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TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Understanding Evacuation Behavior and Regional Resilience

December 11, 2023

4:00pm-5:30pm

PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

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AICP Credit Information

1.5 American Institute of Certified Planners Certification Maintenance Credits

You must attend the entire webinar

Log into the American Planning Association website to claim your credits

Contact AICP, not TRB, with questions

Purpose Statement

This webinar will feature three presentations on how these technologies are utilized as unique automated ways to understand both the transient evacuation behaviors during natural hazards and long-term resilience needs. Presenters will share how these new developments can be leveraged to benefit research, policy making, or transformed into business opportunities.

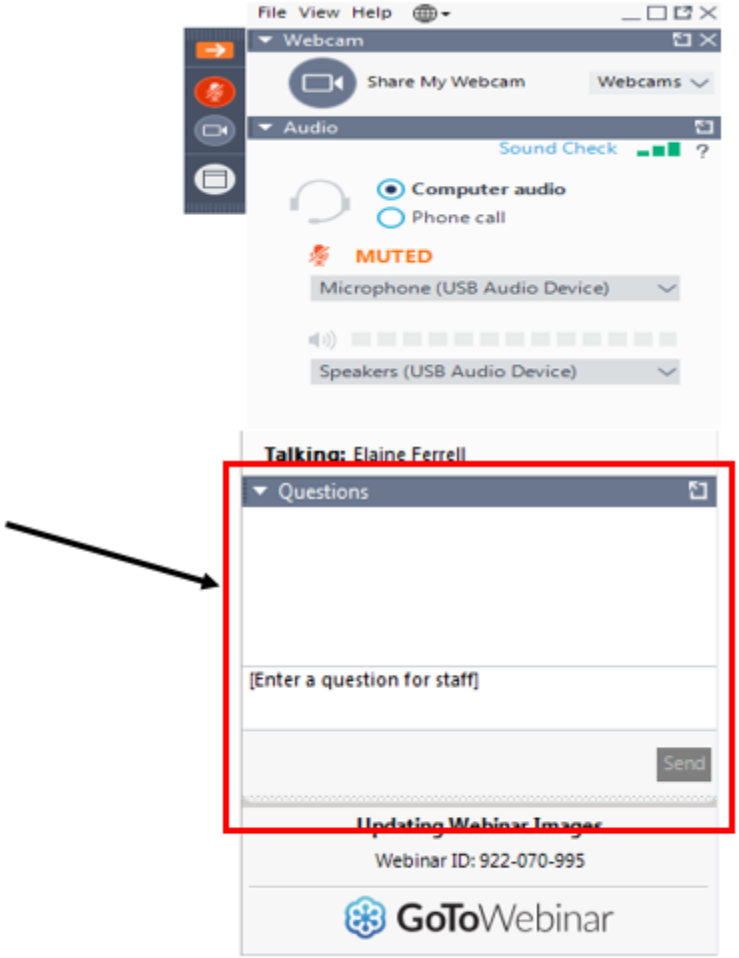
Learning Objectives

At the end of this webinar, you will be able to:

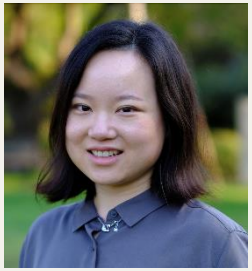
(1) Leverage emerging data sources and modelling methods to better understand evacuation behaviors and regional resilience
(2) Identify the bias and limitations associated with each data source or method
(3) Communicate with experts in the field about the implementation or practical bottlenecks in delivering comprehensive assessments

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



Today's presenters



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NATIONAL ACADEMIES Sciences Engineering Medicine

TRB2023 Webinar: Understanding Evacuation Behavior and Regional Resilience

RMIT UNIVERSITY

An International Perspective on Evacuation Modeling

Erica Kuligowski, PhD
Vice-Chancellor's Senior Research Fellow
School of Engineering
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Melbourne, Australia
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What's next...

Project Team Acknowledgements

- Main funder: U.S. National Institute of Standards and Technology
- Research Team:
  - Lund University (Sweden): Enrico Ronchi and Jonathan Wahlqvist
  - National Research Council (Canada): Max Kinateder, Noureddine Benichou
  - Imperial College London (UK): Guillermo Rein and Harry Mitchell
  - GHD/Movement Strategies (UK): Steve Gwynne, Hui Xie, Pete Thompson
  - Fire Protection Research Foundation (US): Amanda Kimball
  - RMIT University (Australia): Erica Kuligowski

WUI Areas and Fires

- Areas around the world are experiencing extreme fire conditions
- Challenges with WUI areas:
  - Higher density (and rates of population growth)
  - Infrastructure inadequate to support rapid escape
  - Climate change increasing bushfire size and intensity
- In fire seasons, these areas have experienced:
  - Large-scale evacuations
  - Inaccessible routes
  - Traffic congestion
  - Isolated communities

1) The Guardian, 2) CNN; 3) AP News; 4) CNN; and 5) BBC.

The Nature of the Problem…

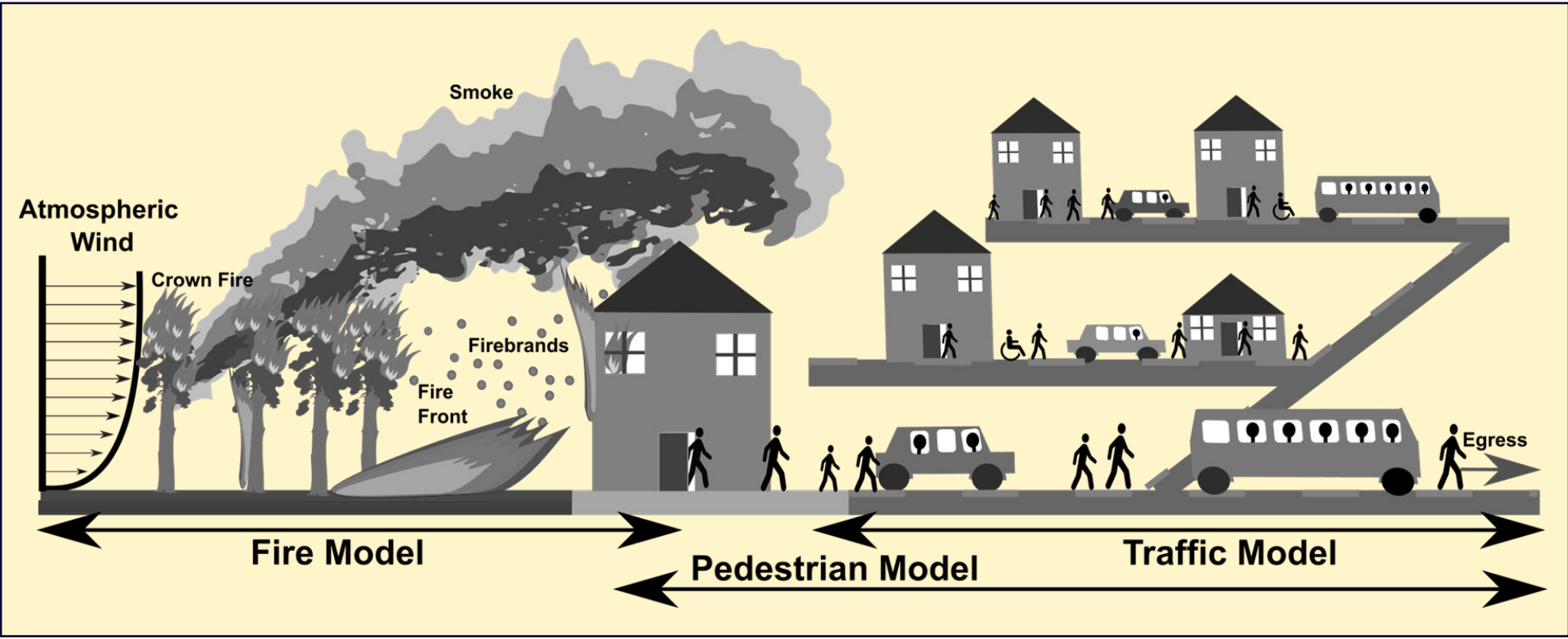


Figure by Harry Mitchell

2019-2020 Inquiries into Bushfires in Australia re: Evacuation

- **South Australia**: "There is insufficient preparation around evacuations including assessment of suitable routes to designated locations to reduce risks." *(Finding 6.4.2)*
- **Victoria**: Victoria Police with EM sector – enhance evacuation plans and processes (considering high risk areas, triggers, potential for isolation, non-evacuees and tourists, and compounding events) *(Rec 11)*
- **Royal Commission**: "State and territory governments should ensure that those responsible for ***evacuation planning*** periodically review those plans, and update them where appropriate, including in relation to:" e.g., adequacies of routes, inabilities to evacuate, risks due to outages/compounding events, worst-case scenarios *(Rec 12.2, 3, 6, 7)*

SA: https://safecom-files-v8.s3.amazonaws.com/current/docs/Independent%2520Review%2520into%2520SA%2527s%25202019-20%2520Bushfire%2520Season%2520-%2520Web%2520Upload.pdf
Vic: https://www.igem.vic.gov.au/publications/publications/inquiry-into-the-2019-20-victorian-fire-season-phase-1-report
Royal Commission: https://www.royalcommission.gov.au/natural-disasters

Evacuation Simulation Platform

WUI-NITY: Integrated simulation platform for WUI fire evacuation scenarios:

- For planning and emergency management
- Integrate models at the core of WUI evacuation
- Model selection optimized for complexity and resolution consistency
- Modular/flexible approach

WUI-NITY Background

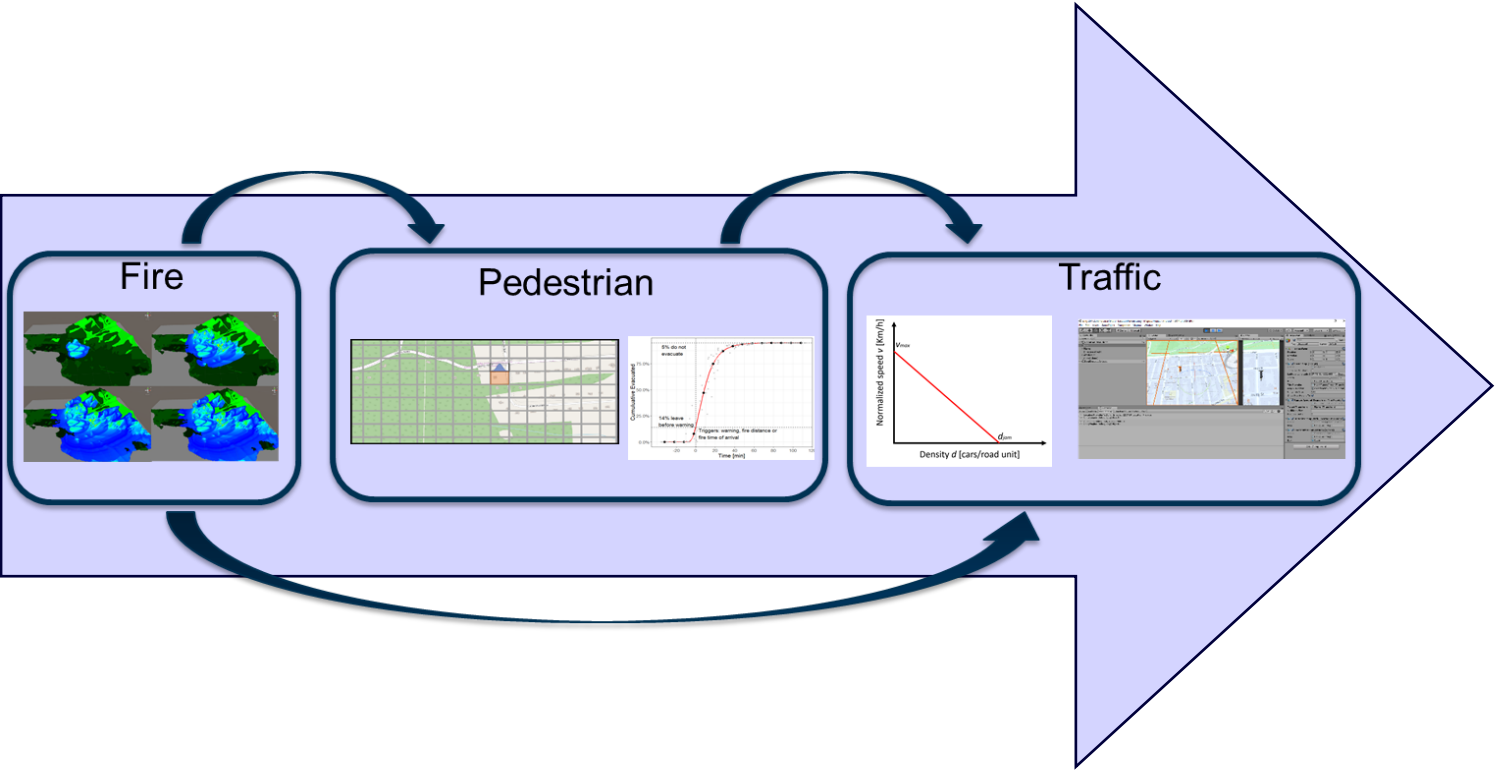
Intention was to provide a tool that …

- was **freely-available,**
- could **quantify** wildfire spread and evacuation performance in a **coupled** environment, and
- would encourage the inclusion of community response (and **vulnerability**) into the assessment of planning and safety levels.

- Completed and ongoing projects with national and international partners and stakeholders.

https://www.nfpa.org/education-and-research/research/fire-protection-research-foundation/projects-and-reports/wuinity-a-platform-for-the-simulation-of-wildlandurban-interface-fire-evacuation

Model Interaction

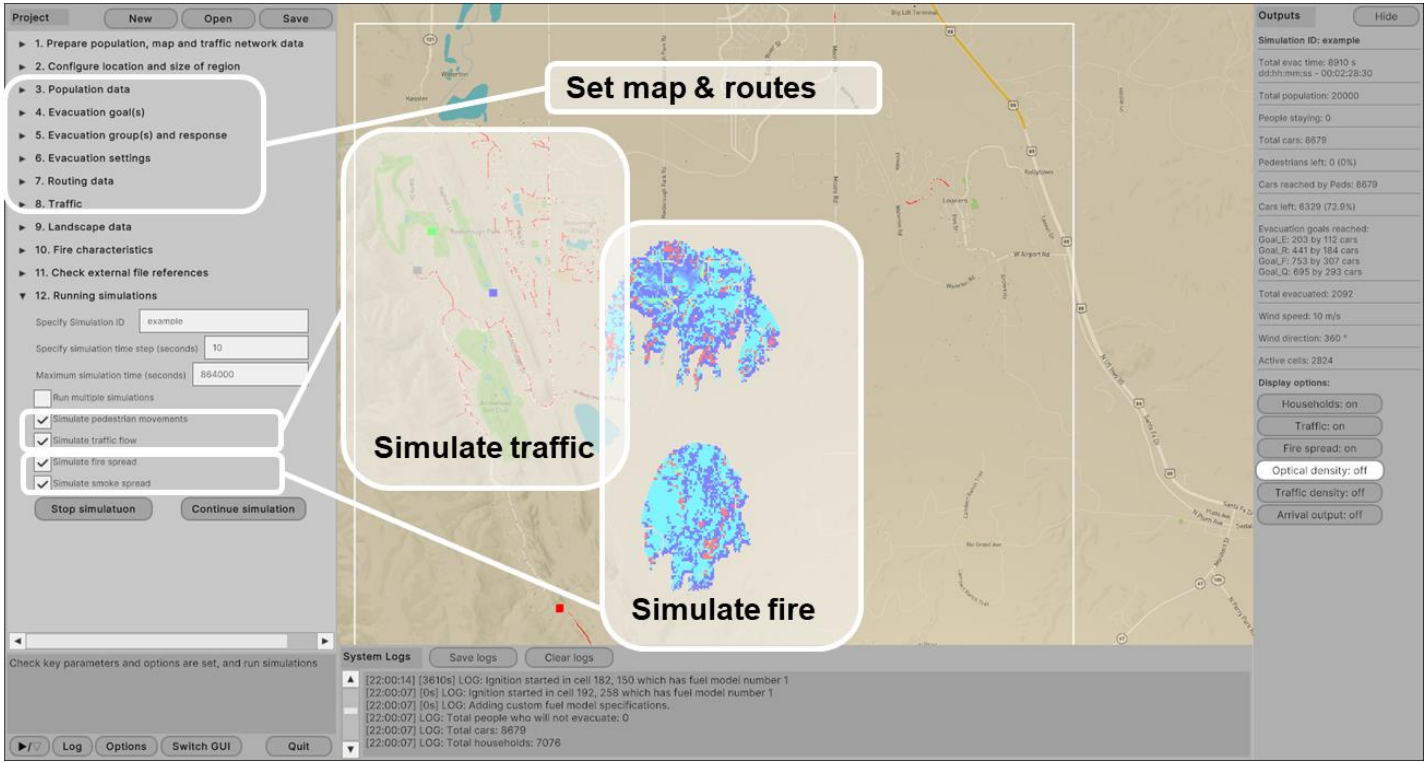


Outputs:

- Clearance time;
- Evacuation (arrival) time curves and flow at destinations;
- # of vehicles (in time) in locations along road network (traffic density);
- # of remaining residents, evacuees, and those located in refuge;
- Level of route use;
- % of target locations used

Vulnerability assessment: # of residents reaching place of safety, # of residents remaining

WUI-NITY – Brief Overview of the GUI



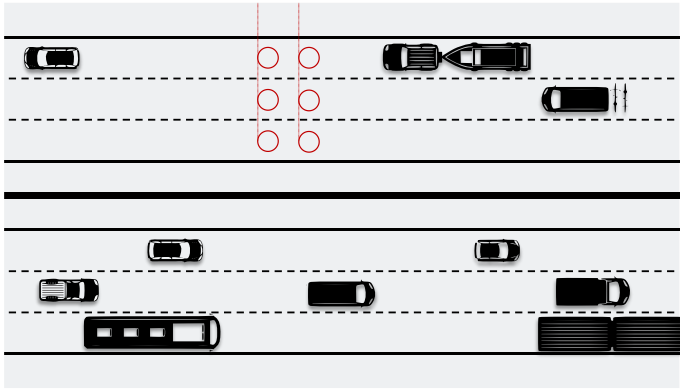
***WUI-NITY evacuation model**: Wahlqvist, J., Ronchi, E., Gwynne, S. M. V., Kinateder, M., Rein, G., Mitchell, H., Bénichou, N., Ma, C., Kimball, A., & Kuligowski, E. (2021). The simulation of wildland-urban interface fire evacuation: The WUI-NITY platform. Safety Science, 136, 105145. https://doi.org/10.1016/j.ssci.2020.105145*

Foundation of WUI-NITY – Data

- **Individual-based behaviour (microscopic):**
  - Traditional: surveys, interviews, (focus groups), travel diaries, experiments
  - Newer technology: virtual reality (VR)

VR: Wetterberg, et al. 2020

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



Rohaert, A., Kuligowski, E. D., Ardinge, A., Wahlqvist, J., Gwynne, S. M., Kimball, A., ... & Ronchi, E. (2023). Traffic dynamics during the 2019 Kincade wildfire evacuation. Transportation Research Part D, 116, 103610.

Insights from VR Studies of Bushfire Evacuation

- Data from 46 participants – how smoke density influenced choice of driving speed and car position

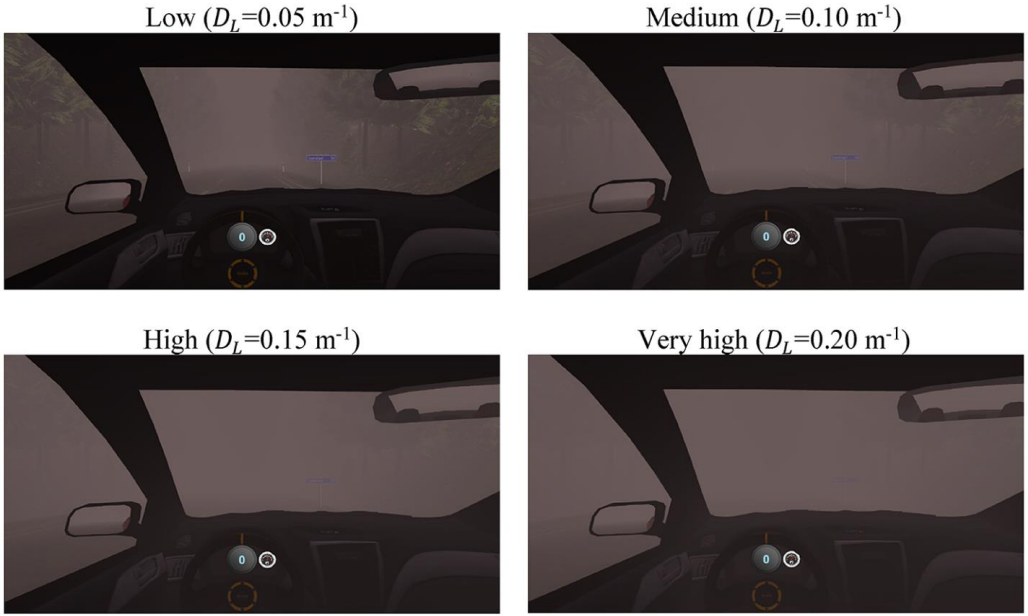


Figure 3. Screenshot of driver view from the car seat in the low (top-left), medium (top-right), high (bottom-left) and very high (bottom-right) optical density conditions. This view includes the road and surrounding terrain.

Wetterberg, N., Ronchi, E., & Wahlqvist, J. (2021). Individual driving behaviour in wildfire smoke. Fire Technology, 57, 1041–1061. https://doi.org/10.1007/s10694-020-01026-5

Insights from VR Studies of Bushfire Evacuation, cont.

- Findings: there was a clear trend that people reduced their driving speeds in smoke filled environments
- No trends found between environmental conditions and car position within the lane

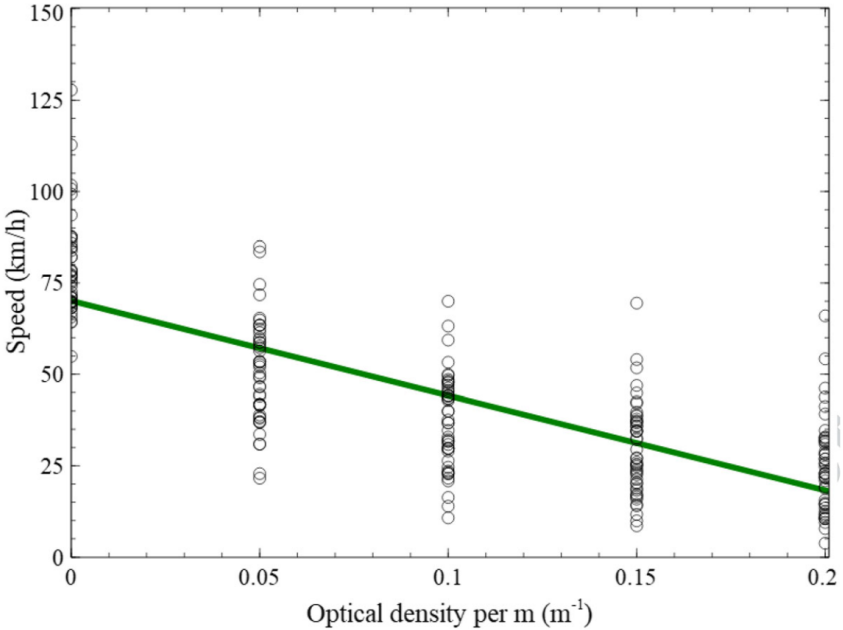
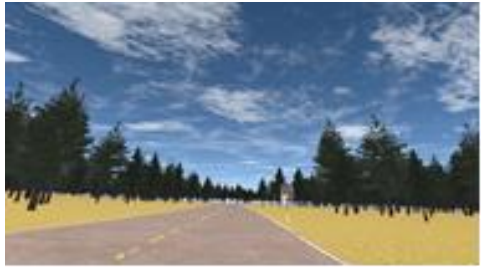


Figure 5. Aggregated average speeds (in km/h) recorded during the experiments at different optical densities per m (m^{-1}). The green solid line is a linear regression model based on the data.

Wetterberg, N., Ronchi, E., & Wahlqvist, J. (2021). Individual driving behaviour in wildfire smoke. Fire Technology, 57, 1041–1061. https://doi.org/10.1007/s10694-020-01026-5

Current Study using VR – WUI-NITY project (NRCC/Lund University)

Zero density condition
Day/night



Misty condition
Day/night

Smoke condition
Day/night

- Ability to characterise visibility (for a range of optical densities in the VR simulations)

Acknowledgements: Berthiaume, Rohaert

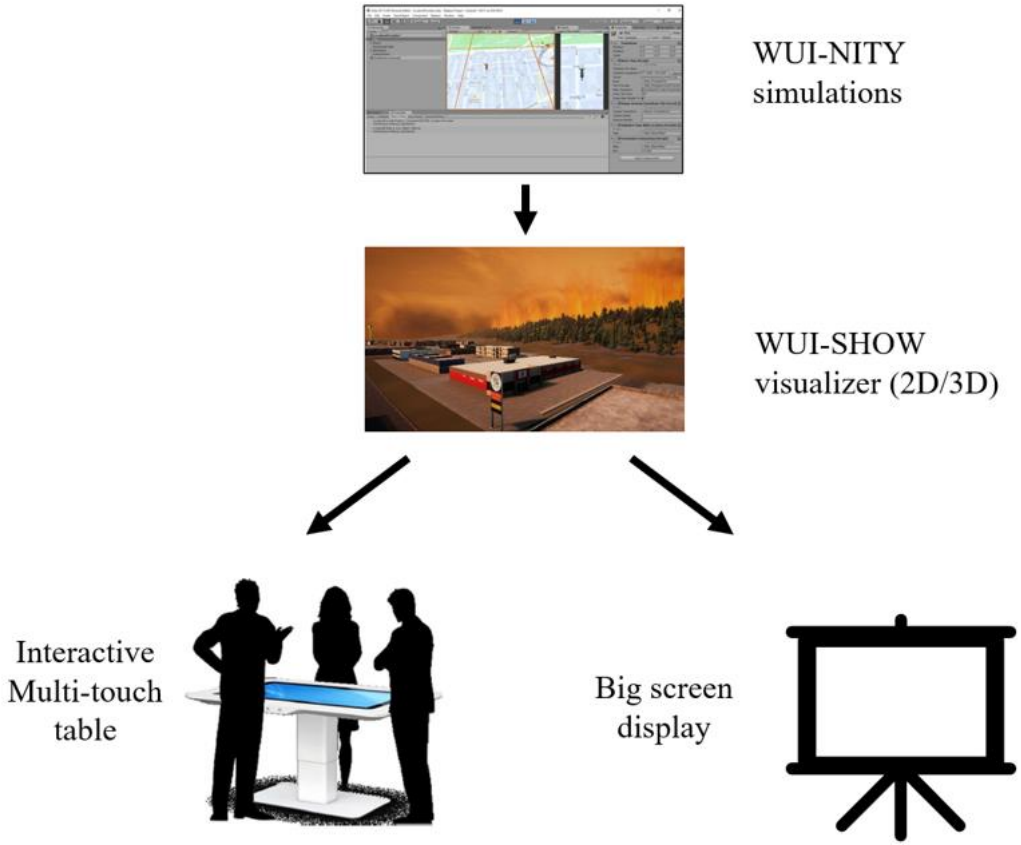
Current Studies using VR – WUI-NITY project (NRCC/Lund University), cont.

- Ability to characterise visibility (for a range of optical densities in the VR simulations)
- Ability to measure headway (density in a single traffic lane)

Acknowledgements: Berthiaume, Rohaert

Next Steps – WUI-NITY (2D/3D visualiser)

- Develop new capability within WUI-NITY - allow users to switch between 2D and 3D views and interactively obtain information regarding the simulated wildfire evacuation
- Displayed either on a screen or through an interactive multi-touch table
- Optimized for collaborative decision making and/or training



Thank you very much!

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Extra slide, as needed

Insights from Traffic Data (aggregate scale)

- 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 are comparable

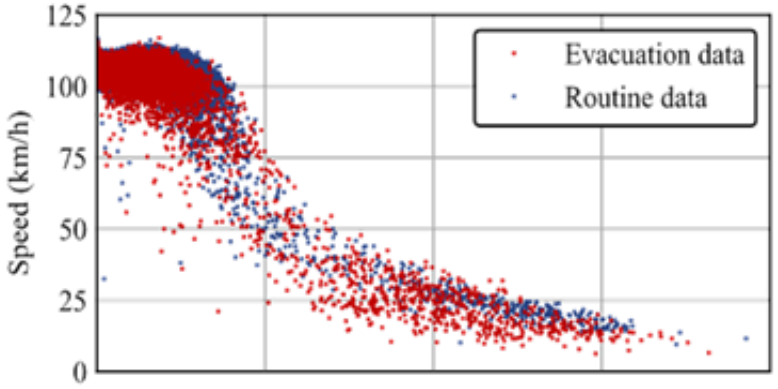
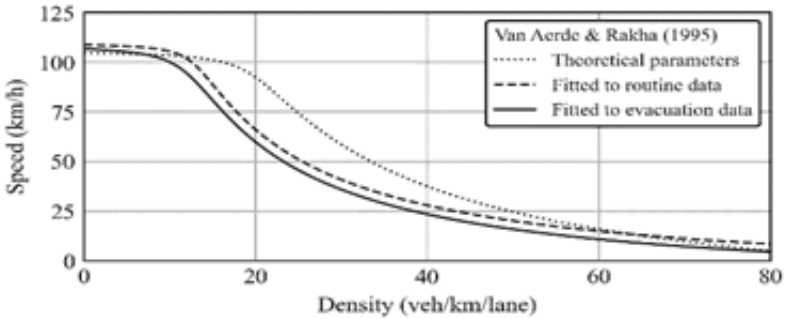


Figure by Arthur Rohaert



Rohaert, A., Kuligowski, E. D., Ardinge, A., Wahlqvist, J., Gwynne, S. M., Kimball, A., ... & Ronchi, E. (2023). Traffic dynamics during the 2019 Kincade wildfire evacuation. *Transportation research part D: transport and environment*, *116*, 103610.

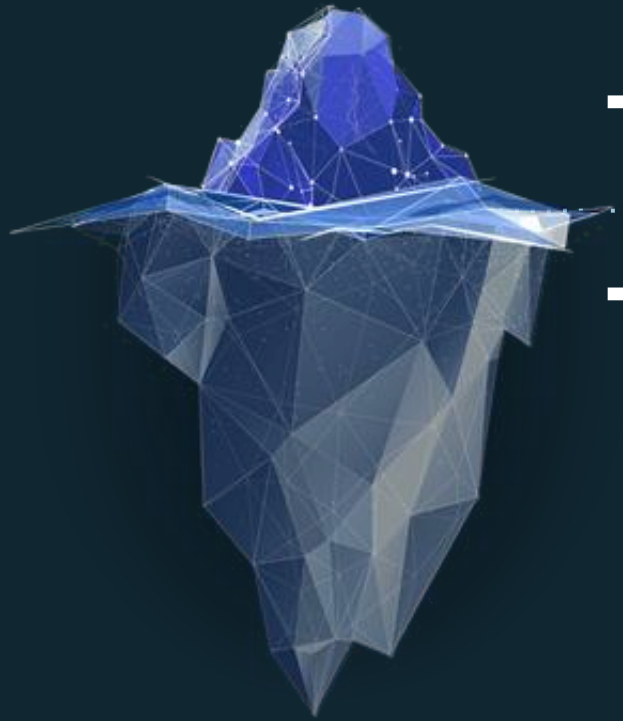
Integrated resilience modeling framework with digital twin development

Youngsuk Kim, Ph.D.
Head of Resilience Modeling
One Concern, Inc.

Outline

- Introduction of Integrated Resilience Modeling
- Digital Twin Development
  - Overview
  - AI/ML Application
- Summary

Exposing the Hidden Risks in the Built Environment



Traditional Direct Risks:
Direct Facility Damage

Only Direct Damage to Property

Dependency Risks: the risk from the surrounding infrastructure ("lifelines") that individual/business/community depend on which account for the majority of the physical risk

Power Grid Damage

Road Damage

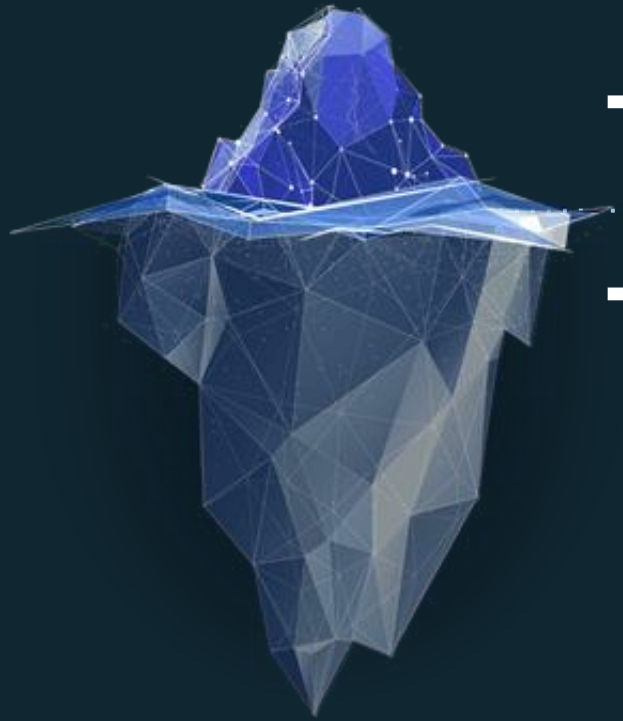
Port Damage

Airport Damage

Bridge Damage

Community Damage

Exposing the Hidden Risks in the Built Environment



Traditional Direct Risks:
Direct Facility Damage

CAT Models

Dependency Risks: the risk from the surrounding infrastructure ("lifelines") that individual/business/community depend on which account for the majority of the physical risk

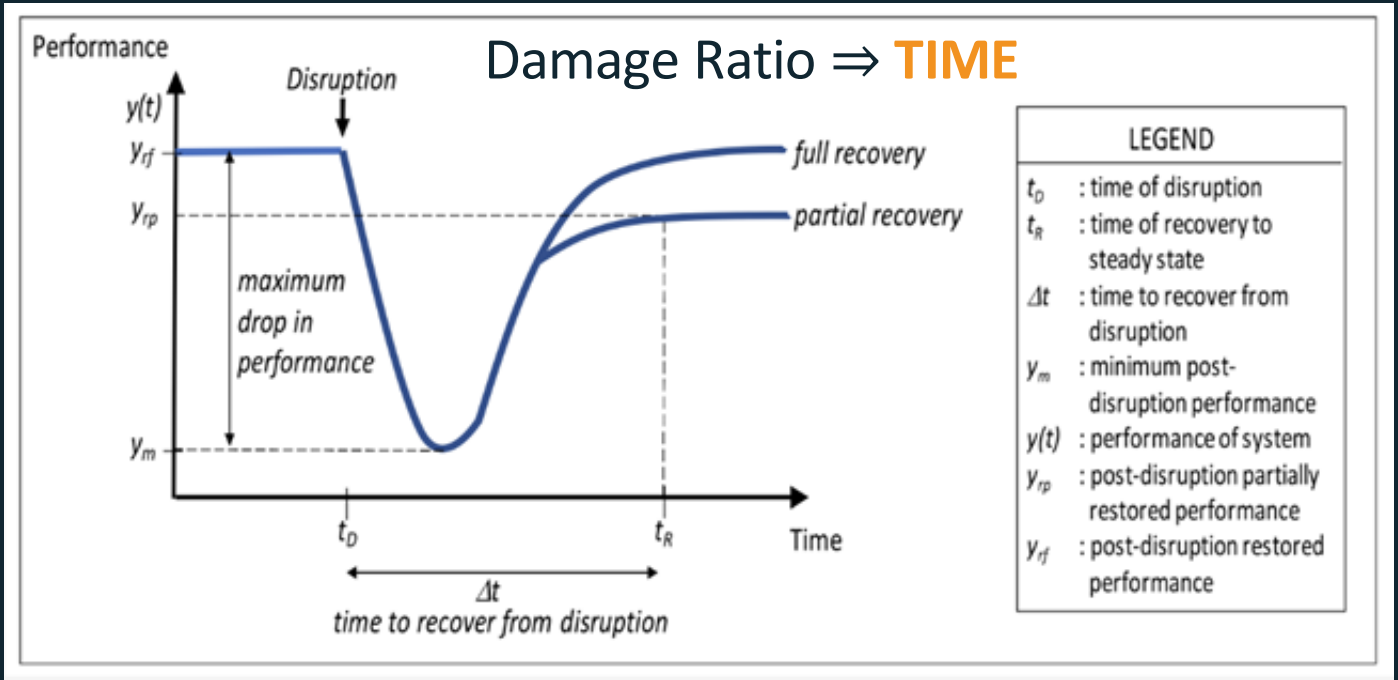
Often referred as
Known Unknowns* or *Protection Gap

Resilience Modeling

RESILIENCE

- The ability to withstand, adapt and to quickly recover from stresses and shocks
- Immediate functional degradation (vulnerability) and time component for regaining functionality (recovery; downtime)

Resilience Modeling - A Paradigm Shift

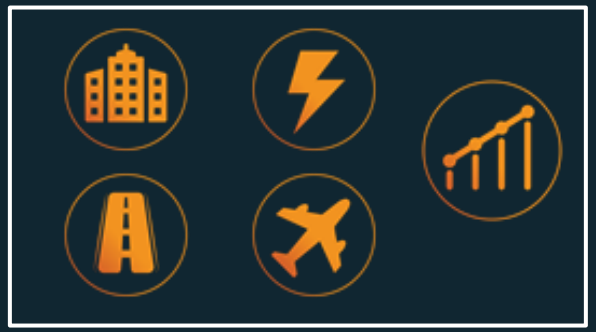


Constructing Models for Systems Resilience: Challenges, Concepts, and Formal Methods, A. Madni et.. al., Systems 2020, 8(1), 3;

Inventory

Natural/Man-made Hazard

Integrated Resilience Platform



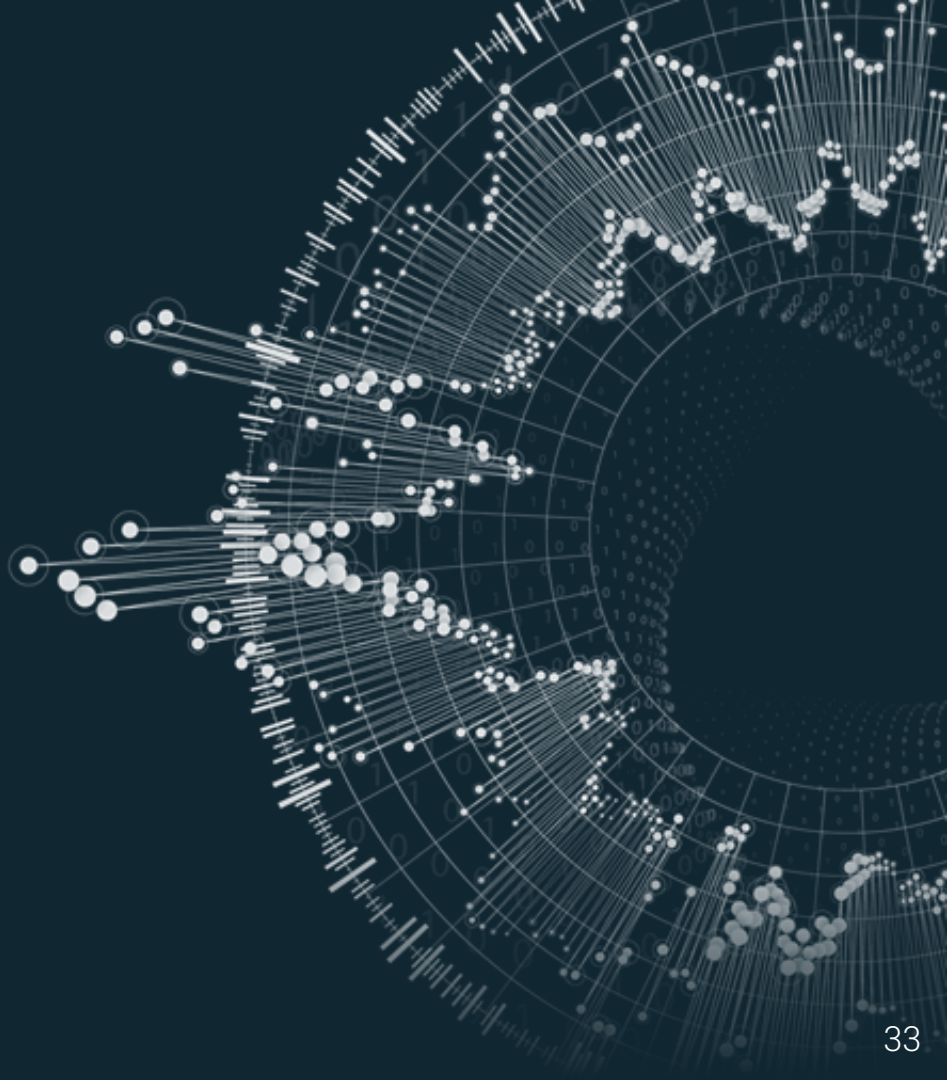
Impact & Recovery

Resilience Quantification

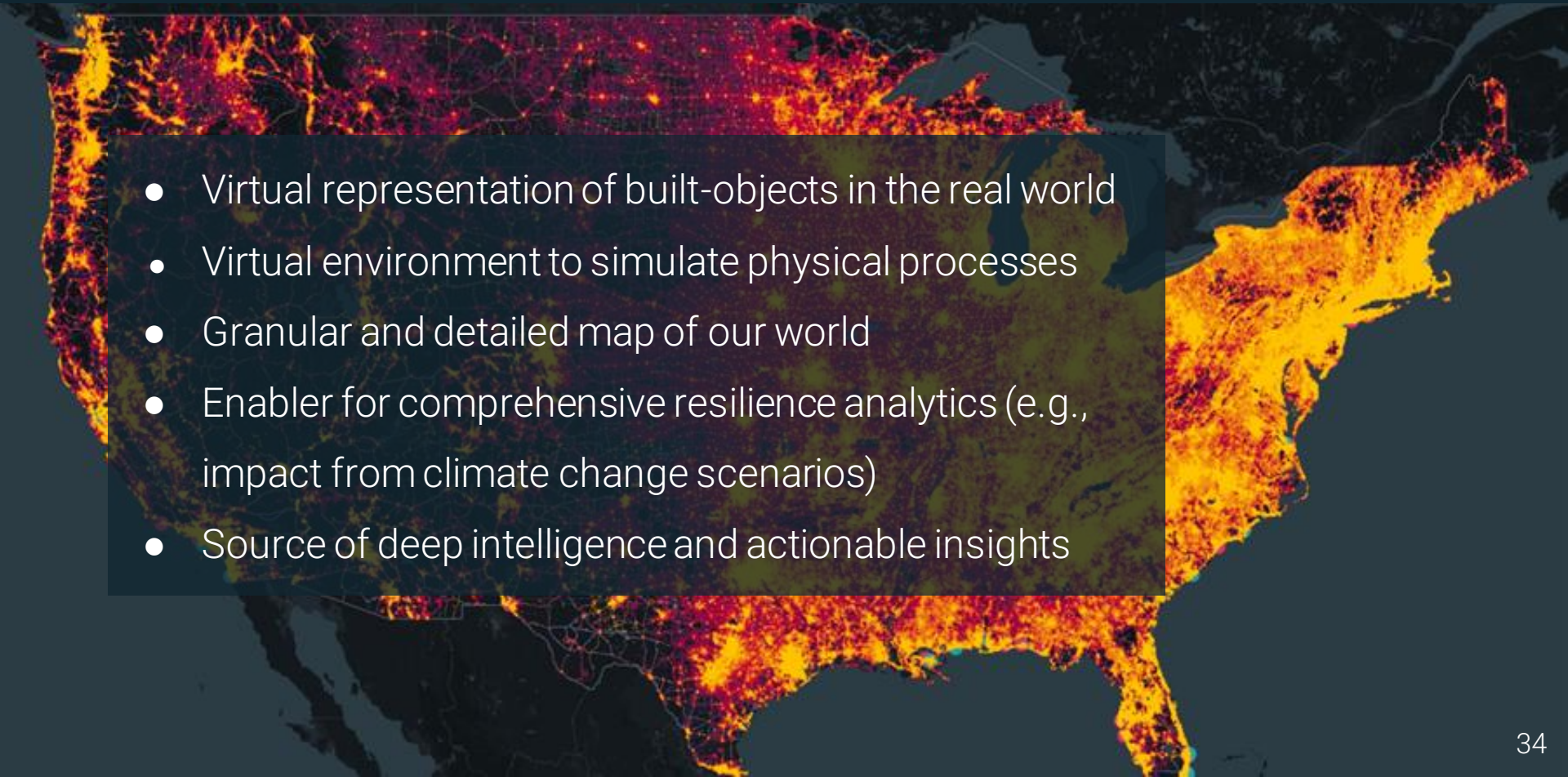
Integrated Resilience Modeling

- Evaluate infrastructure system as connected ones
- Captures disruptions due to a direct and dependency
- Downtime reflects impacts to intricate details and interconnections
- Downtime translates to actual individual/business impact of disasters at an asset level

Digital Twin

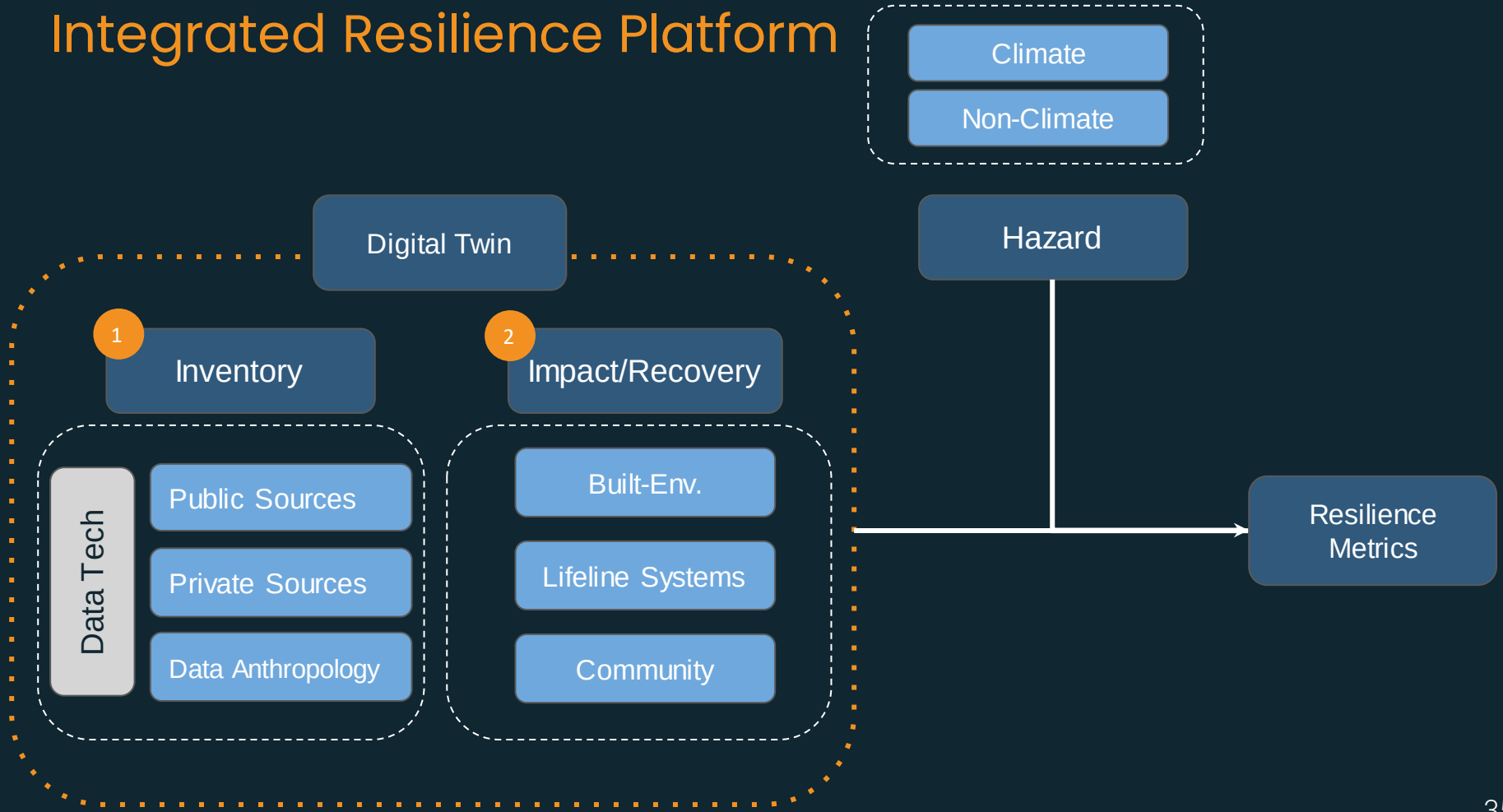


What is a Digital Twin?



- Virtual representation of built-objects in the real world
- Virtual environment to simulate physical processes
- Granular and detailed map of our world
- Enabler for comprehensive resilience analytics (e.g., impact from climate change scenarios)
- Source of deep intelligence and actionable insights

Integrated Resilience Platform



One Concern's Resilience Platform

Digital Twin - Inventory

~39M Commercial Buildings

25 Sea Ports

~ 50k Substations
~ 170M Poles

128 Airports

~2.7M Highway Segments

~108M Residential Buildings

~600k Bridges

Hazard

Earthquake

Flood
Baseline, RCP 4.5, + RCP 8.5
View at YR 2035 & 2050

Windstorm
Baseline, RCP 4.5, + RCP 8.5
View at YR 2035 & 2050

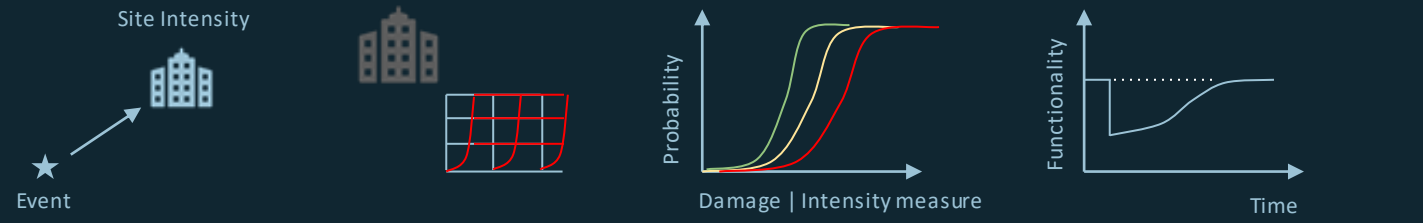
Resilience Simulation

Damage Ratio
Mean and standard deviation of loss for each commercial building due to each hazard at each return period and planning horizon

Downtime
Mean and standard deviation of downtime for each asset due to each hazard at each return period and planning horizon

Recovery Curve
Probabilistic distribution of recovery time for each asset due to each hazard at each return period

Resilience Modeling (Cont.)



Hazard Analysis

- Hazard
- Inventory (e.g., building, ports)

Structural Analysis

- Obtain structure responses under different hazard intensities

Fragility Analysis

- Generate fragility curves from responses
- Probabilities of damage levels

Recovery Analysis

- Recovery functions of damage level
- Combine with fragility curve to identify recovery trajectory given a hazard intensity

Traditional Risk Analysis

Application of ML/AI

Inventory

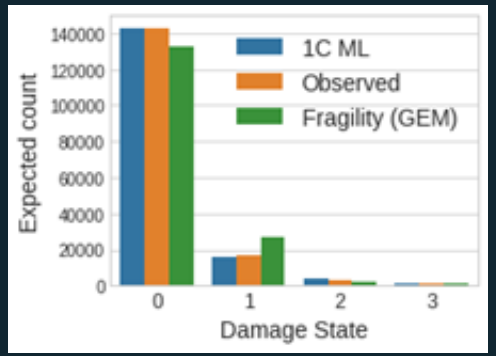
- Extend coverage
- Fill data gaps
- Data generation

Impact/Recovery

- Impact prediction
- Recovery prediction

Power substation identification

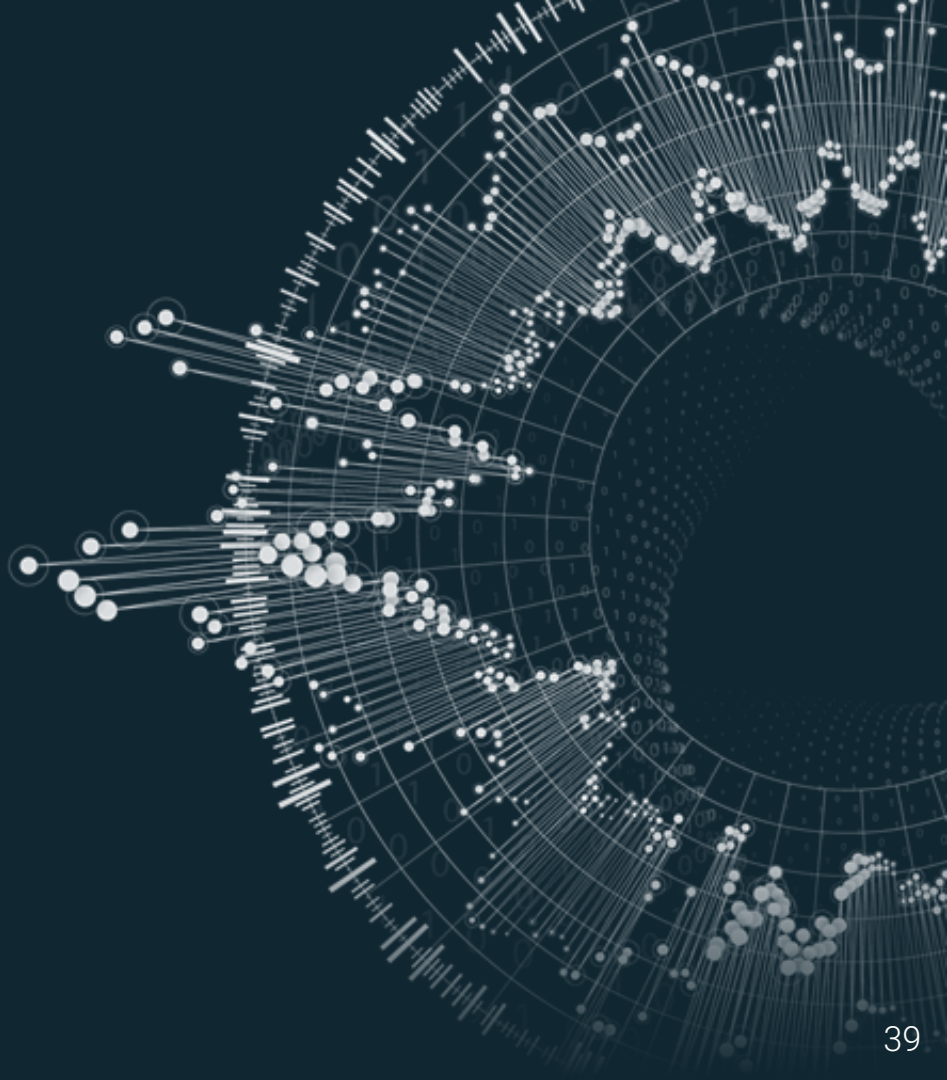
Power distribution classification



Synthetic Levee Generation

EQ Damage Prediction

Summary



Key Differentiators

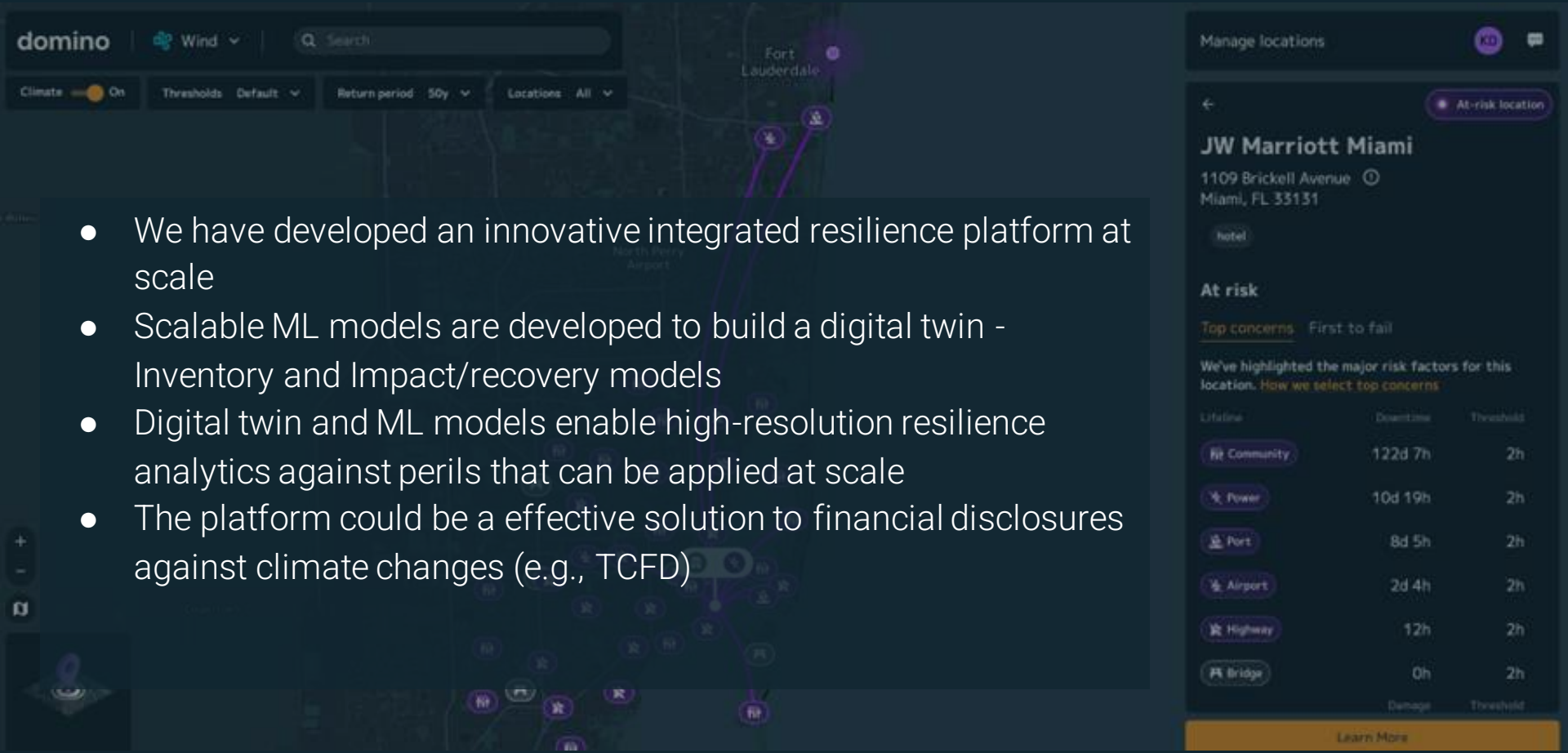
Holistic Dependency Analysis

Digital Twin

Best of ML + Best of Traditional

Scale of Data

Recovery Modeling



- We have developed an innovative integrated resilience platform at scale
- Scalable ML models are developed to build a digital twin - Inventory and Impact/recovery models
- Digital twin and ML models enable high-resolution resilience analytics against perils that can be applied at scale
- The platform could be a effective solution to financial disclosures against climate changes (e.g., TCFD)

Thank You

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oneconcern.com

Should we stay or leave now? Improving understanding of wildfire evacuation with large-scale GPS data

Xilei Zhao, Ph.D.

Department of Civil and Coastal Engineering, University of Florida

This is the joint work with Yuran Sun, Xiaojian Zhang, Yiming Xu, Alex Wu, Ruggiero Lovreglio, Erica Kuligowski, Thomas Cova, and Daniel Nilsson.

Increasing wildfire risk

- Climate change
- Wildland-urban interface (WUI) expansion (population growth)
- **Goal: Timely evacuate people from harm's way**

Source: https://www.unep.org/news-and-stories/press-release/number-wildfires-rise-50-2100-and-governments-are-not-prepared

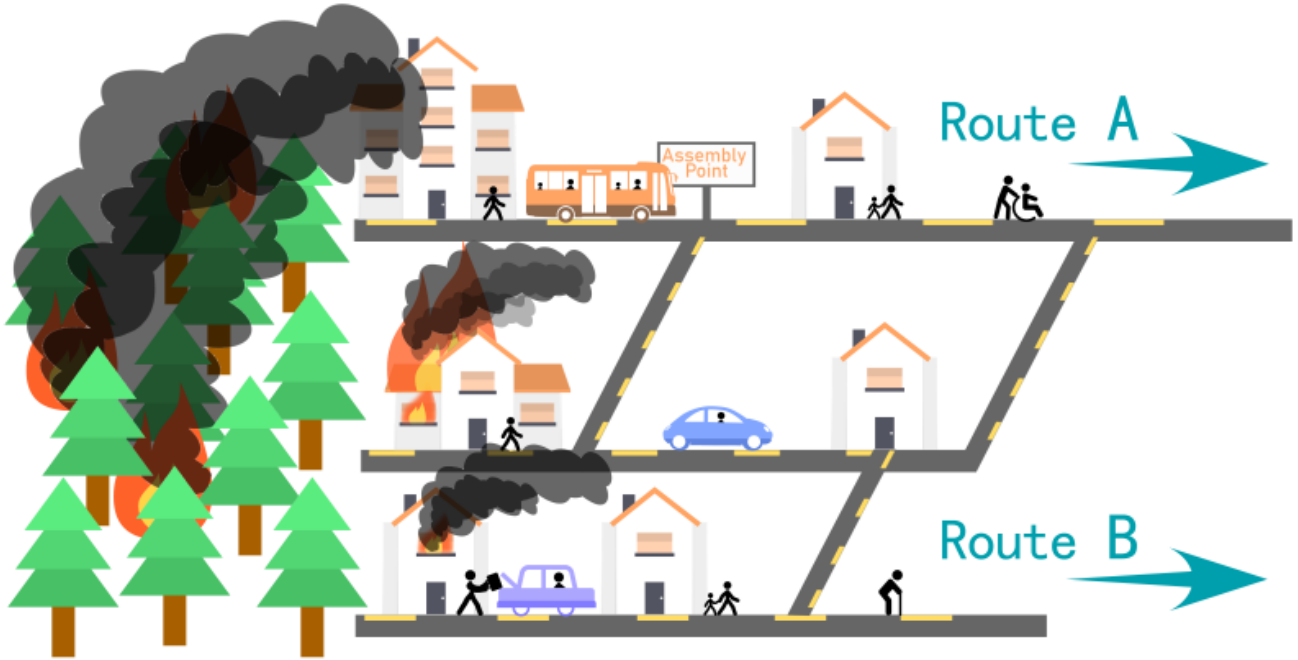
Wildfire evacuation is challenging

- **Outcomes**:
  - Delayed evacuations, esp. for vulnerable populations
  - Traffic congestions & bottlenecks
  - Inaccessible evacuation routes
  - Inadequate public assistance and shelters
  - …
- **Reasons**:
  - Lack of plans
  - Poor communications
  - Ineffective traffic control or traffic incident management
  - Insufficient preparedness
  - …
- **Pressing need:** Understanding evacuation behavior in wildfires

Insider (2019)

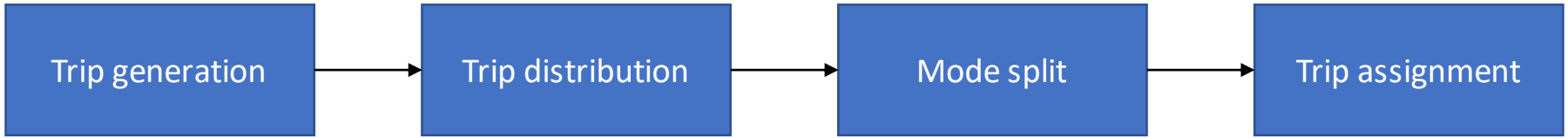
Kent Porter / The Press Democrat (2019)

Wildfires and human decision-making



Evacuation demand modeling

Four-step approach



- Evacuation Decision
- Departure Time

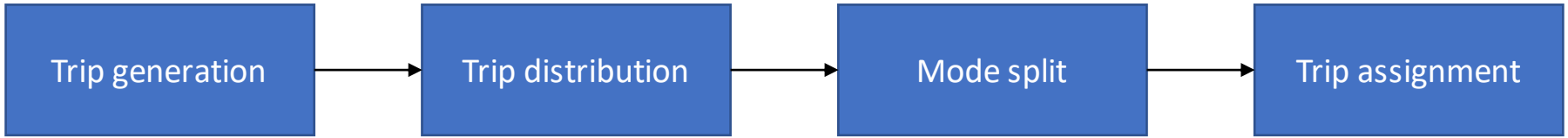
- Destination Choice

- Mode Choice

- Route Choice

Evacuation demand modeling

Four-step approach



- Evacuation Decision
- Departure Time

- Destination Choice

- Mode Choice

- Route Choice

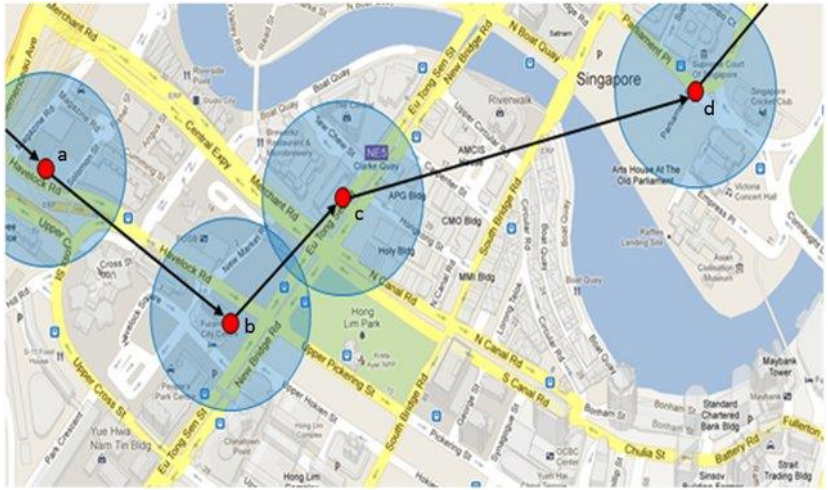
Lack of research in these areas

Data limitations: survey data

Methodological limitations: logit models

The potential of GPS data for evacuation analysis

- Low cost to collect data
- Do not rely on human memory
- Large sample size (millions of data points)
- Detailed spatiotemporal trajectory data at individual level
- Relatively low sampling bias

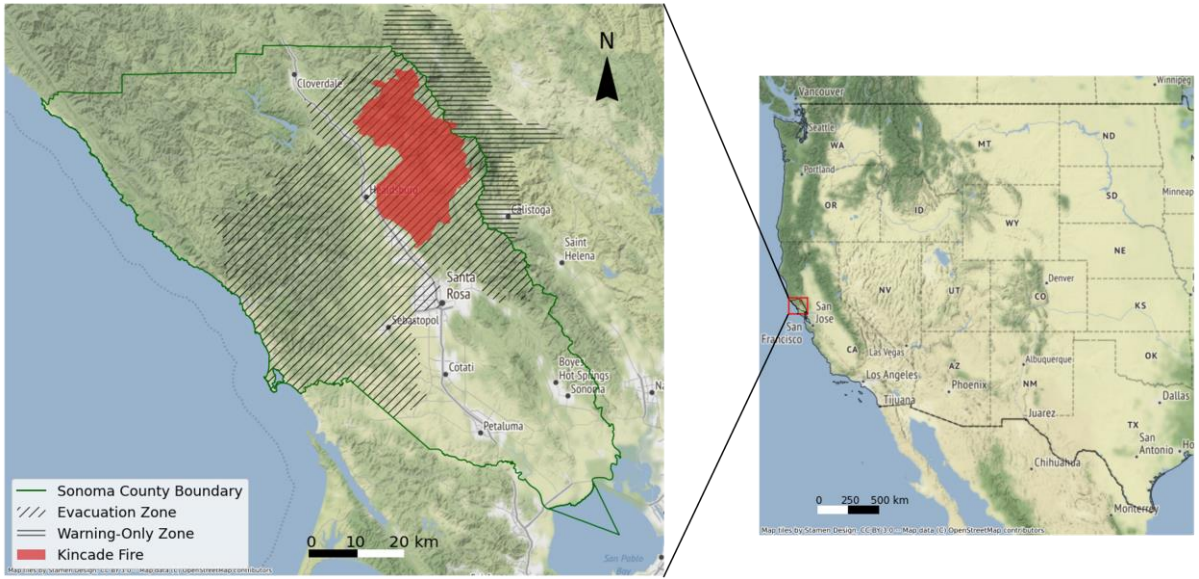


Example of a GPS trajectory (Almeida et al., 2016)

Case study of the 2019 Kincade fire

2019 Kincade fire, Sonoma County, CA:

- Started at 9:27 pm on October 23, 2019 and was fully contained at 7:00 pm on November 6, 2019.
- Burned 77,758 acres, destroyed 374 structures, damaged 60 structures, and caused 4 injuries.



Sonoma County and the Kincade Fire perimeter

Zhao, X., Xu, Y., Lovreglio, R., Kuligowski, E., Nilsson, D., Cova, T. J., ... & Yan, X. (2022). Estimating wildfire evacuation decision and departure timing using large-scale GPS data. *Transportation Research Part D: Transport and Environment*, *107*, 103277.

Data description and cleaning

- The GPS data was provided by Gravy Analytics and built on privacy-friendly mobile location data.
- After the data cleaning process, we had 100,913,550 GPS signal records.

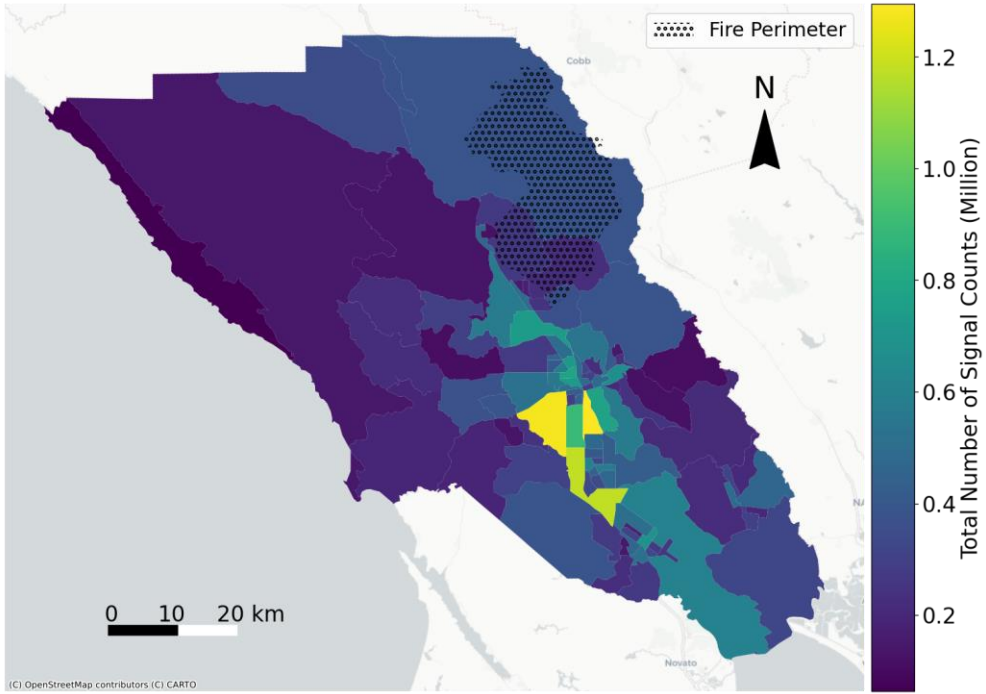
Table 1. Synthetic GPS Data Samples

ID	LATITUDE	LONGITUDE	GEOHASH9	TIMESTAMP_EPOCH	TIMEZONE	FLAG
00001	y_1	x_1	9qbd*****	15715********	TZ1	0
00002	y_2	x_2	9qbc*****	15715********	TZ1	0
00003	y_3	x_3	9qbs*****	15712********	TZ1	0
00003	y_4	x_4	9qbe*****	15726********	TZ1	0
00004	y_5	x_5	9qbd*****	15713********	TZ1	0
00004	y_6	x_6	9qbd*****	15714********	TZ1	0

Data description and cleaning

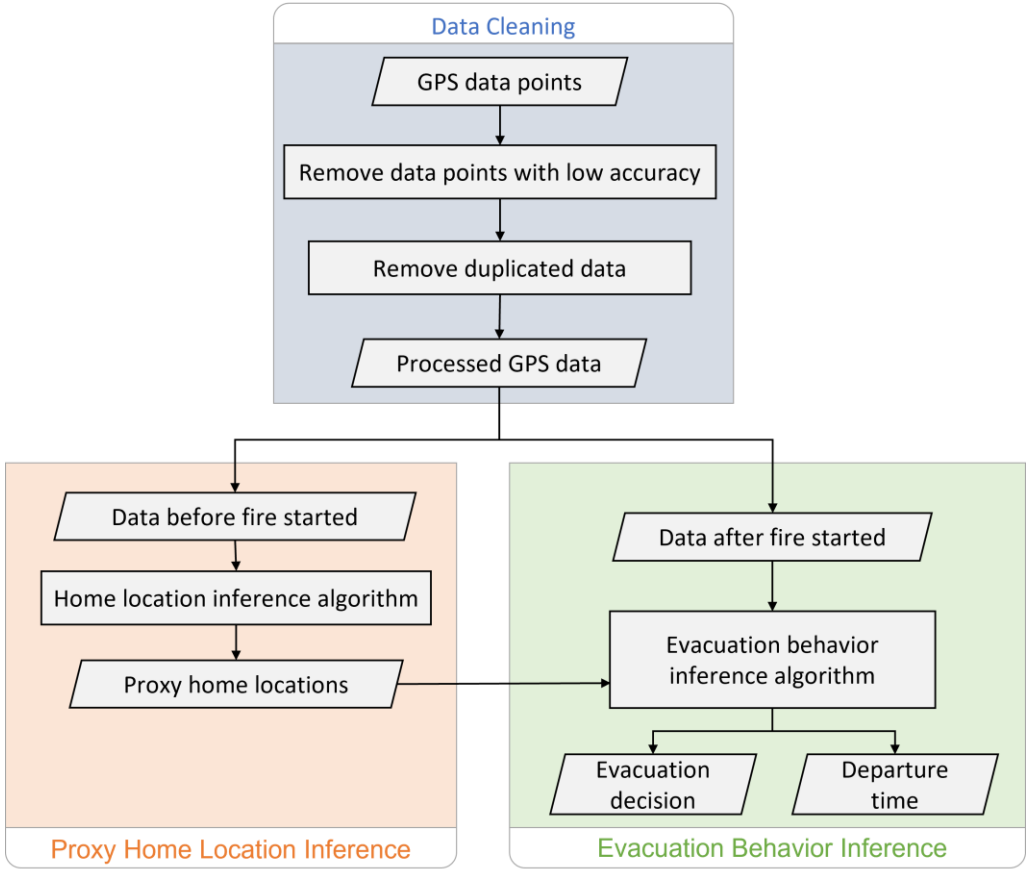
- We only used the records of daily frequent users of mobile devices in this study.

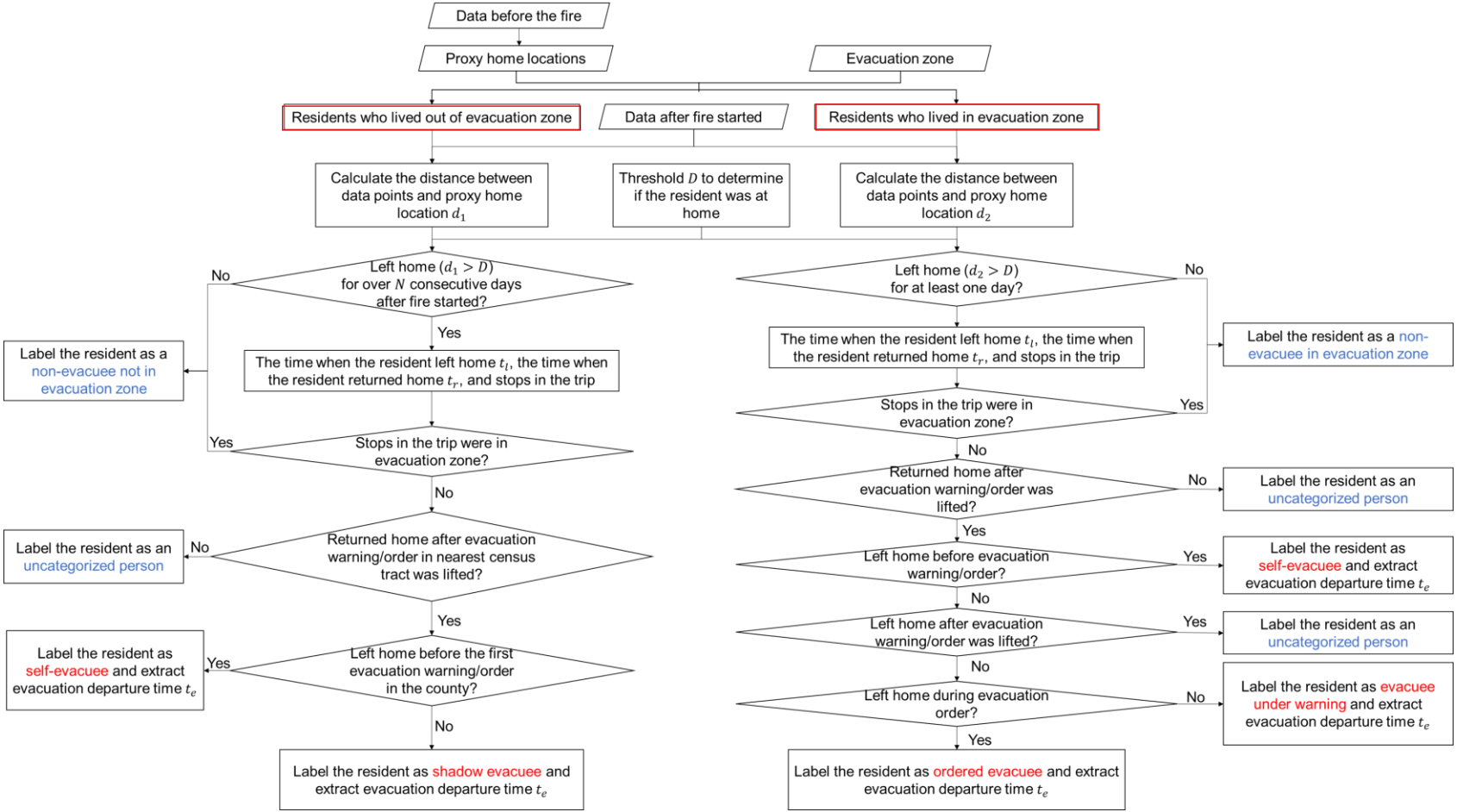
- We retained 44,211,050 records, or a total of 5,338 residents for analysis.



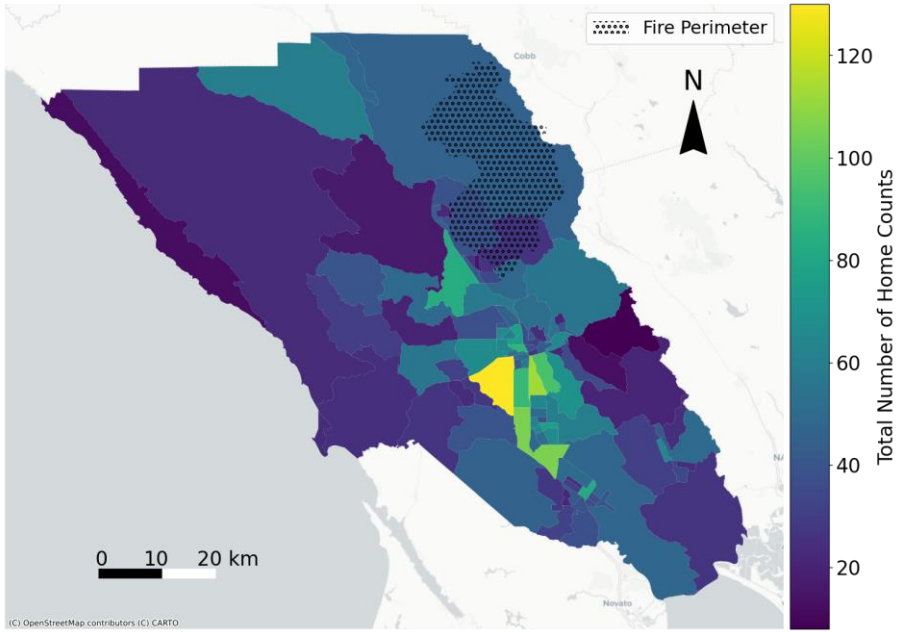
Distribution of total signal counts for residents at the census tract level

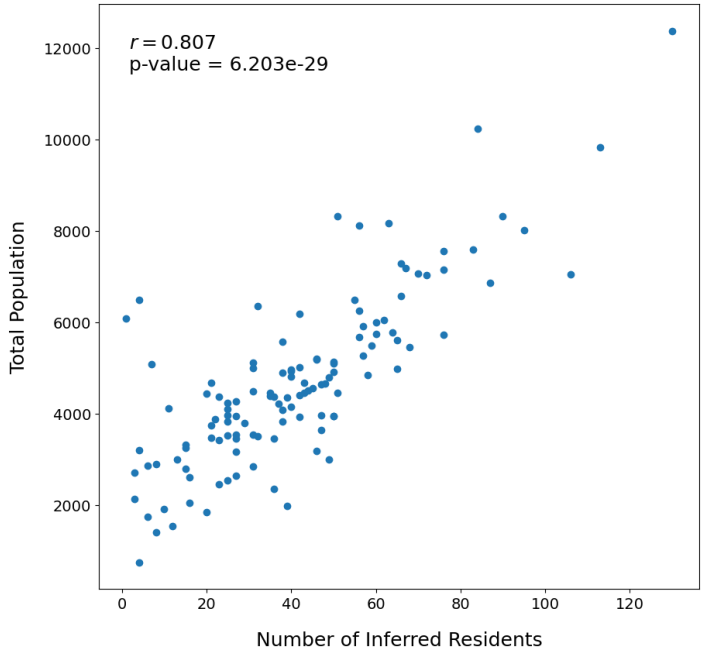
Methodological framework for evacuation decision and departure time inference



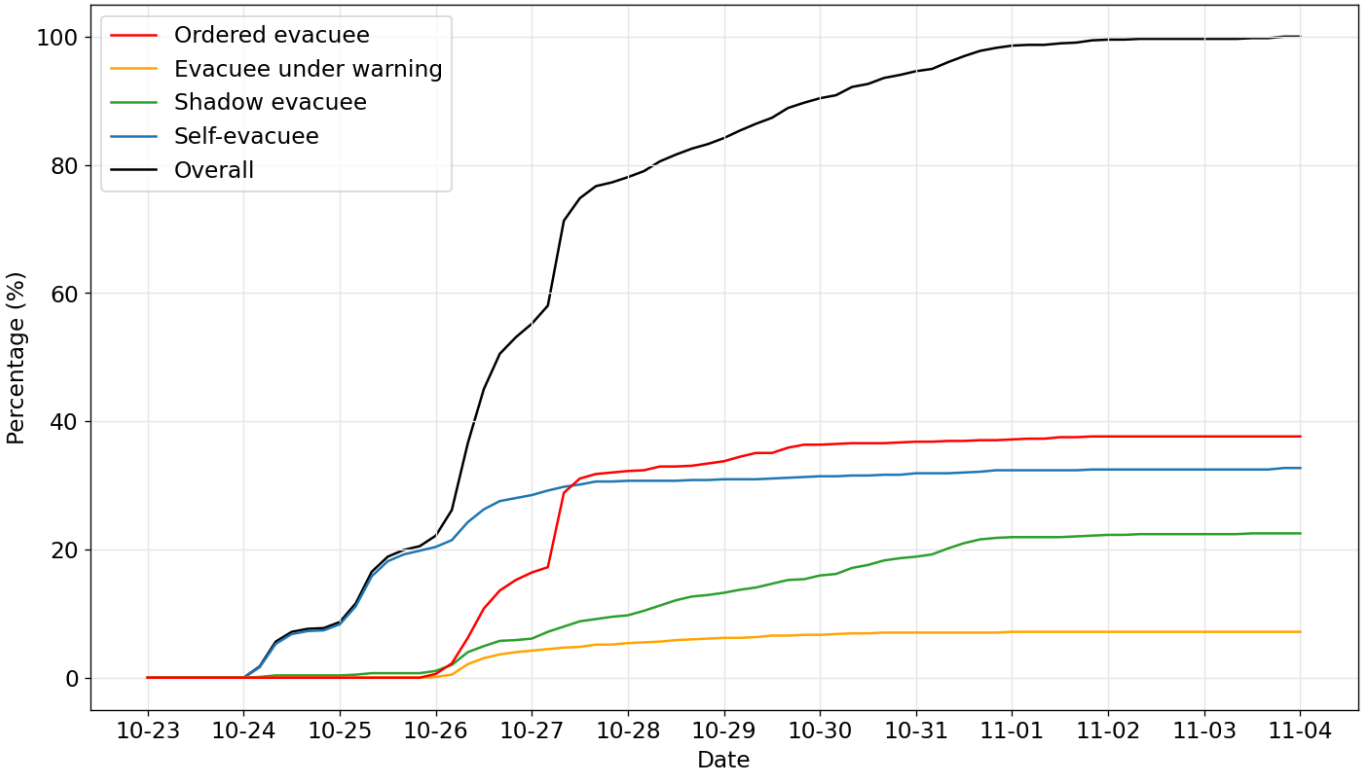

Data before the fire
Proxy home locations
Evacuation zone
Residents who lived out of evacuation zone
Data after fire started
Residents who lived in evacuation zone
Calculate the distance between data points and proxy home location d_1
Threshold D to determine if the resident was at home
Calculate the distance between data points and proxy home location d_2
Left home ($d_1 > D$) for over N consecutive days after fire started?
No
Yes
Label the resident as a non-evacuee not in evacuation zone
The time when the resident left home t_l, the time when the resident returned home t_r, and stops in the trip
Stops in the trip were in evacuation zone?
Yes
No
Label the resident as an uncategorized person
Returned home after evacuation warning/order in nearest census tract was lifted?
No
Yes
Label the resident as self-evacuee and extract evacuation departure time t_e
Left home before the first evacuation warning/order in the county?
Yes
No
Label the resident as shadow evacuee and extract evacuation departure time t_e
Left home ($d_2 > D$) for at least one day?
No
Label the resident as a non-evacuee in evacuation zone
The time when the resident left home t_l, the time when the resident returned home t_r, and stops in the trip
Stops in the trip were in evacuation zone?
Yes
No
Returned home after evacuation warning/order was lifted?
No
Label the resident as an uncategorized person
Yes
Left home before evacuation warning/order?
Yes
Label the resident as self-evacuee and extract evacuation departure time t_e
No
Left home after evacuation warning/order was lifted?
Yes
Label the resident as an uncategorized person
No
Left home during evacuation order?
No
Label the resident as evacuee under warning and extract evacuation departure time t_e
Yes
Label the resident as ordered evacuee and extract evacuation departure time t_e

Home location inference results

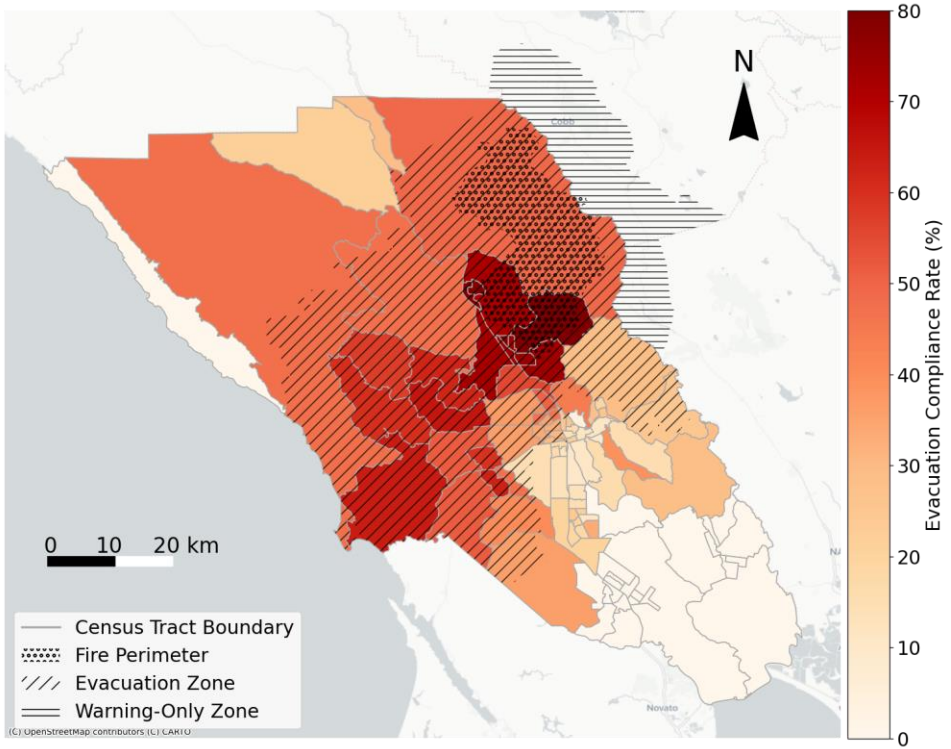




Temporal patterns of departure times



Spatial patterns of evacuation compliance



GPS data: 46% evacuated versus
Survey data: 80% evacuated

Why?

What's the true compliance rate?

Kuligowski, E. D., Zhao, X., Lovreglio, R., Xu, N., Yang, K., Westbury, A., … & Brown, N. (2022). Modeling evacuation decisions in the 2019 Kincade fire in California. *Safety Science*, *146*, 105541.

Comparison between Survey and GPS data

	Strengths	Limitations
GPS Data	• Relatively low cost to collect data • Do not rely on human memory • Large sample size • Spatiotemporal trajectories at individual level • Relatively low sampling bias	• Lack individual-level data on socio-demographics, attitudes, perceptions, etc. • Need to specify parameter values of inference algorithms • Inability to conduct individual-level causal analysis (only associations)
Survey Data	• Detailed data on individuals' socio-demographics, attitudes, perceptions, etc. • Ability to conduct individual-level causal analysis	• Hard to collect data on departure timing, evacuation routing, etc. • Small sample size • Sampling bias (esp. reporting bias) • Rely on human memory

Key take-aways

- Understanding wildfire evacuation decision-making is critical.
- GPS data has a high potential to improve knowledge of wildfire evacuation behavior.
- GPS data and survey data are complementary and should be integrated to form a comprehensive understanding of human behavior in wildfires.

Acknowledgement

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Thank you for your attention!

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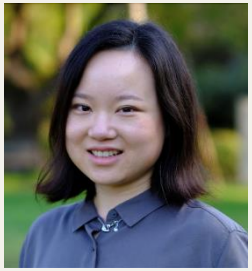
Today's presenters



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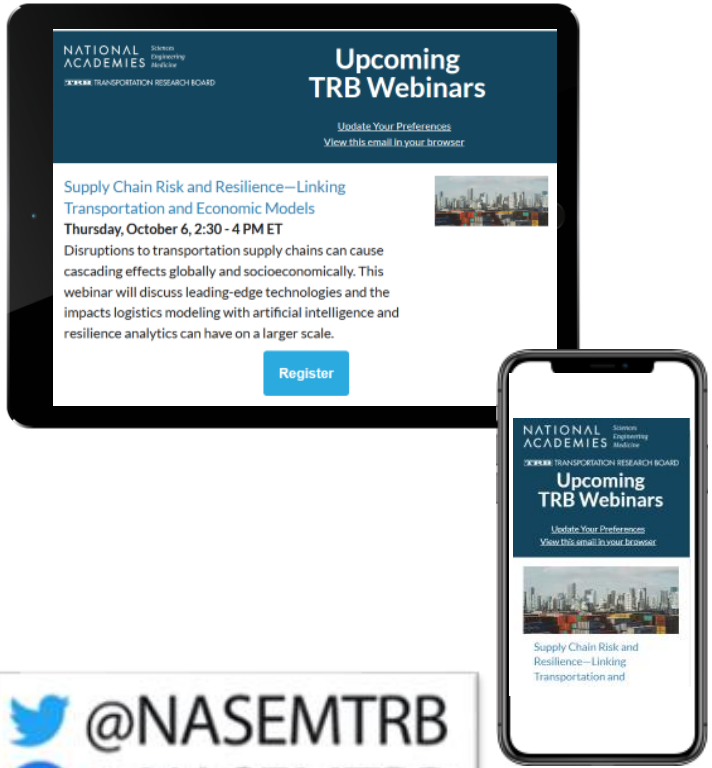

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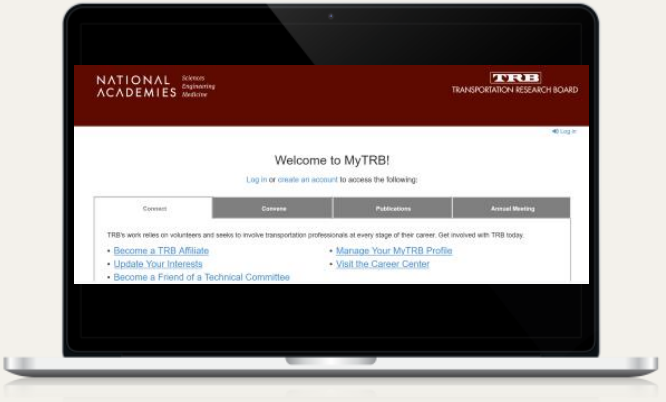

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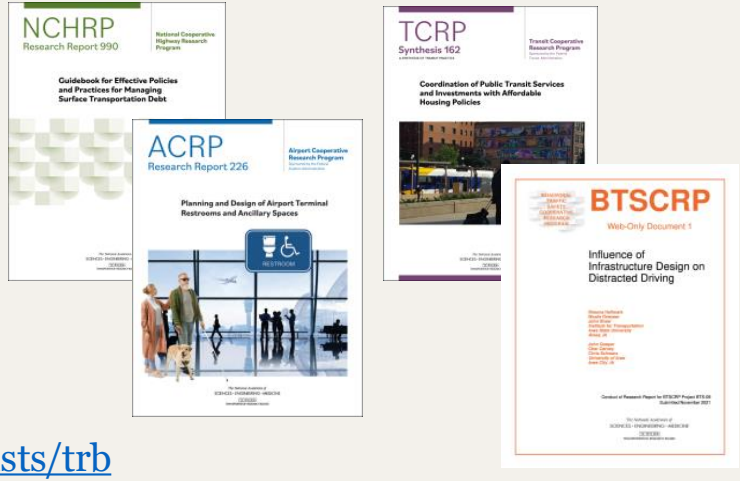

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