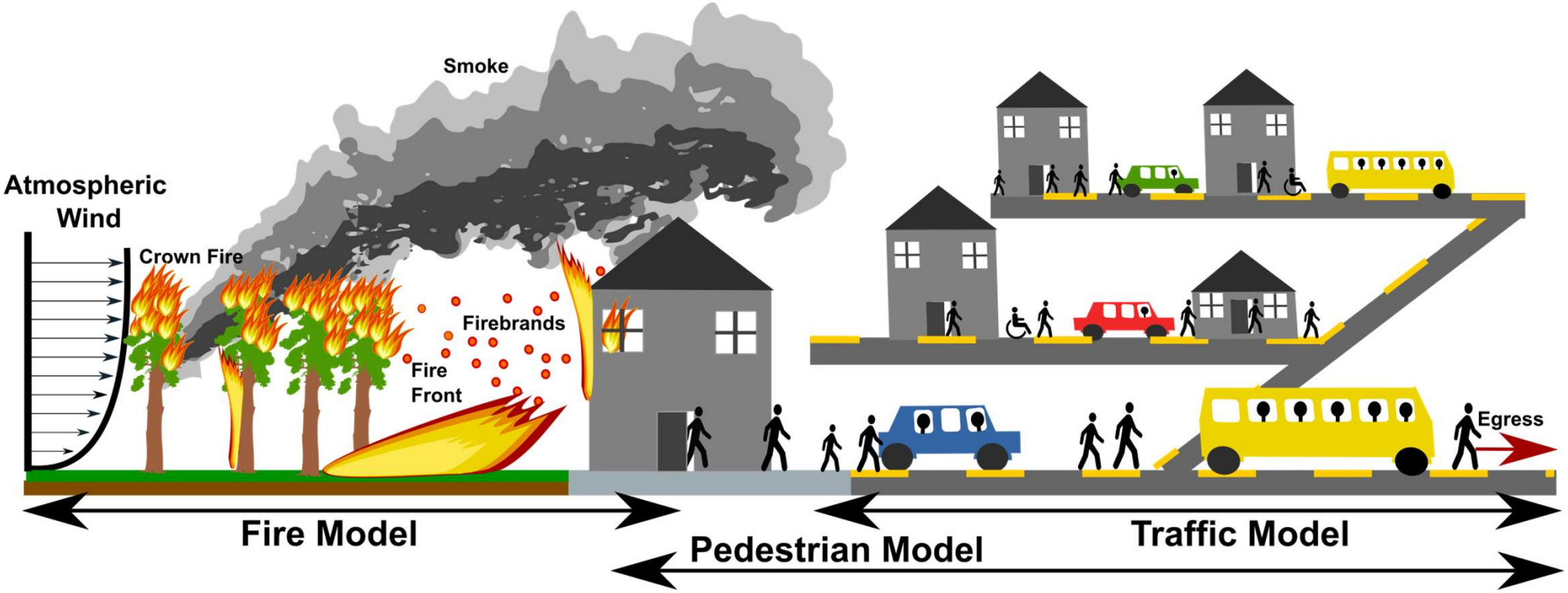
- Basic description

- Advances in WUINITY3
  - Testing Improvements
  - Impact of Smoke
  - Including projected GUI design.

- Applications:
  - Royal Academy – Wildfire Complexity
  - Roxborough
  - PERIL application to Swinley/Roxborough



WUI-NITY Basic Description



- The aim of this project is to build on an existing research tool (WUI-NITY) and produce a tested, calibrated, and configurable model that can be used by stakeholders to assess wildfire evacuation performance in real-world situations.
- **The aim is to move this tool from research to practice.**

WUI-NITY Basic Description – Current Project

Fire

Spatial/Temporal Evolution of the threat → network availability

Pedestrians

Population assessment

Evacuation time within a building/area

Input into traffic departure time

Traffic

Vehicle demand

Road network capacity and management

Route choice

Route availability

Current tasks:

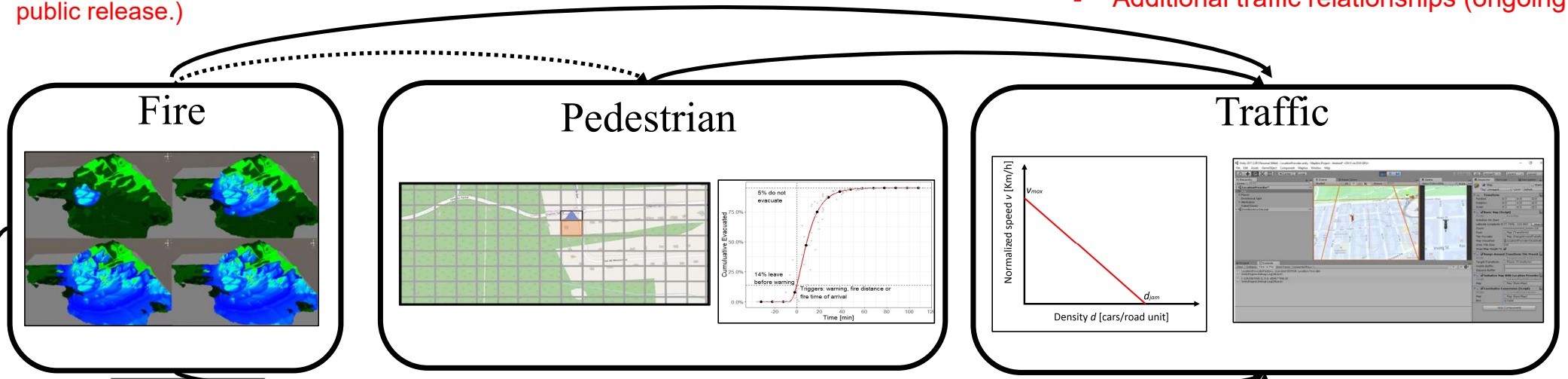
- Extraction of data from traffic database (enhanced testing)
  - Completion of wildfire case studies – more confidence in performance
- Smoke Interaction – include more impact on performance
- PERIL enhancements – increase planning use
- GUI Development – increase accessibility for practitioners.

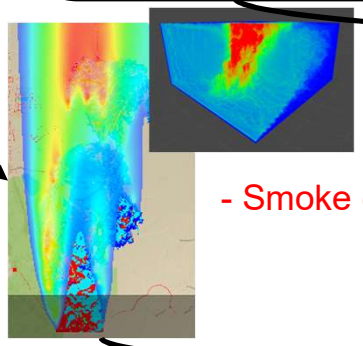
WUI-NITY Basic Description – Ongoing

- FARSITE outputs
- Custom CA model based on BEHAVE
- Prometheus/ PSaaS (Imperial College) (PSaaS uses same wildfire spread algorithms as Prometheus - will be implemented on its public release.)

- Customizable human response curves
- Simple pedestrian movement to vehicles

- LWR / Greenshield model implementation, calibrated based on HCM
- Shortest/fastest/custom destinations
- Additional traffic relationships (ongoing)





- Fire affects availability of destinations over time

Shelter capacity (ongoing)

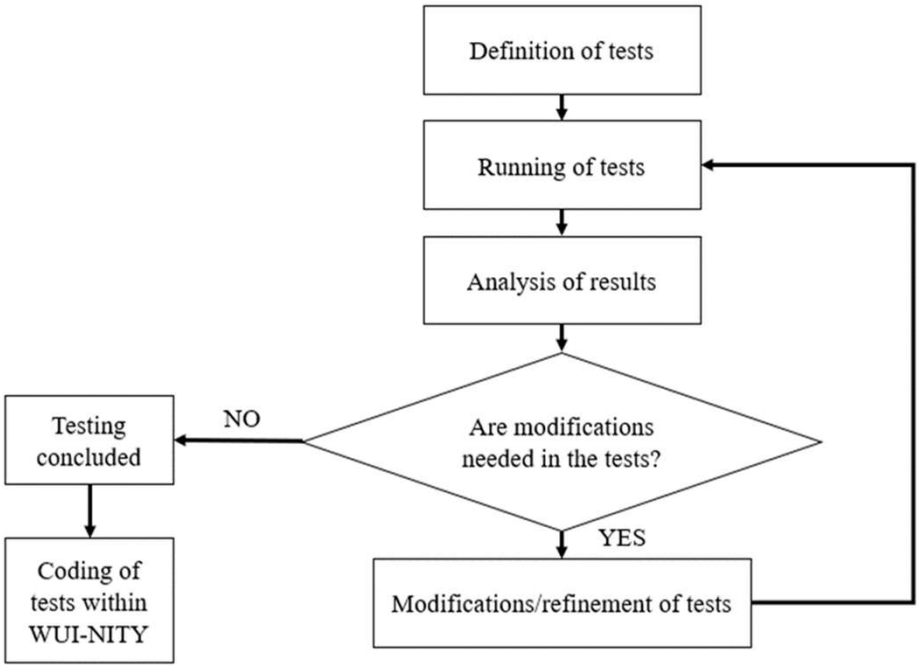
- Smoke (ongoing)

- Smoke affecting traffic (ongoing)

Advances in WUI-NITY3: Testing

- **No testing protocol existed** for WUI fire evacuation models (theonly for building evacuation models, e.g., Rimea test, NIST tests, IMO test, ISO 20414)
- Developed a new **protocol** for WUI fire evacuation models
- **Suite of verification** tests has been developed, mostly addressing traffic modelling layer and interactions with other layers, sorted by core component they address
- **Validation** testing: Roxborough Park evac drill, traffic data from 2019 Kincade Fire
- **Embedded testing** in the source code to re-run them at each code update (inspired by approach of FDS developers)

Verification testing



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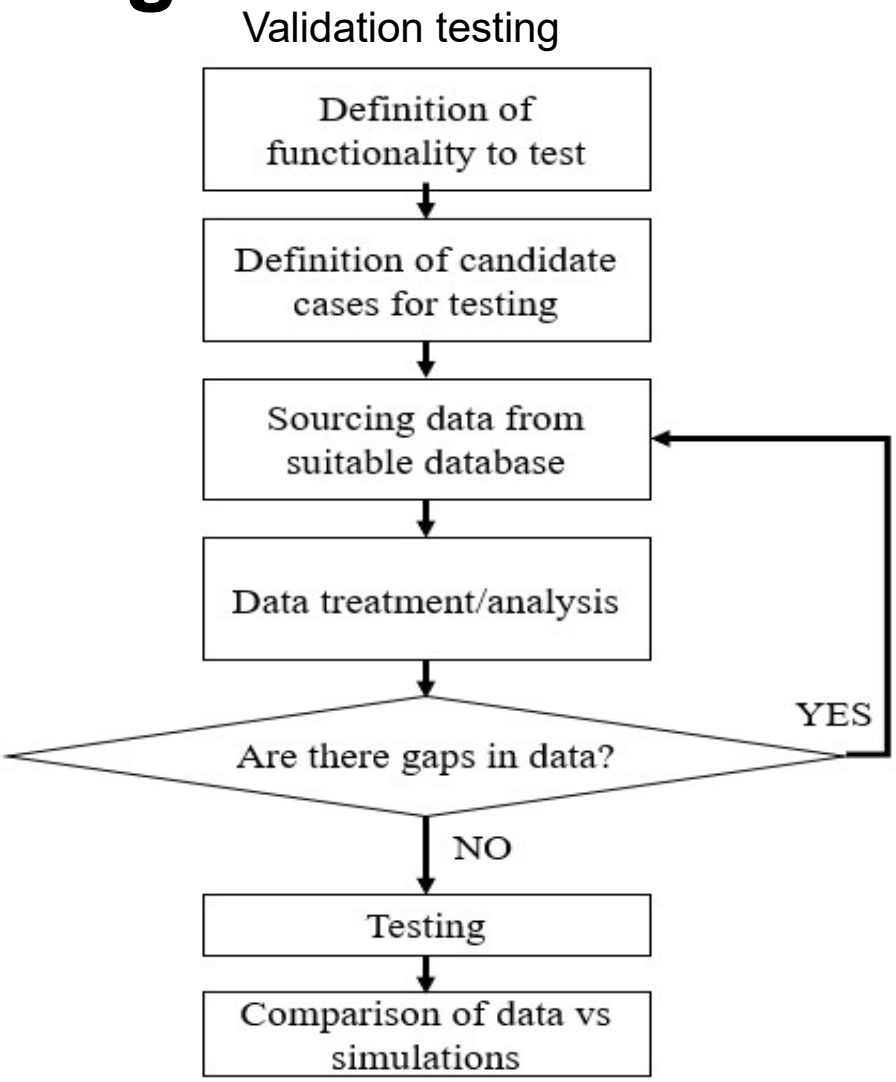


Advances in WUI-NITY3: Testing - Verification

- Most of the verification test could be conducted with WUI-NITY except those that required a **microscopic modelling approach**.
- **The difference in results ranged from 0.5 – 8 %.**
- All in all, WUI-NITY performed as expected.

Layer tested	Core component	Test code	Test title
Pedestrian	Population	P.1	Pedestrian re-distribution
Pedestrian	Population	P.2	Max vehicles per household
Pedestrian	Pre-evacuation	P.3	Response curve
Pedestrian	Movement	P.4	Pedestrian walking speed
Integration Pedestrian + Traffic	Movement	PT.1	Pedestrian distance to vehicle
Traffic	Movement	T.1	Uni-directional single vehicle flow
Traffic	Movement, Flow constraints	T.2	Background traffic
Traffic	Movement	T.3	Change in carriageway configuration
Traffic	Movement, Flow constraints	T.4	Relationships between speed-density and flow-density
Traffic	Movement, Flow constraints	T.5	Vehicle speed reduction in reduced visibility
Traffic	Movement, Flow constraints	T.6	Flow at destination
Traffic	Movement, Route selection	T.7	Group evacuation
Traffic	Movement, Flow constraints	T.8	Lane changing/overtaking
Traffic	Movement, Flow constraints	T.9	Acceleration/deceleration
Traffic	Movement, Flow constraints, Event	T.10	Road accident
Traffic	Movement, Flow constraints	T.11	Intersection
Traffic	Route selection	T.12	Forced Destination
Traffic	Route selection	T.13	Destination choice in traffic
Traffic	Route selection	T14	Route choice in traffic
Traffic	Movement, Flow constraints	T.15	Vehicle demand vs arrival distribution
Integration Wildfire + Traffic	Route selection	WT.1	Route loss
Integration Wildfire + Traffic	Movement, Events	WT.2	Lane reversal
Integration Wildfire + Traffic	Movement, Flow constraints, Event	WT.3	Loss of exit or shelter
Integration Wildfire + Traffic	Movement, Flow constraints, Event	WT.4	Refuge capacity

Advances in WUI-NITY3: Case Study - Validation

- Two validation efforts:
  - Previously: Data-set from an evacuation drill in Roxborough Park (Colorado, USA)
  - Now: Traffic evacuation data-set from 2019 Kincade fire (involving 186k evacuees). Required considerable effort to extract / import data

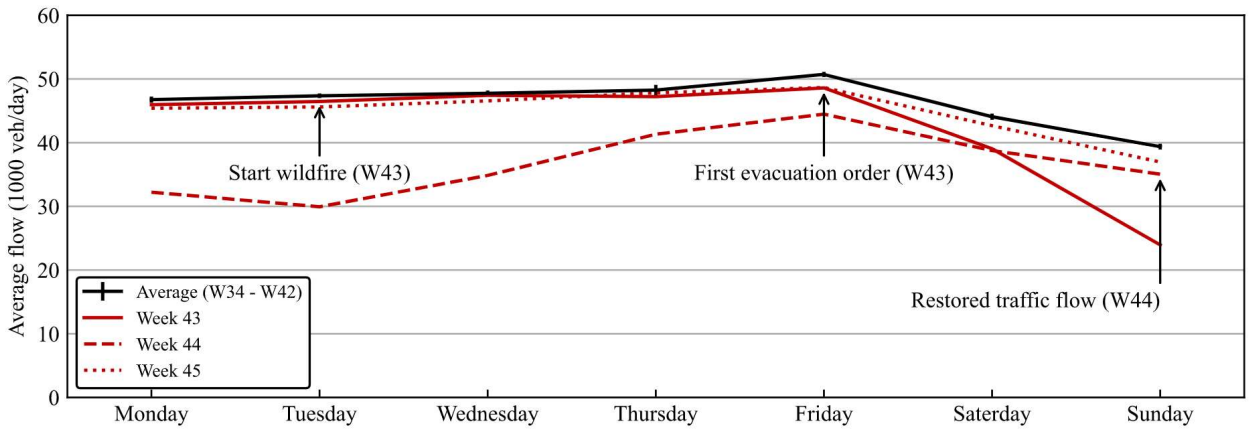


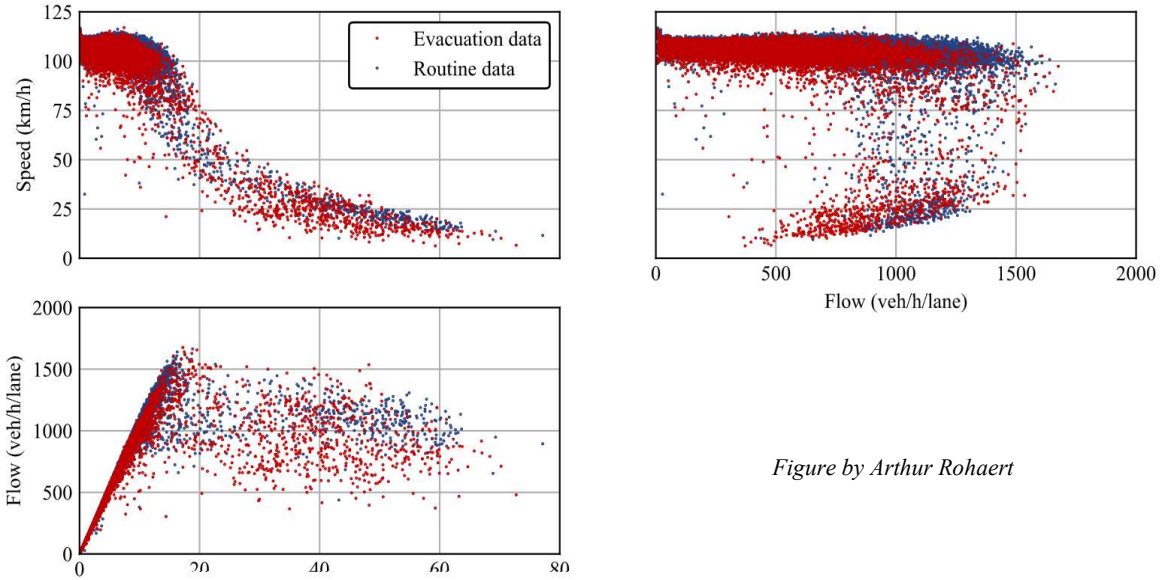
Figure by Arthur Rohaert

- At this stage, trying to understand if results and order of magnitudes produced are **reasonable.**

- Examined freely available state-level traffic data (e.g. CalTrans).
- Data extracted/analyzed to better understand traffic movements for a highway/highway segment during incidents – i.e. for evacuation during a wildfire event.

Advances in WUI-NITY3: Case Study - Validation

- Developed **speed-density and flow-density** relationships for 2019 Kincade fire based on CalTrans traffic database.
- Compared **theoretical curves** (based on Highway Capacity Manual) and our modelling approach, e.g., van Aerde & Rakha model.
- Theoretical speeds in WUI-NITY vs measured speed is **comparable**
- **Need to explore more differences between routine and evacuation traffic** (e.g. impact of headways, vehicle lengths)
- Need to investigate other incidents, road types and different conditions.



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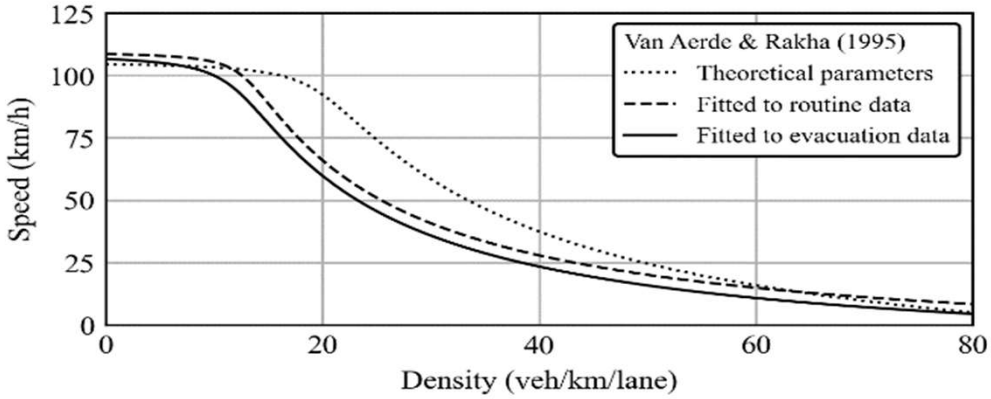
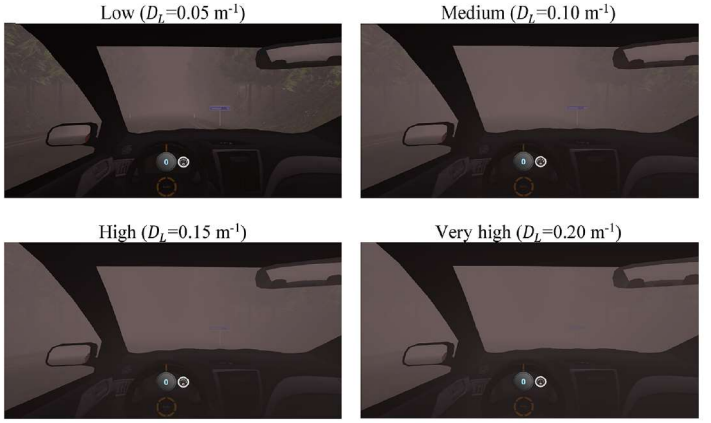


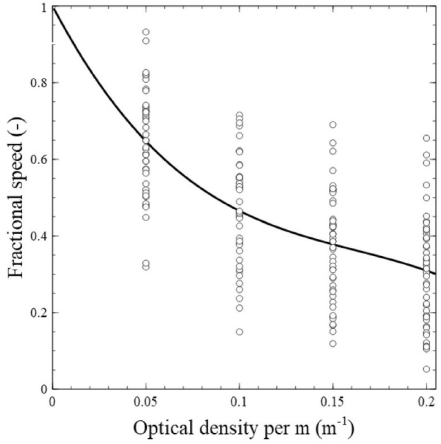
Advances in WUI-NITY3 – Smoke Interaction

- So far, only one study (in VR) looked specifically at individual driving in smoke (Wetterberg et al, 2020).
- Conditions: no smoke to very high smoke, optical density per m DL from 0 to 0.20 m
- Intini et al (2022) calibrated van Aerde and Greenshields models using a fractional reduction of speed through a coefficient β related to optical density per m
- This is based on Wetterberg et al data, ensuring a monotonic function and fractional reduction of speed in clear conditions

$$\beta = -101.57\ {D_L}^3 + 49.43\ {D_L}^2 - 9.28\ D_L + 1$$

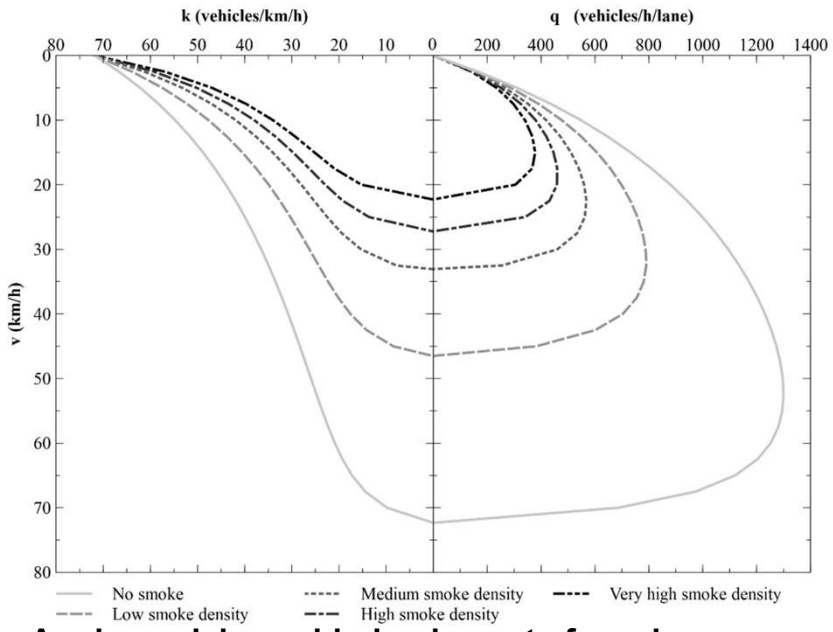


Wetterberg et al, 2020

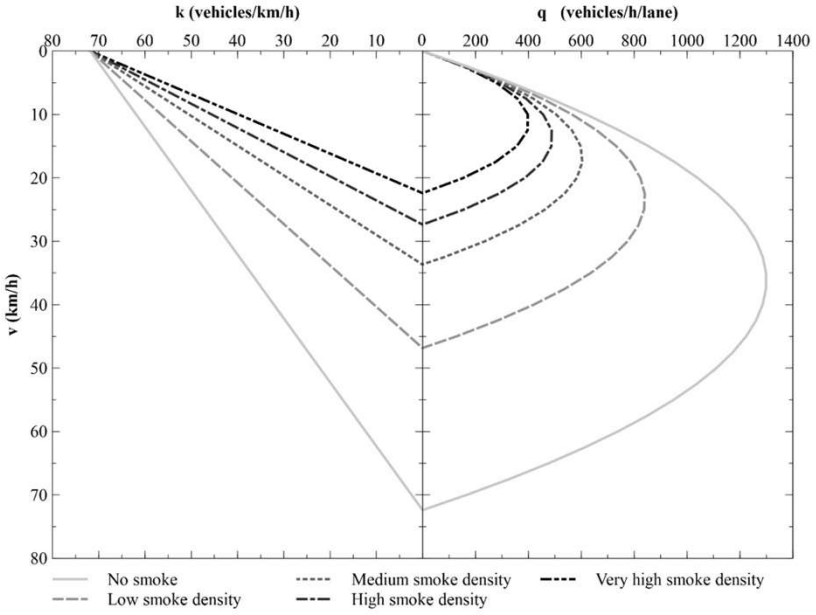


Advances in WUI-NITY3 - Smoke Interaction

- We developed a mathematical sub-model for the impact of smoke on driving speed.
- This is currently implemented for LWR/Greenshield and van Aerde traffic models
- Based on Wetterberg et al (2020), driver behaviour in fog and in collaboration with Dr Intini (previously postdoc at LU).



van Aerde model considering impact of smoke



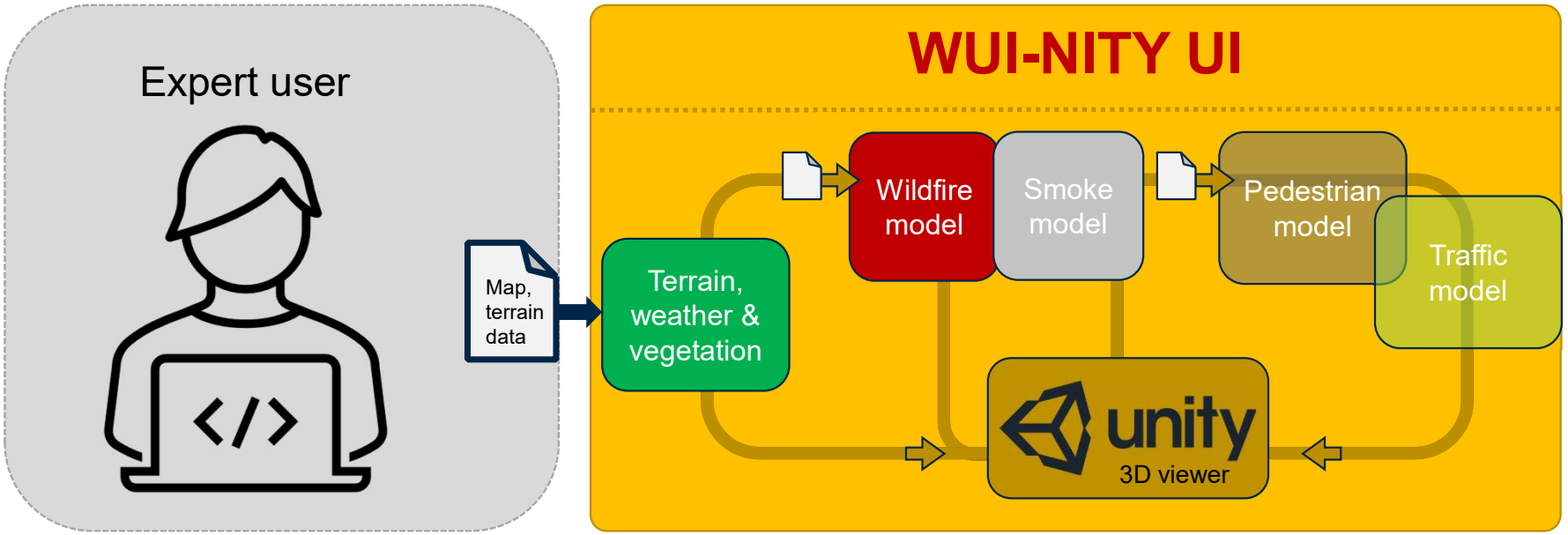
LWR/Greenshield model considering impact of smoke

Advances in WUI-NITY3 - Smoke Interaction

•More VR experiments are planned together with NRC Canada!

Advances in WUI-NITY3: Existing GUI Architecture

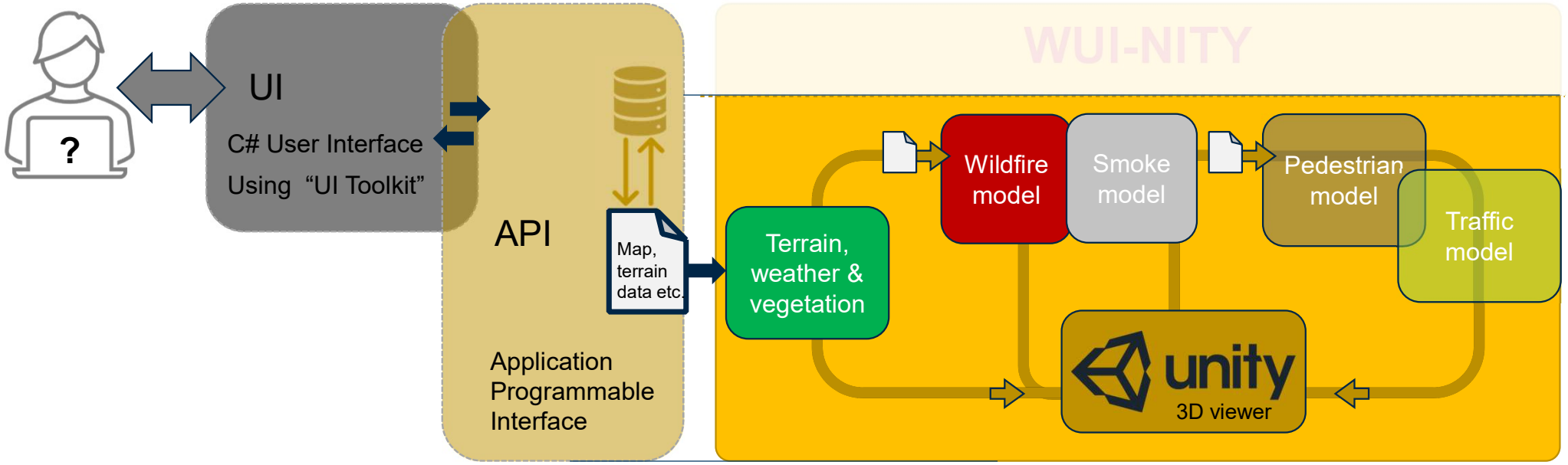
Current technology stack: desktop software



Text-based data files

Advances in WUI-NITY3: Proposed architecture

Proposed technology stack: desktop software

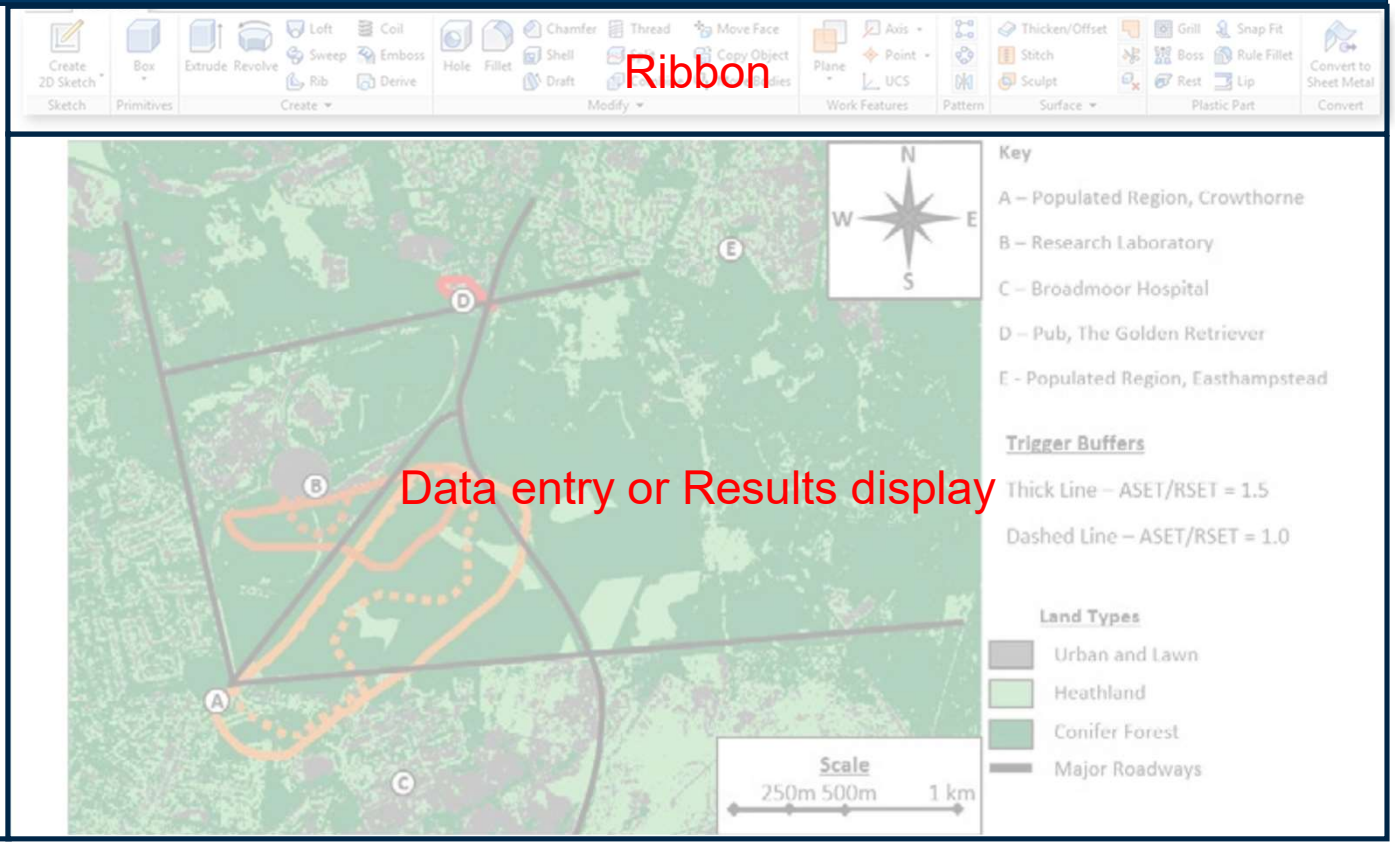


Text-based data files

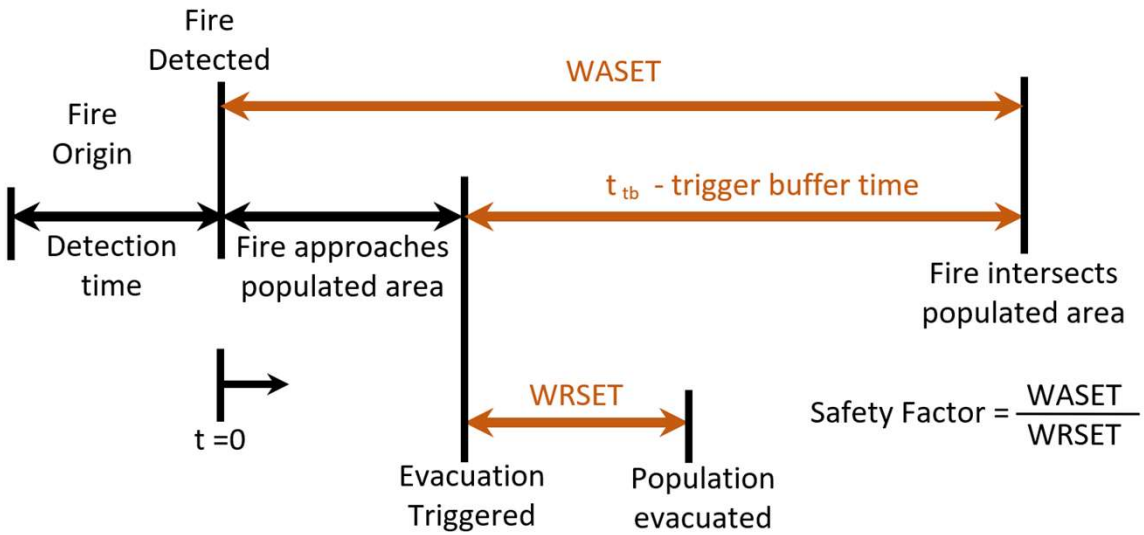
Advances in WUI-NITY3: Planned UI layout

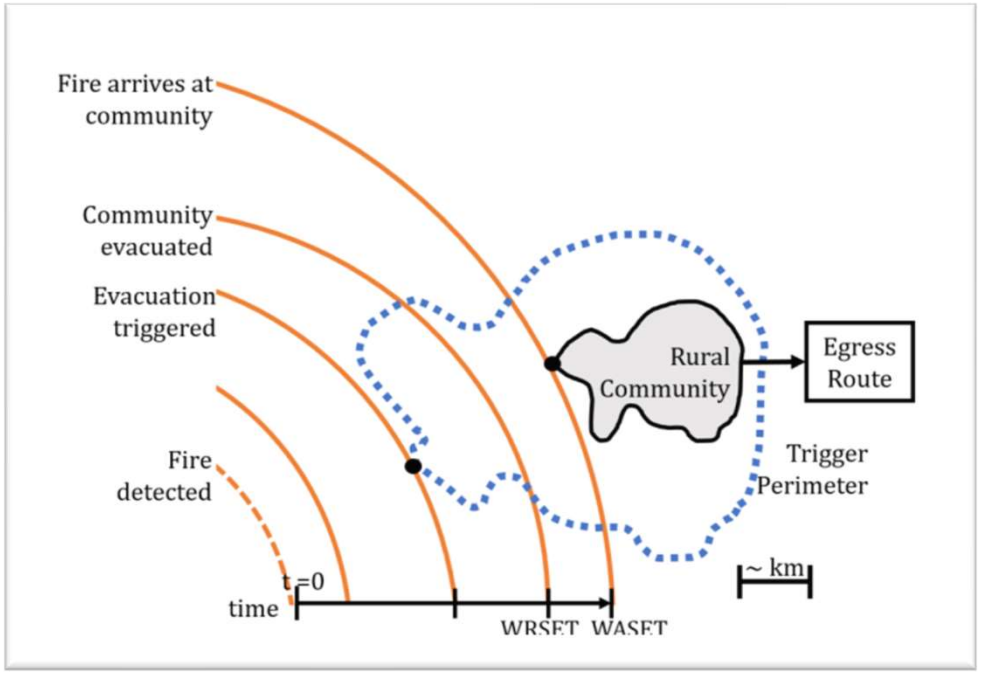
Optional Menus

- ☑ Map/terrain
  - ☑ Specify lat/long
  - ☑ Download map/roads
- ❑ Population(s)
  - ❑ Apply to areas
  - ❑ Define groups etc.
- ❑ Fuel/vegetation
  - ❑ Define vegetation
  - ❑ Combustible properties.
- ❑ Scenarios
  - ❑ Define scenarios.
- ❑ Simulation(s)
  - ❑ Run simulations
  - ❑ Review results.



Advances in WUI-NITY3: PERIL Trigger Buffer Assessment





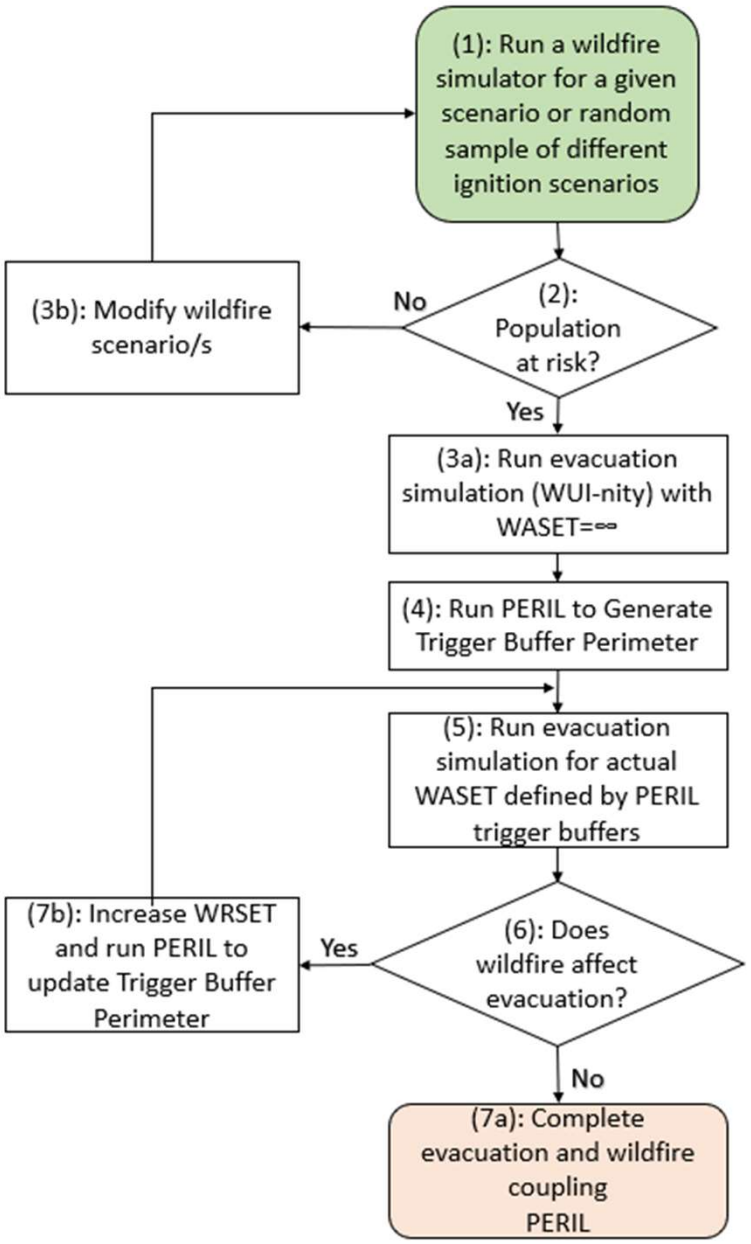
Available Safe Evacuation Time: WASET

Required Safe Evacuation Time: WRSET

- k-PERIL: Algorithm to calculate safe evacuation trigger boundaries.
- Started in 2018 as PERIL, evolved to k-PERIL in 2020, when it was first integrated to WUINITY
- Now can create probabilistic boundaries for any case number (ignition, evacuation, weather…).
- Future work: Egress route interruption – **assist in notification planning.**

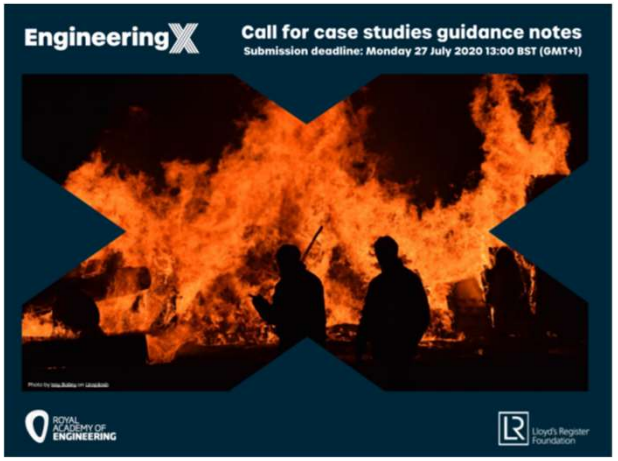
Advances in WUI-NITY3: : PERIL Trigger Buffer Assessment

- Method to test and refine trigger buffer perimeters based on multiple wildfire and evacuation scenarios.
- Iterative component to assess effectiveness of generated trigger buffers.
- Currently being integrated given the current developments of WUI-NITY to ensure that it can drive the overall model (based on the findings produced) and be more directly sensitive to the results produced by the other core components of WUI-NITY.

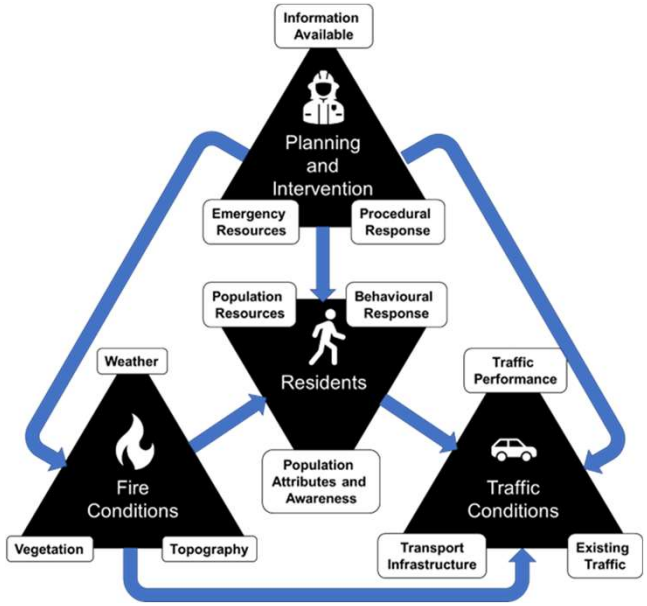


Applications: Roxborough Park Exercise

- WUI-NITY tool used to support Royal Academy of Engineering effort – as part of their Engineering X programme (2019 – 2020).



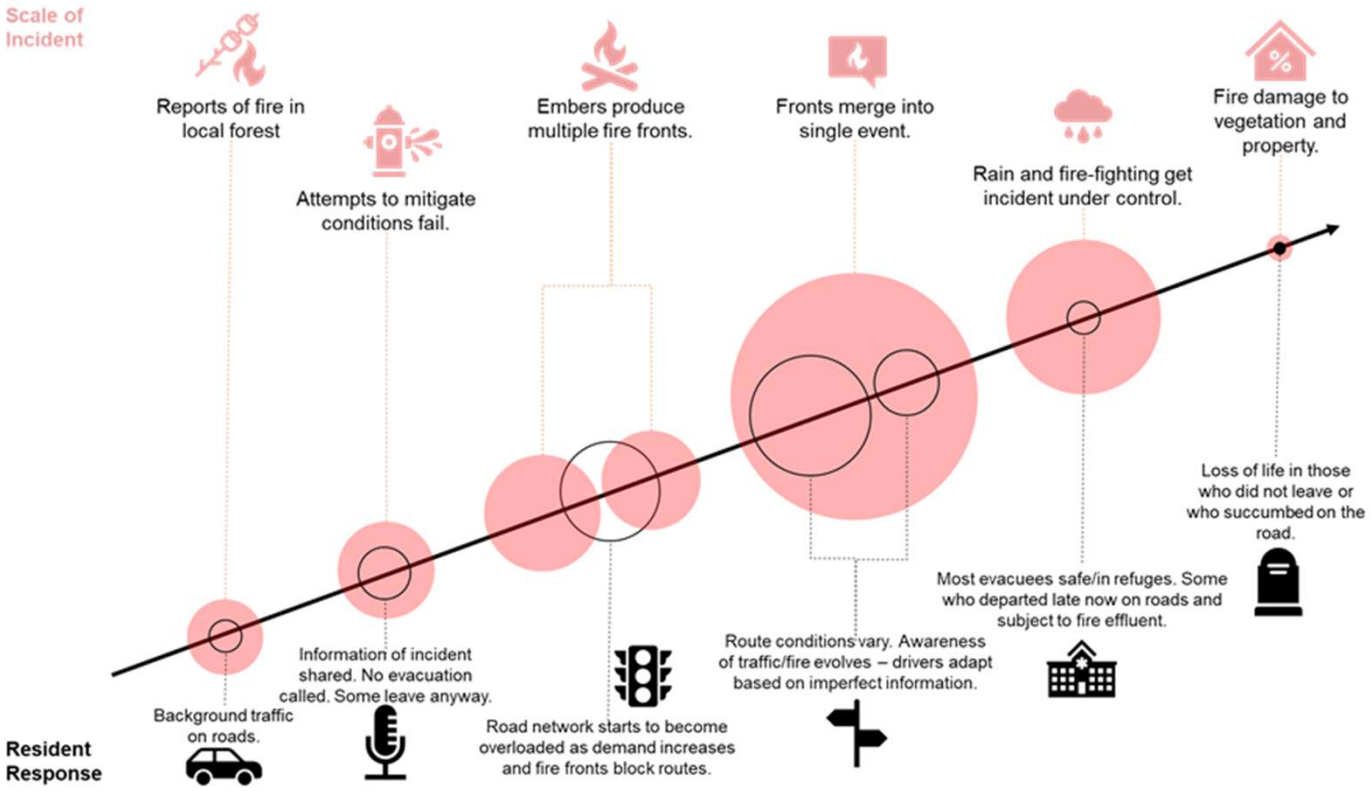
- Develop outreach material to show wildfire evacuations are complex. Has properties that add to its complexity:
  - Multiple domains that are highly coupled
  - Multiple organisations / actors over time.
  - Many modes of movement, information sharing, and intervention.
  - Large-scale / Potentially multiple incidents.
- Actors/ factors interact producing emergent conditions that evolve in non-linear ways.
- These differ over time and the area affected.
- These affect information available, perceived risk and actions performed.



- Gain clearer insights by accounting for interactions and aggregate outcomes – **seeing the whole process as a complex system.**

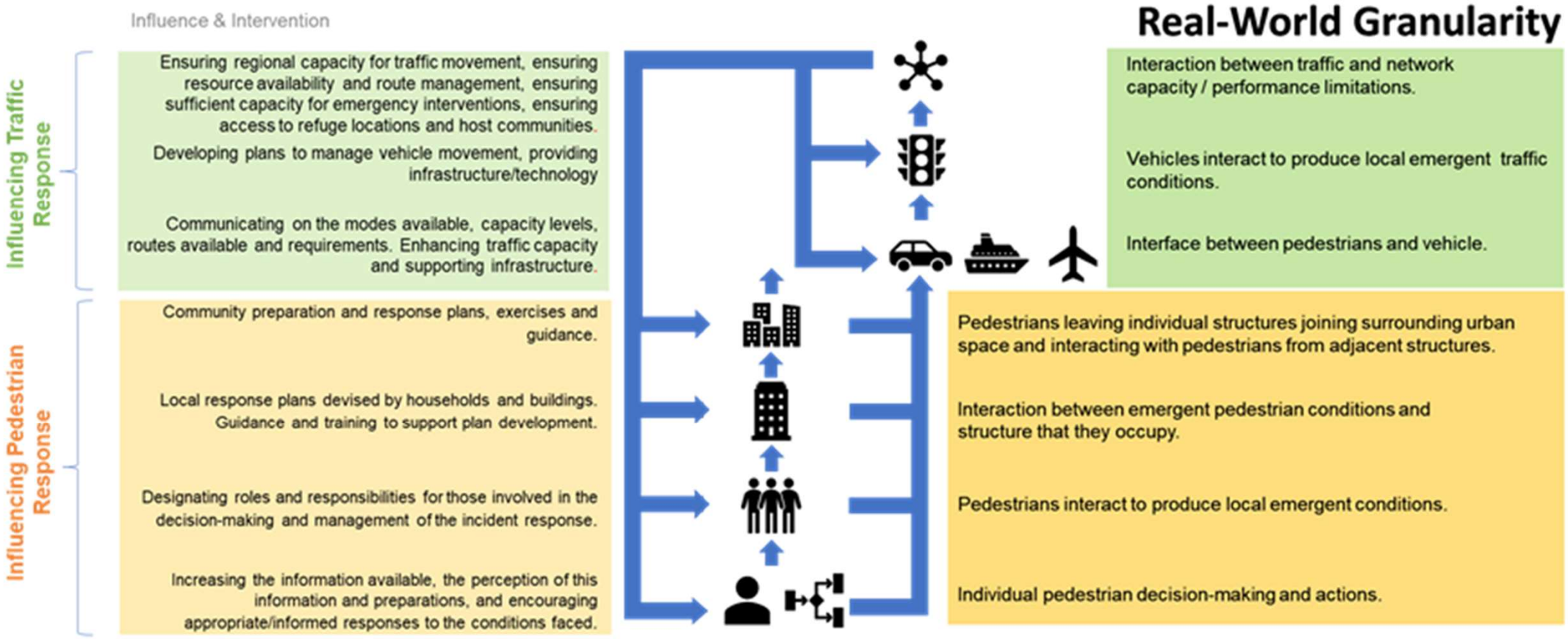
Applications: Roxborough Park Exercise - Evolving Scales

- Community and responder actions will change conditions.
- Fire may develop and spawn new fires.
- Fires may spread rapidly (faster than we can run) with fire fronts extending kilometres in length.
- Smoke may affect communities tens of kilometres away.
- Multiple communities may be affected by a single fire and be subject to different information and guidance.
- 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.



Example include development: pink circles – time/size of fire(s); black circles – time/scale of evacuation(s).

Applications: Roxborough Park Exercise – Levels of Action and Interaction

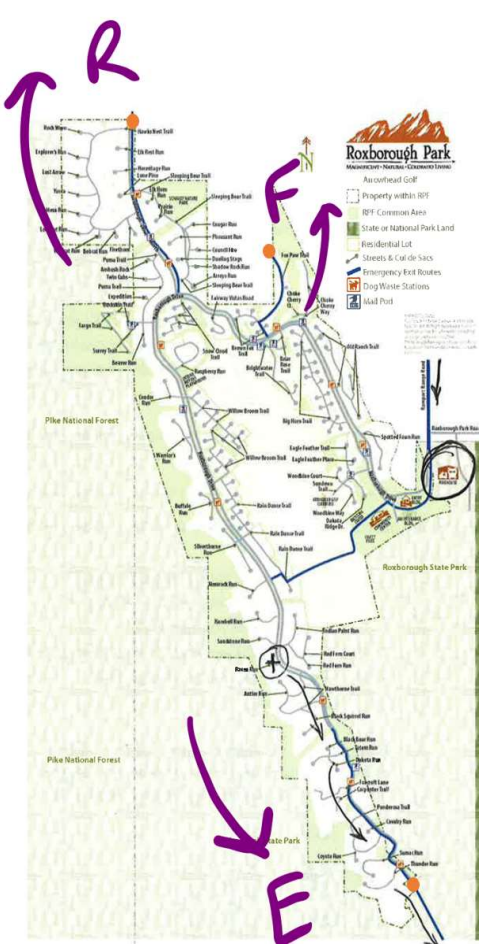


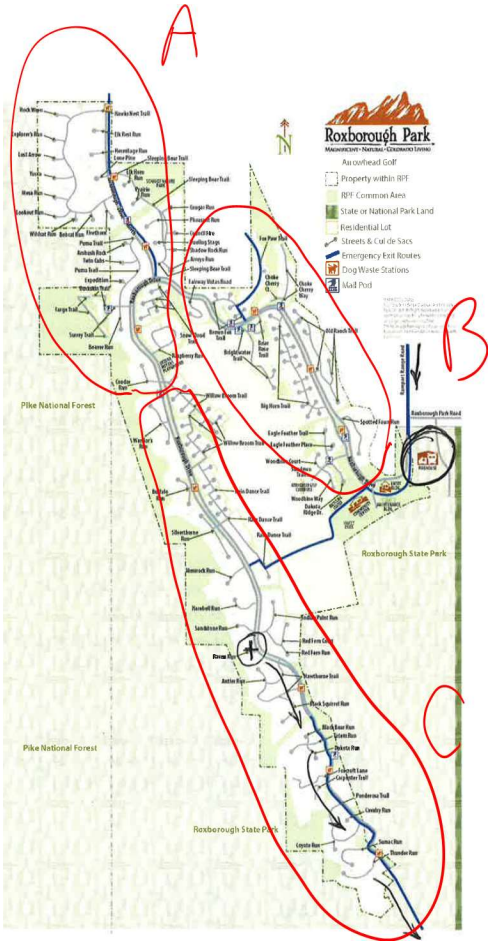
Applications: Roxborough Park Exercise

- On 27th of July 2019, Roxborough Park in Colorado (US) arranged an evacuation drill.
- Approximately 900 homes and an approximate area of 8.98 km^2 (2230 acres).
- Roxborough Park exposed to two wildfires in the past: the 1996 Buffalo Creek Fire and the 2002 Hayman Fire.

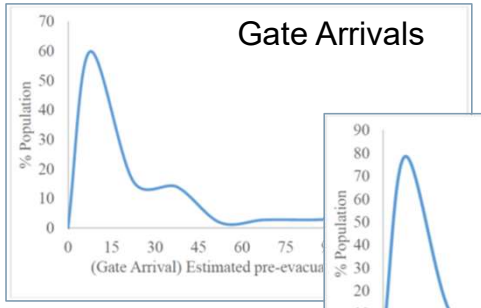
- Three routes were available: Roxborough drive via main gate [R], via emergency egress easement [E], or the Fox Paw Trail to Ravenna [F].
- Starting points were grouped into three areas [A-C].

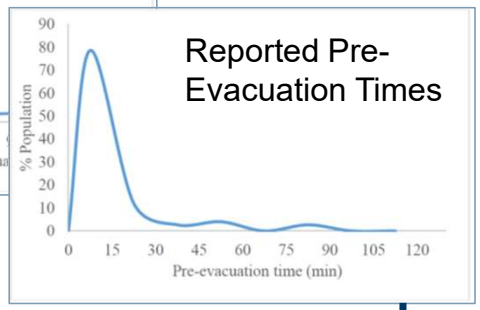
- 133 households registered to participate. **62** surveys were returned on the day of the drill, while 15 more arrived afterwards.
- Observers were located at the three gates used and at the assembly point. 107 arrival observations made at the gates and 53 arrival times were recorded at the assembly point.



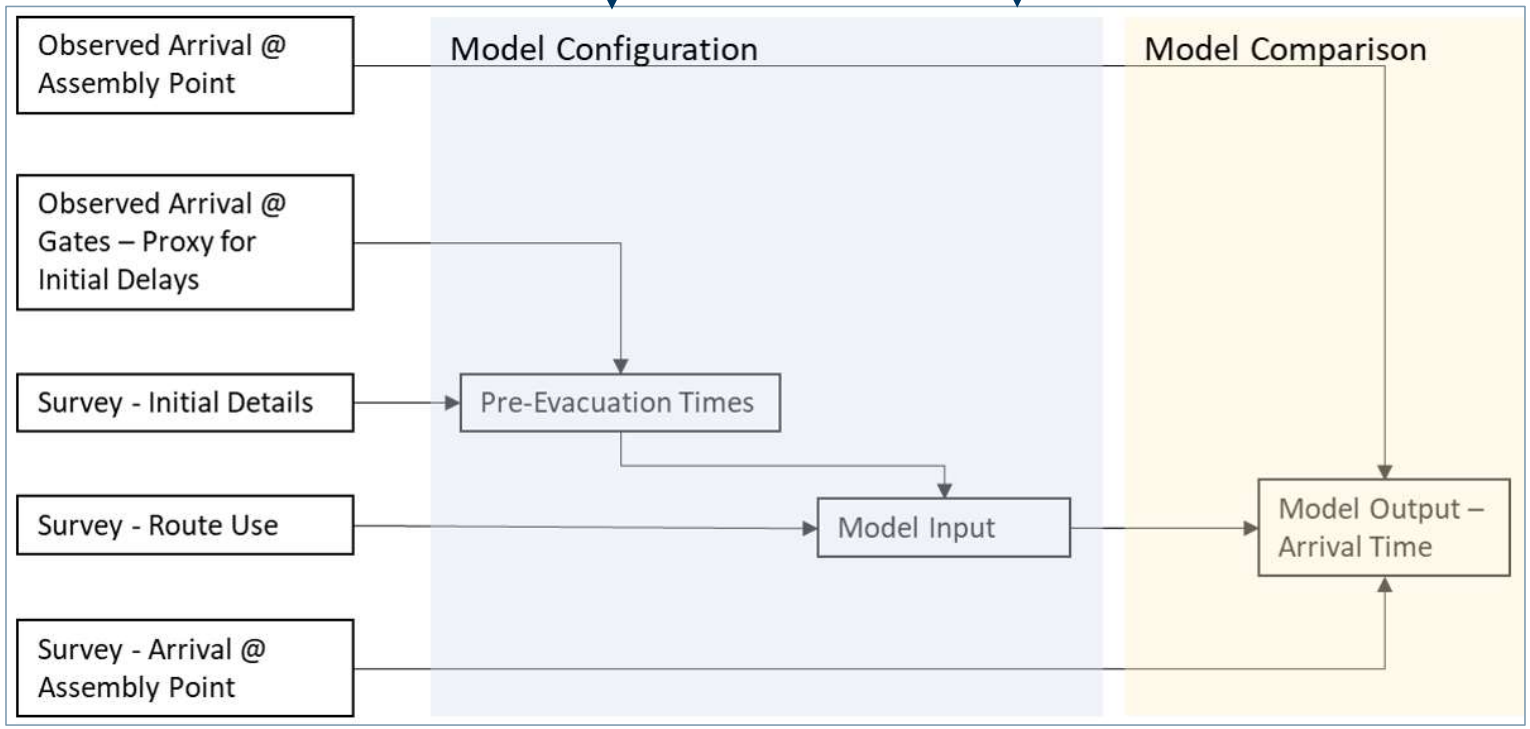


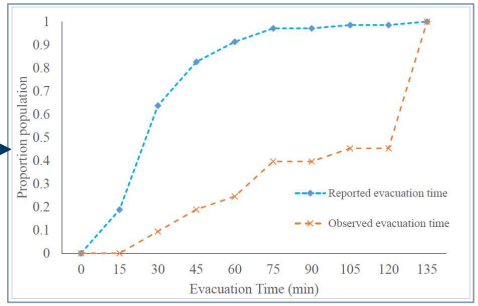
Applications: Roxborough Park Exercise - Data Use



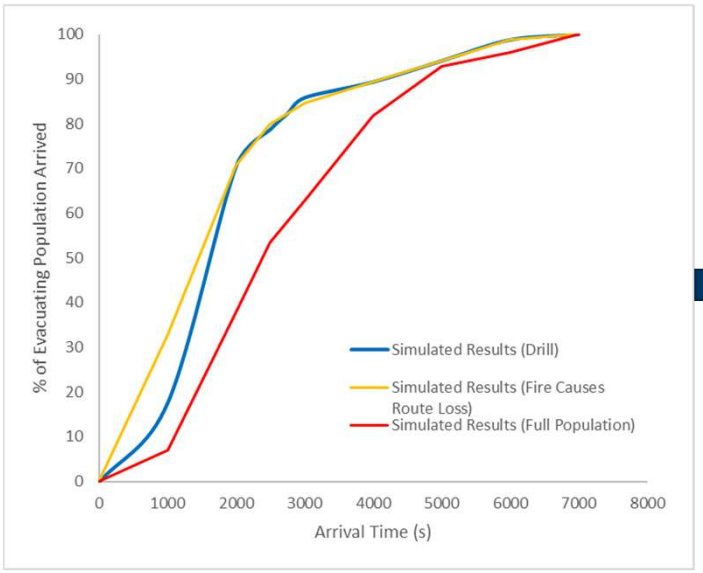


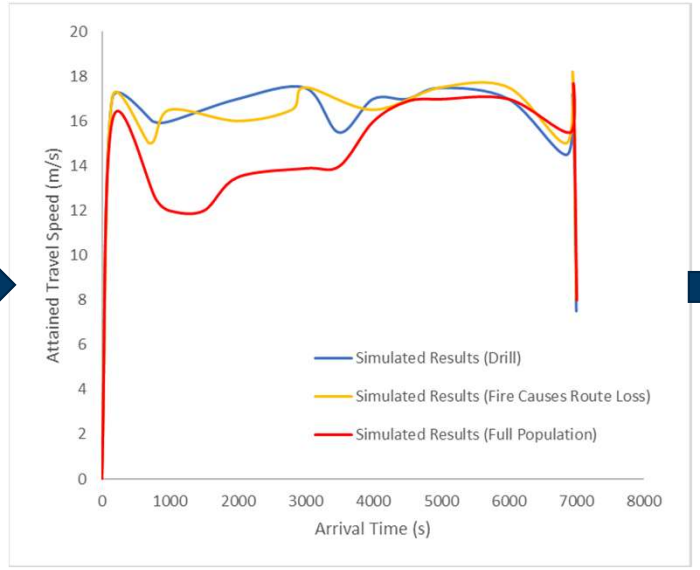
Route/ Zone	# of people	% of usage	Route/ Zone	# of people	% of usage	Route/ Zone	# of people	% of usage
R | A	20	83.3	R | B	0	0.0	R | C	13	38.2
E | A	1	4.2	E | B	2	13.3	E | C	19	55.9
F | A	3	12.5	F | B	13	86.7	F | C	2	5.9

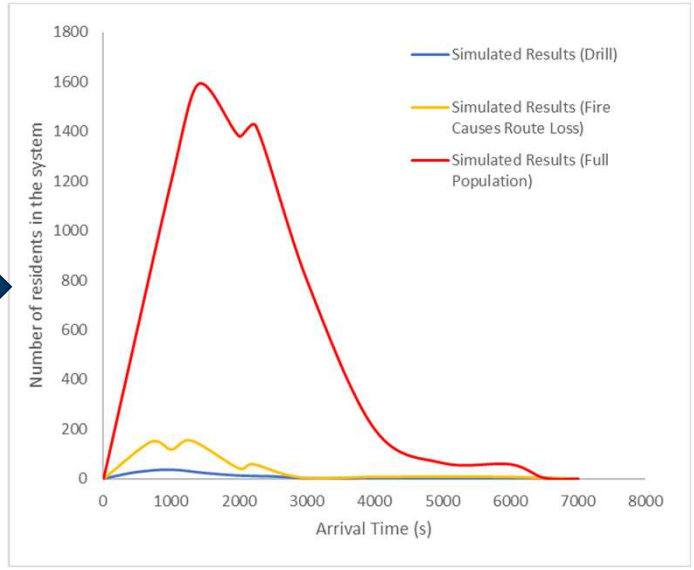




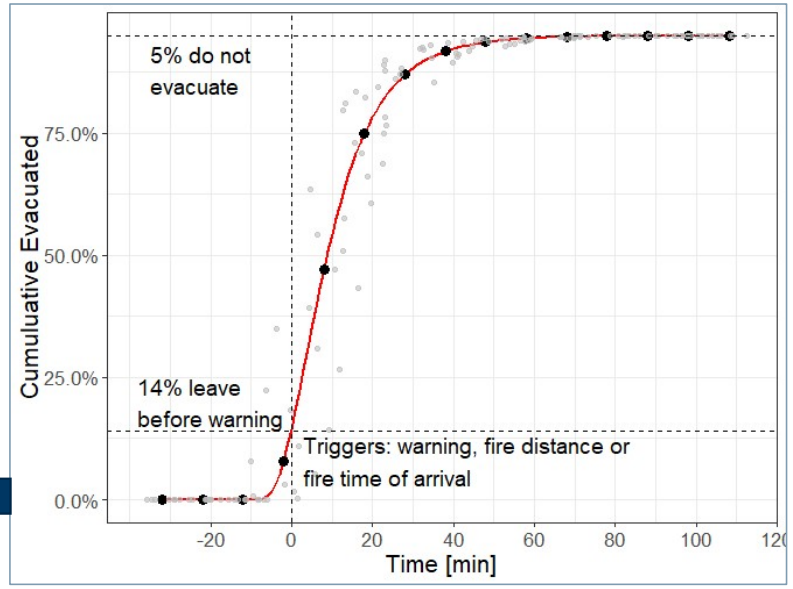
Applications: Roxborough Park Exercise - Reproducing the Original Conditions

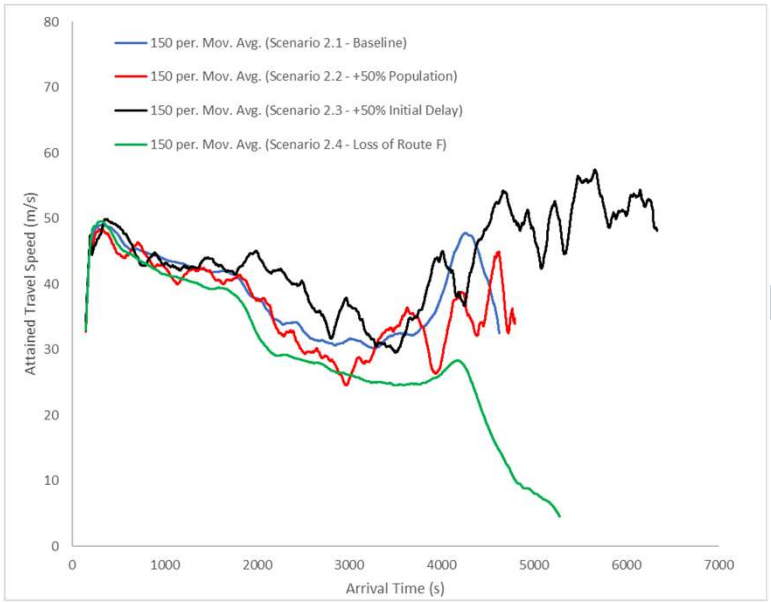


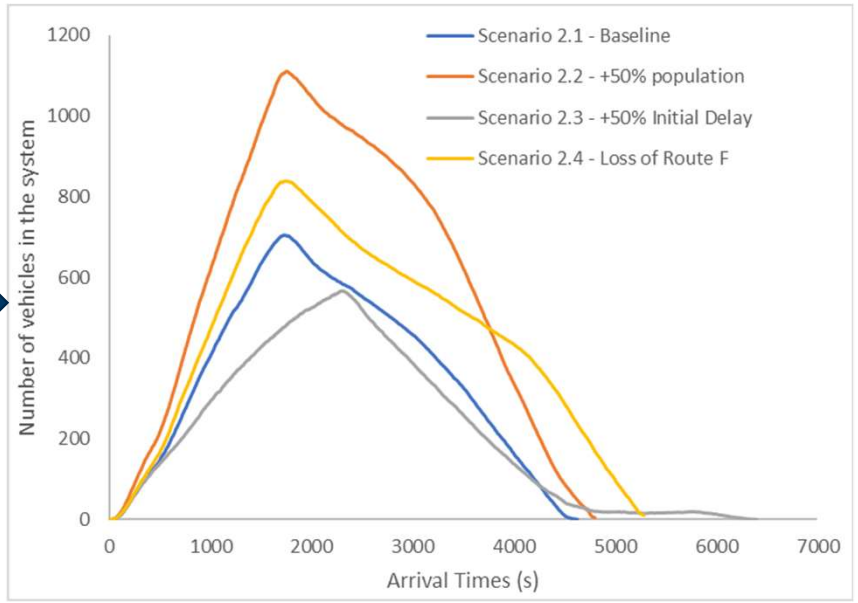




Applications: modelling with fewer knowns







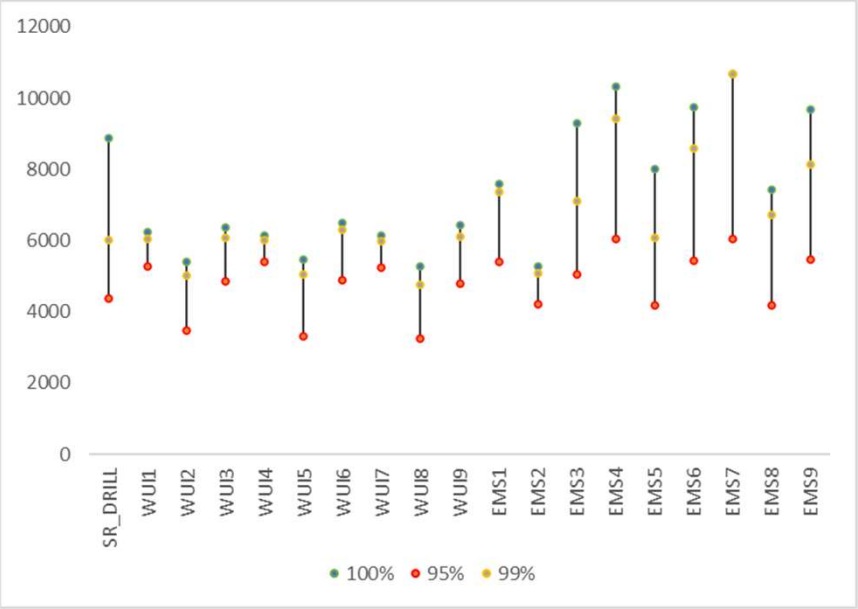
Applications: Roxborough Park Exercise - Comparison with other tools

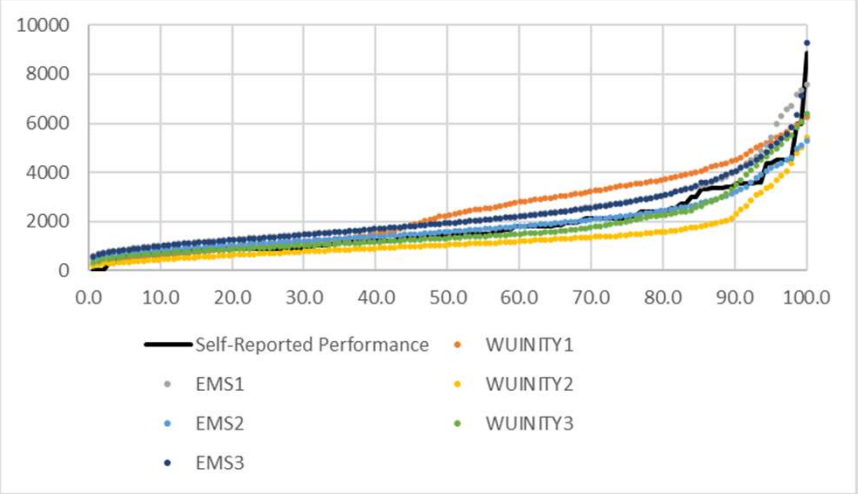
Provisional Results: Roxborough data compiled such that can be employed within evacuation models: WUI-NITY and EMS.

Objectives are to

- establish the capacity of such models to capture the complexity of wildfire evacuation and explore the underlying dynamics driving these events
- examine the sensitivity of such models to different interpretations and use of real-world data-sets and provide insights into the suitability and robustness of such models to community evacuation scenarios and associated engineering applications.

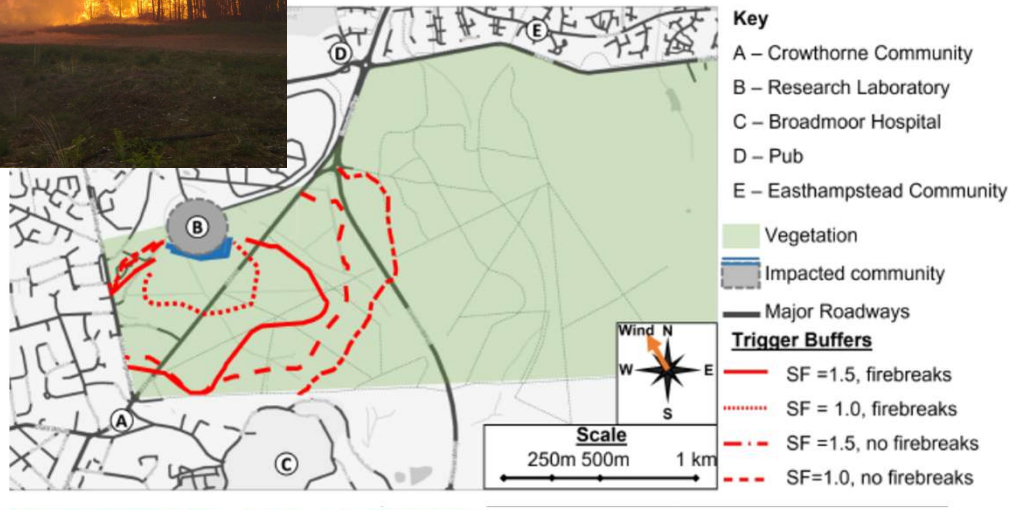
Scenario name	Pre-evacuation time	Destination usage
1_PEvacES_DestDrill	PEvacES	DestDrill
2_PEvacCSR_DestDrill	PEvacCSR	DestDrill
3_PEvacCES_DestDrill	PEvacCES	DestDrill
4_PEvacES_DestClose	PEvacES	DestClose
5_PEvacCSR_DestClose	PEvacCSR	DestClose
6_PEvacCES_DestClose	PEvacCES	DestClose
7_PEvacES_DestFast	PEvacES	DestFast
8_PEvacCSR_DestFast	PEvacCSR	DestFast
9_PEvacCES_DestFast	PEvacCES	DestFast



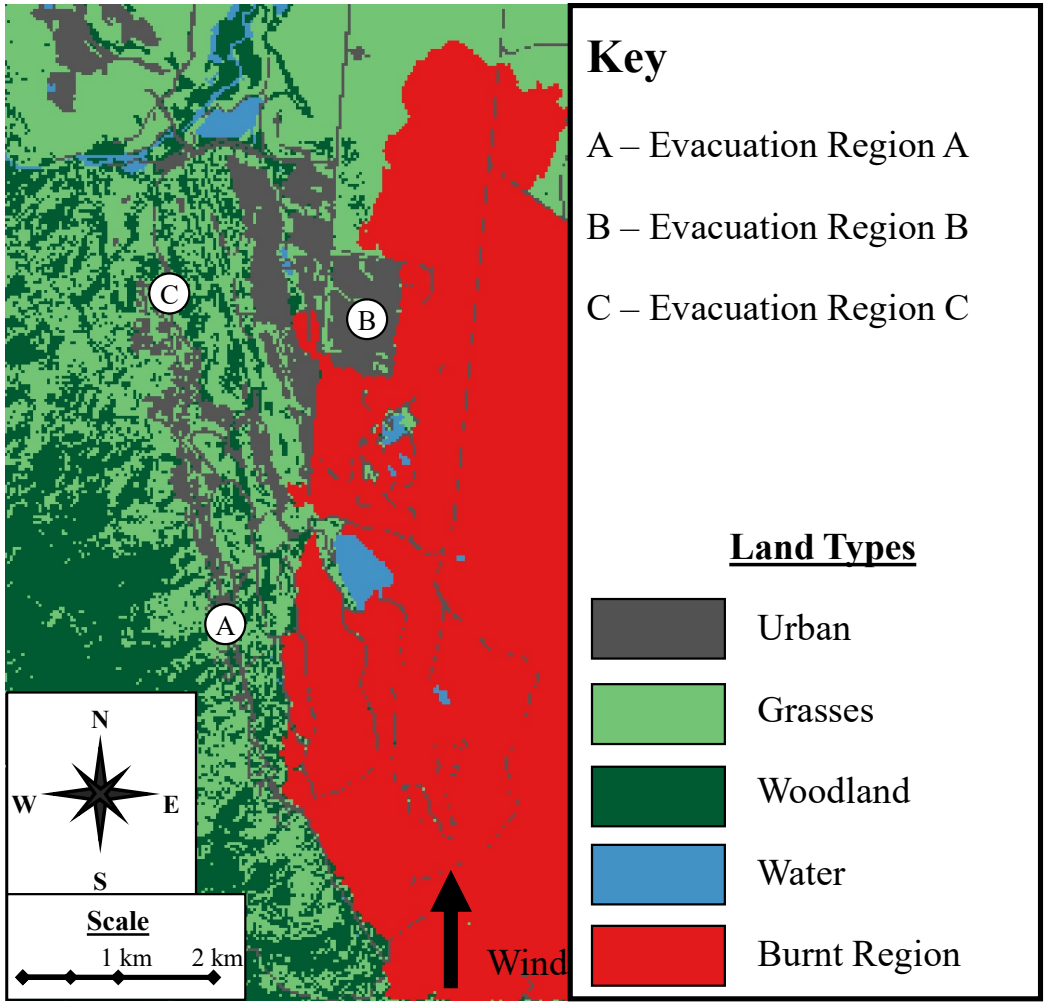


Applications: PERIL Trigger Buffer Assessment

Applied: Swinley, UK - 2011



Applied: Roxborough, CO, US.



Applications: PERIL Trigger Buffer Assessment

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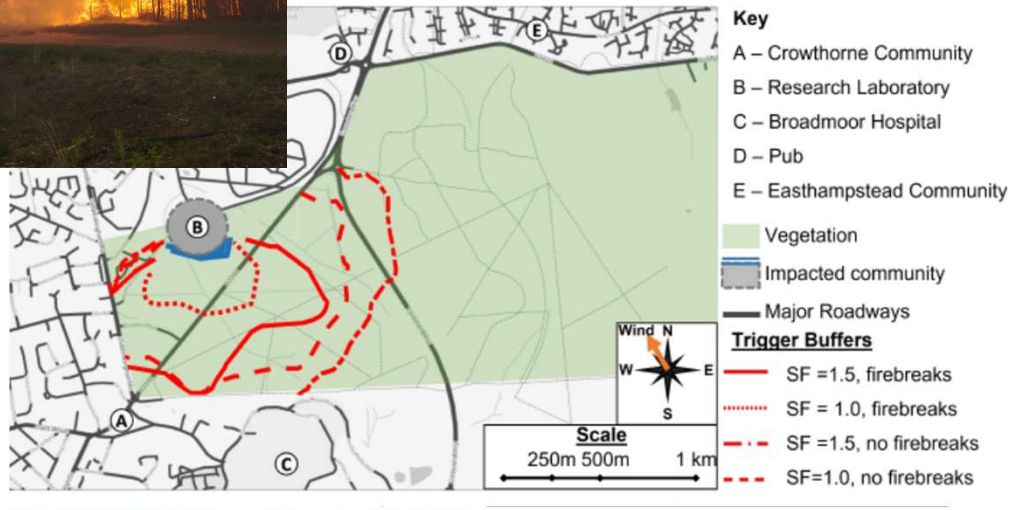
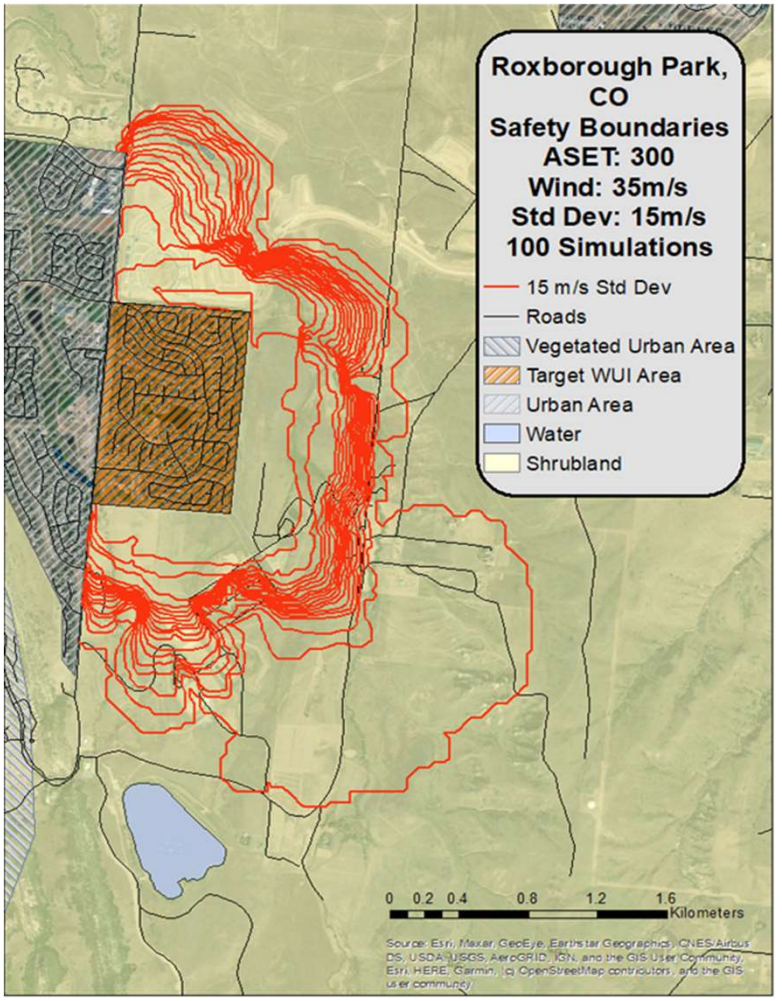
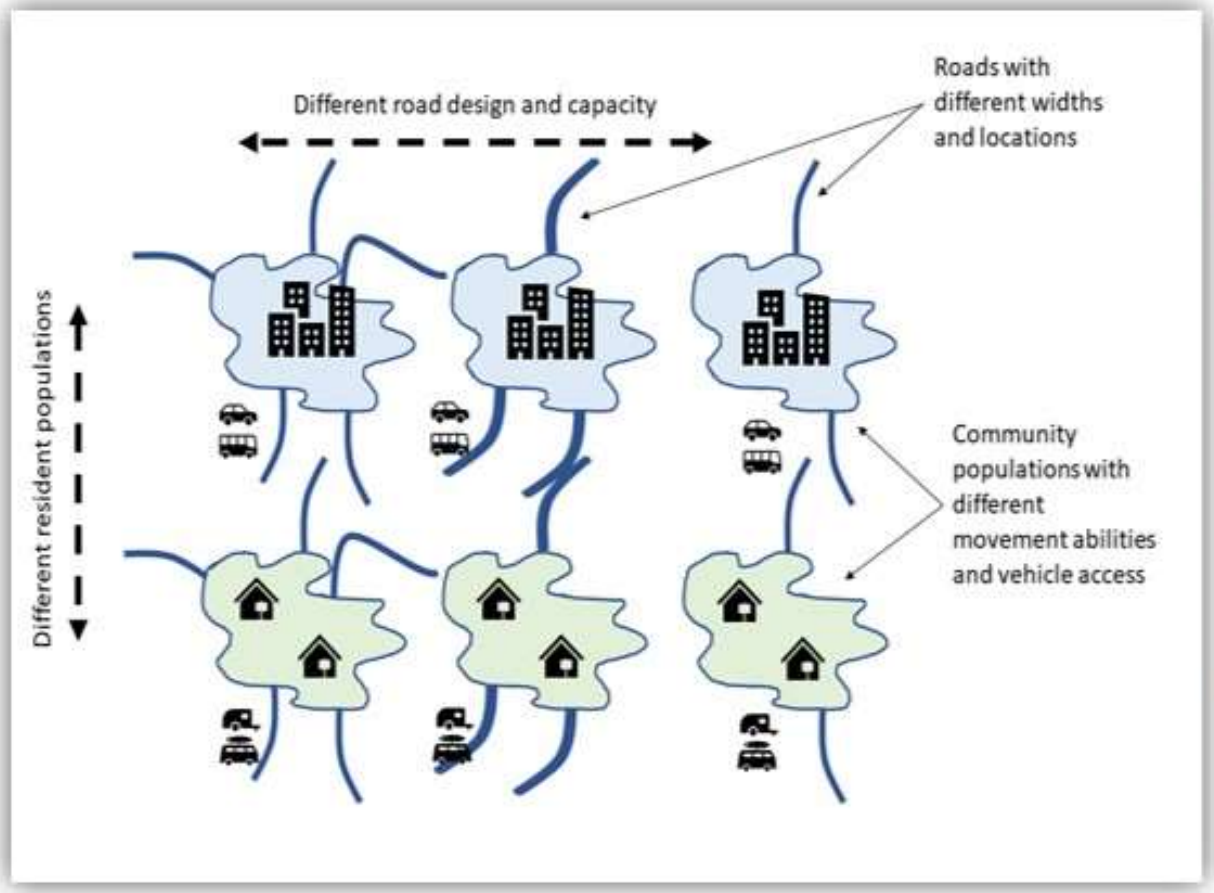
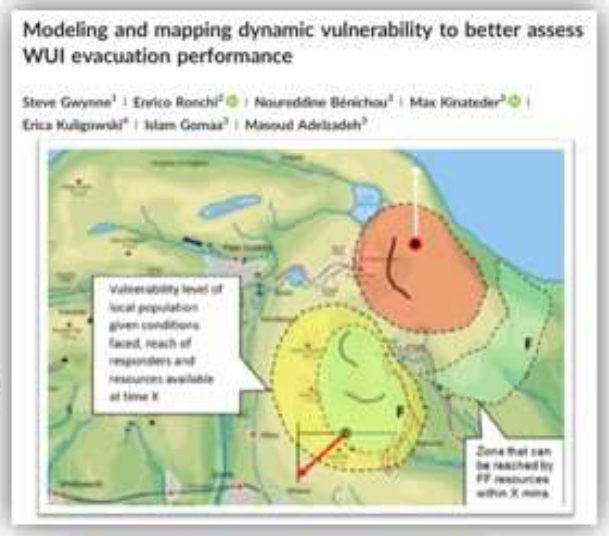


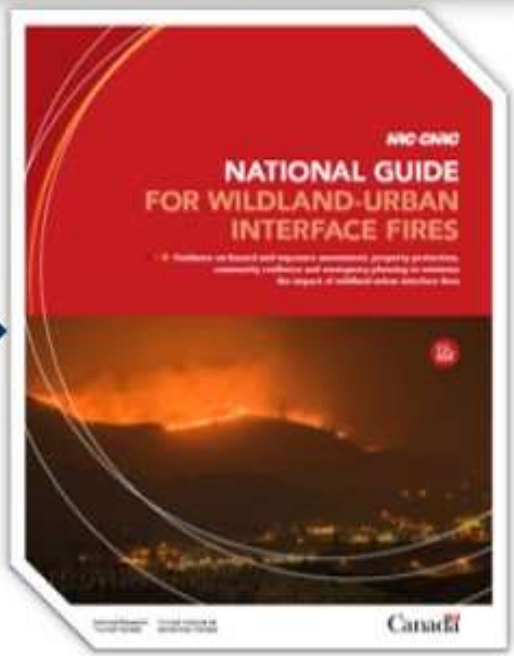
Applied: Roxborough, CO, US.



Modelling and Mapping







So what?

- Physical conditions and social conditions changing.
- Outcomes not just dependent on physical conditions – influenced by **community's capacity to cope**.
- Given complexity of wildfire evacuations, likely to need a model as a proxy - to estimate underlying dynamics and outcomes.
- May allow vulnerabilities to be identified, and different scenarios / response to be explored.
- Regulators / practitioners may need models to identify where problems arise, quantify impact of design/plan changes and identify means of addressing them.
- Such models would certainly be needed for performance-based approach to wildfire planning.
- Further development - **focus on moving from research to practice**, requiring more feedback from the user community
- Gathering additional data for validation and development (evacuation exercises, real events – traffic databases).