Coupling fire and traffic simulation models to set wildfire evacuation triggers

Dapeng Li, Ph.D.
Department of Geography, South Dakota State University
Email: dapeng.li@sdstate.edu
Thomas J. Cova, Ph.D.
Philip E. Dennison, Ph.D.
Department of Geography, University of Utah

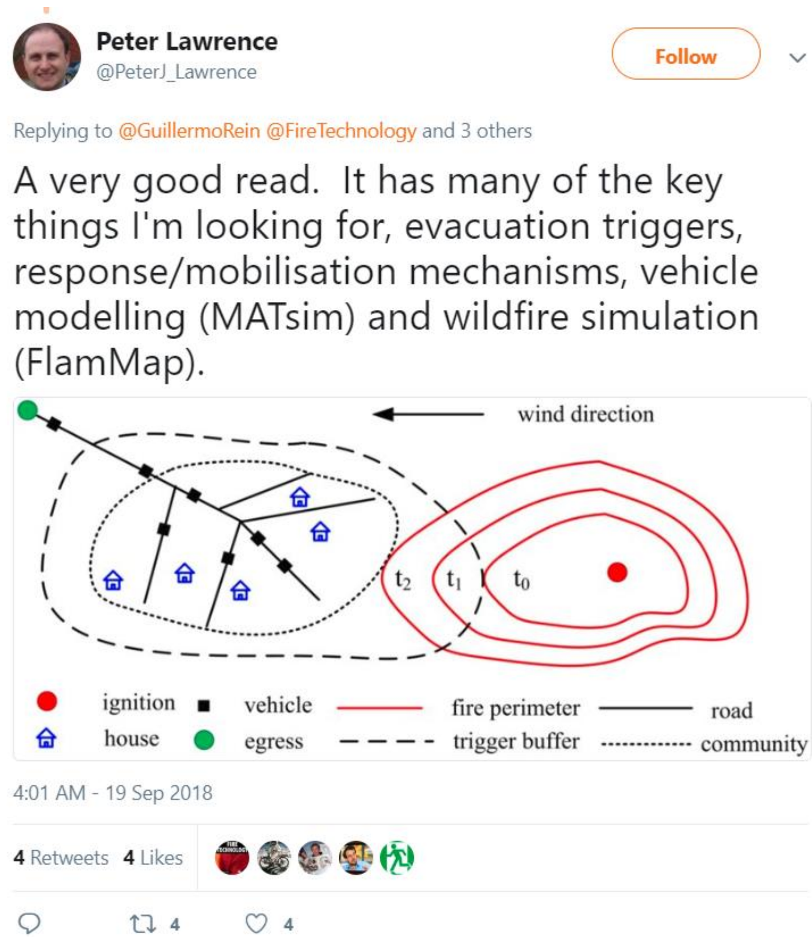
South Dakota State University

JACKRABBITS
SOUTH DAKOTA STATE UNIVERSITY

Outline

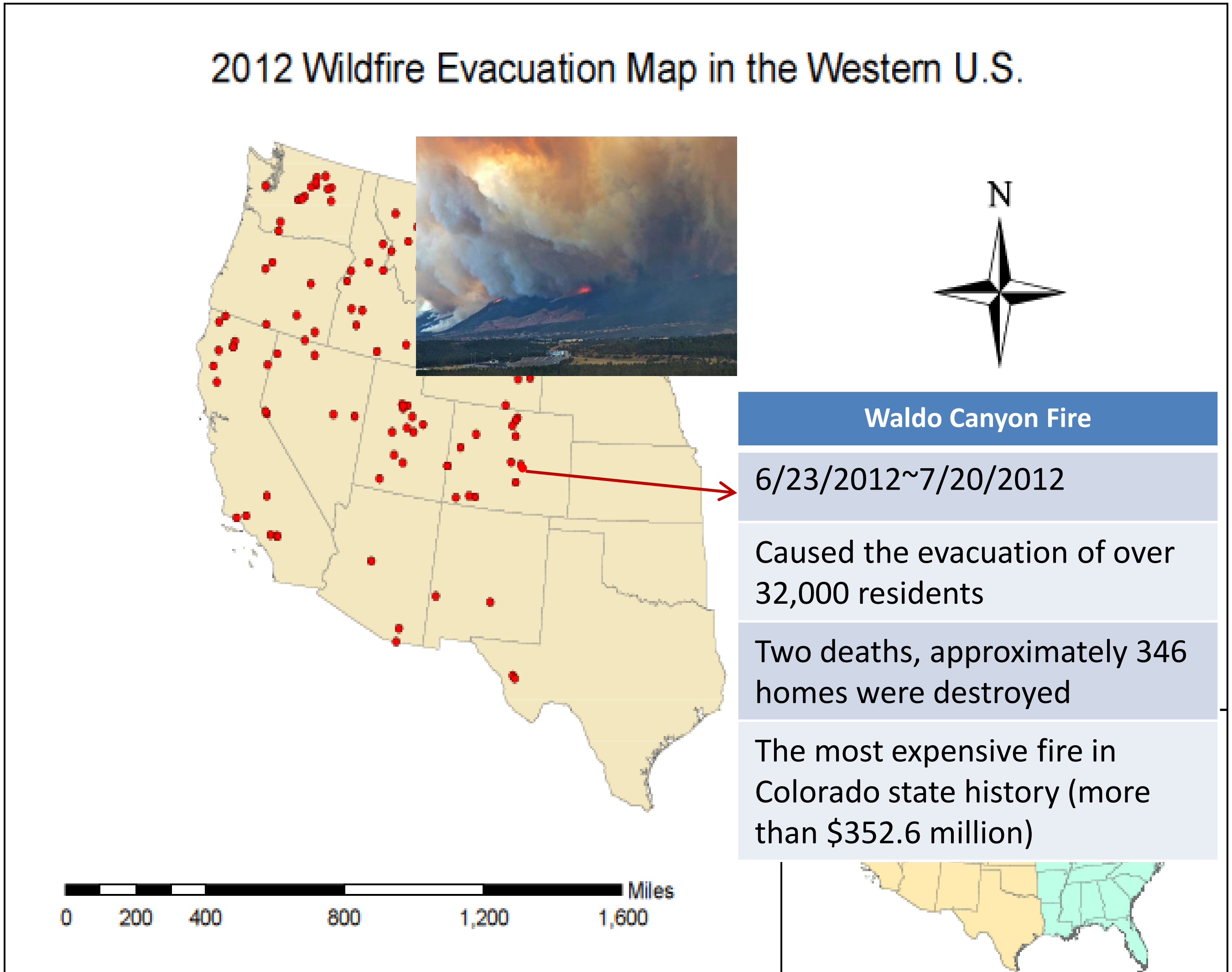
- Introduction to wildfire evacuation
- A review of wildfire evacuation modeling
- System coupling in wildfire evacuation modeling
  - Coupling wildfire spread and traffic simulation models to improve evacuation timing and warning (Li, Cova, & Dennison, in press)
- Ongoing and future work

Setting Wildfire Evacuation Triggers by Coupling Fire and Traffic Simulation Models: A Spatiotemporal GIS Approach



Li, D., Cova, T.J. & Dennison, P.E . (2018). *Fire Technology*. https://doi.org/10.1007/s10694-018-0771-6

Wildfire evacuation in the western U.S.



Top 20 Most Destructive California Wildfires

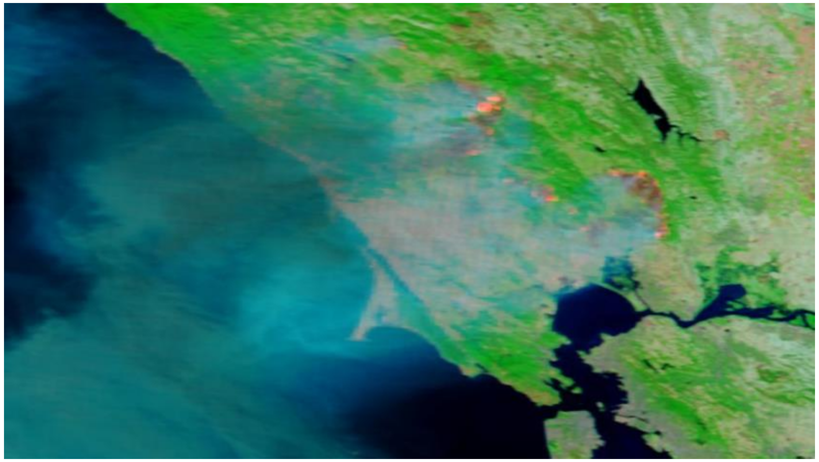
	FIRE NAME *(CAUSE)*	DATE	COUNTY	ACRES	*STRUCTURES*	DEATHS
1	**TUBBS** *(Under Investigation)*	October 2017	Sonoma	36,807	**5,643**	22
2	**TUNNEL - Oakland Hills** *(Rekindle)*	October 1991	Alameda	1,600	**2,900**	25
3	**CEDAR** *(Human Related)*	October 2003	San Diego	273,246	**2,820**	15
4	**VALLEY** *(Electrical)*	September 2015	Lake, Napa & Sonoma	76,067	**1,955**	4
5	**WITCH** *(Powerlines)*	October 2007	San Diego	197,990	**1,650**	2
6	**NUNS** *(Under Investigation)*	October 2017	Sonoma	54,382	**1,355**	2
7	**THOMAS** *(Under Investigation)*	December 2017	Ventura & Santa Barbara	281,893	**1,063**	1
8	**OLD** *(Human Related)*	October 2003	San Bernardino	91,281	**1,003**	6
9	**JONES** *(Undetermined)*	October 1999	Shasta	26,200	**954**	1
10	**BUTTE** *(Powerlines)*	September 2015	Amador & Calaveras	70,868	**921**	2
11	**ATLAS** *(Under Investigation)*	October 2017	Napa & Solano	51,624	**781**	6
12	**PAINT** *(Arson)*	June 1990	Santa Barbara	4,900	**641**	1
13	**FOUNTAIN** *(Arson)*	August 1992	Shasta	63,960	**636**	0
14	**SAYRE** *(Misc.)*	November 2008	Los Angeles	11,262	**604**	0
15	**CITY OF BERKELEY** *(Powerlines)*	September 1923	Alameda	130	**584**	0
16	**HARRIS** *(Under Investigation)*	October 2007	San Diego	90,440	**548**	8
17	**REDWOOD VALLEY** *(Under Investigation)*	October 2017	Mendocino	36,523	**544**	9
18	**BEL AIR** *(Undetermined)*	November 1961	Los Angeles	6,090	**484**	0
19	**LAGUNA** *(Arson)*	October 1993	Orange	14,437	**441**	0
20	**ERSKINE** *(Under Investigation)*	June 2016	Kern	46,684	**386**	2

**"Structures" include homes, outbuildings (barns, garages, sheds, etc) and commercial properties destroyed.
***This list does not include fire jurisdiction. These are the Top 20 regardless of whether they were state, federal, or local responsibility.

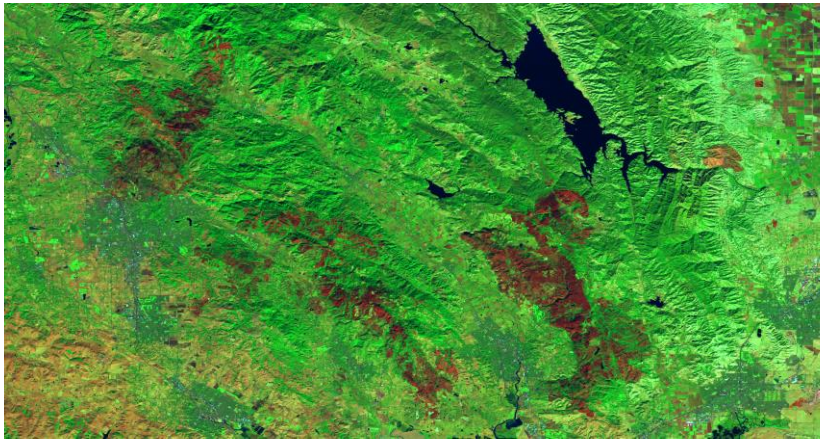
1/12/2018

The Tubbs Fire

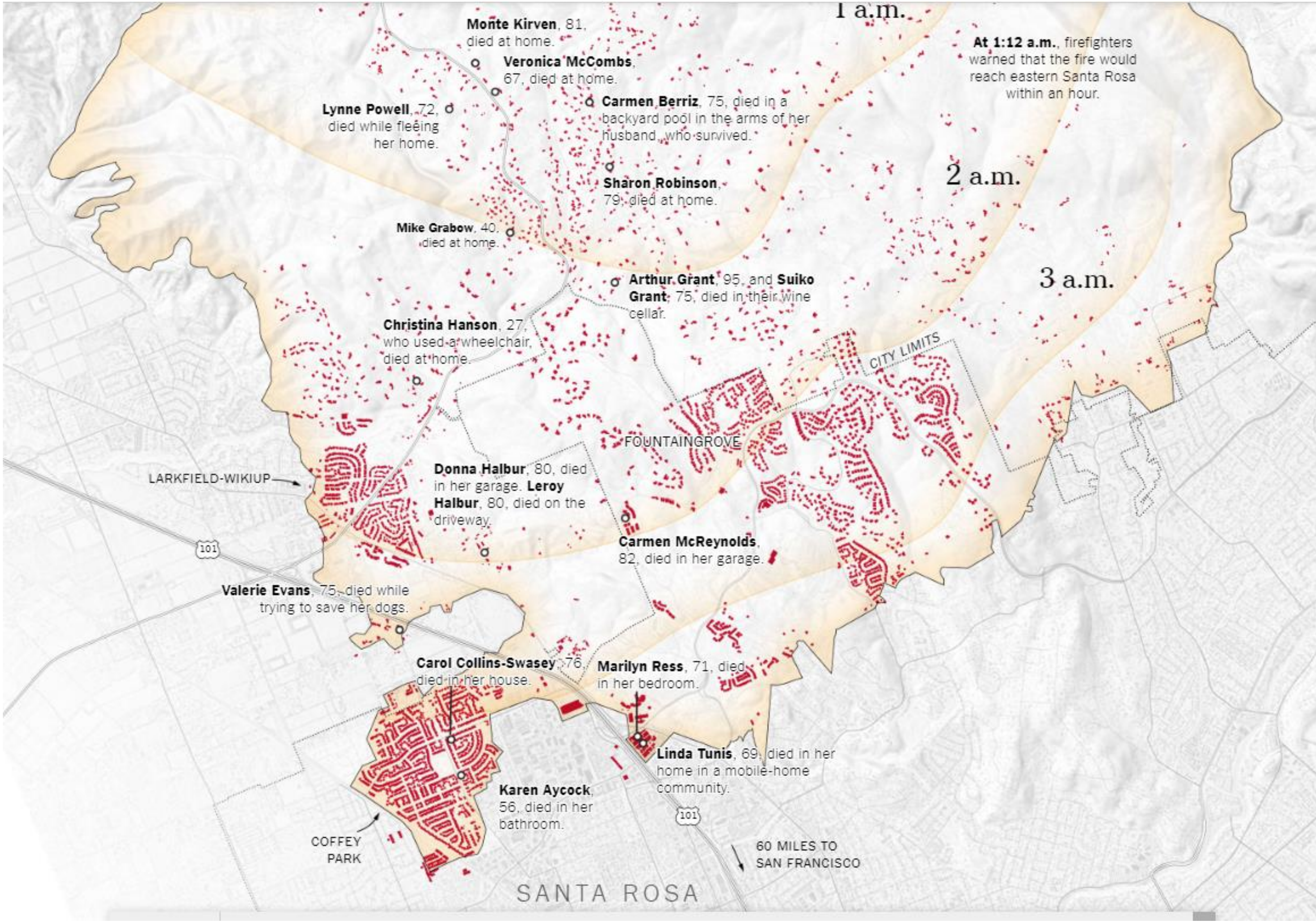
- Oct. 8 – 31, 2017
- The most destructive wildfire in California history
  - 5,100+ structures
  - 22 deaths



October 9, 2017, MODIS



November 2017, Napa, Sonoma fires, Landsat 8, bands 753

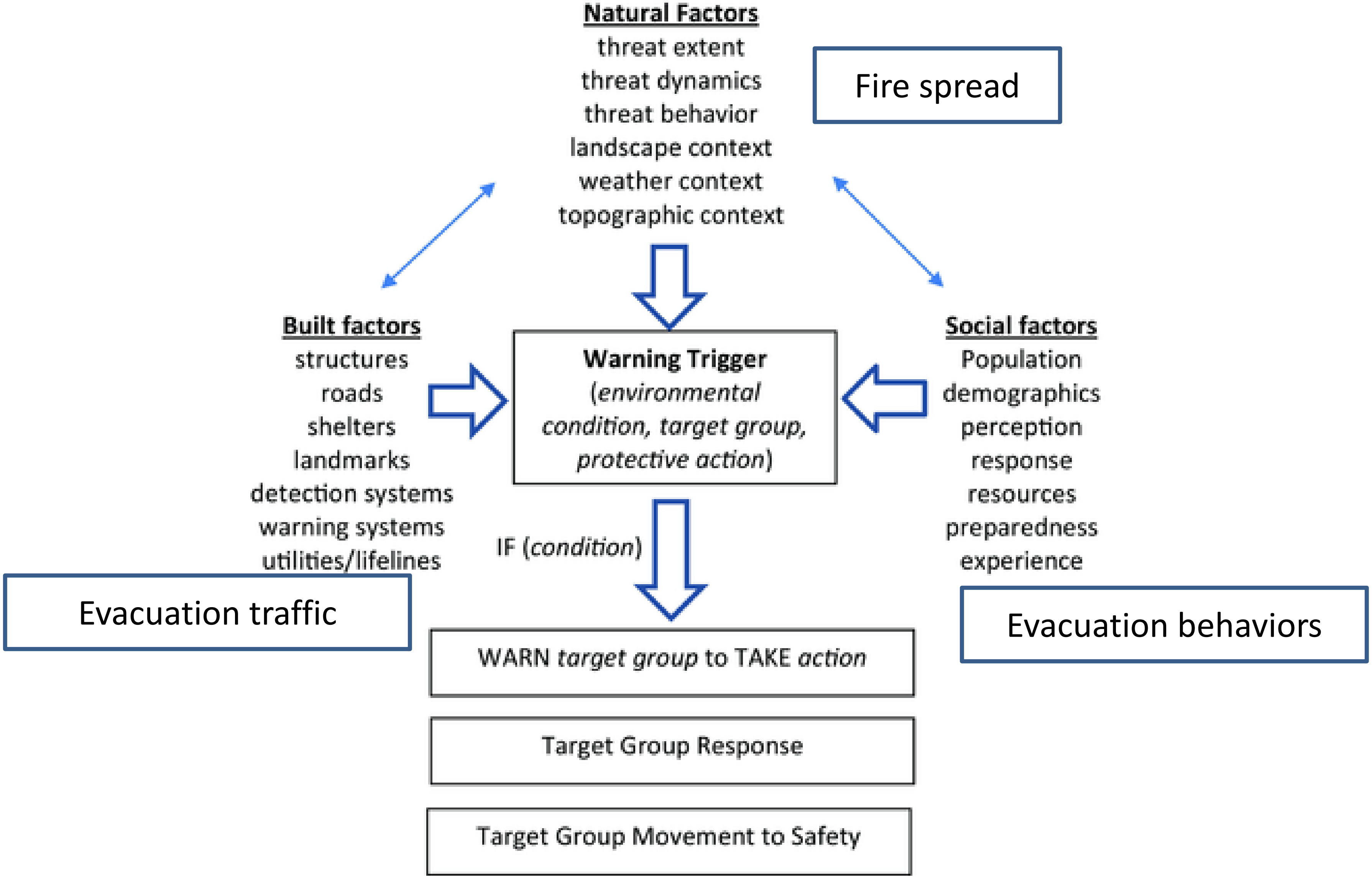


https://www.nytimes.com/interactive/2017/10/21/us/california-fire-damage-map.html

Wildfire evacuation modeling

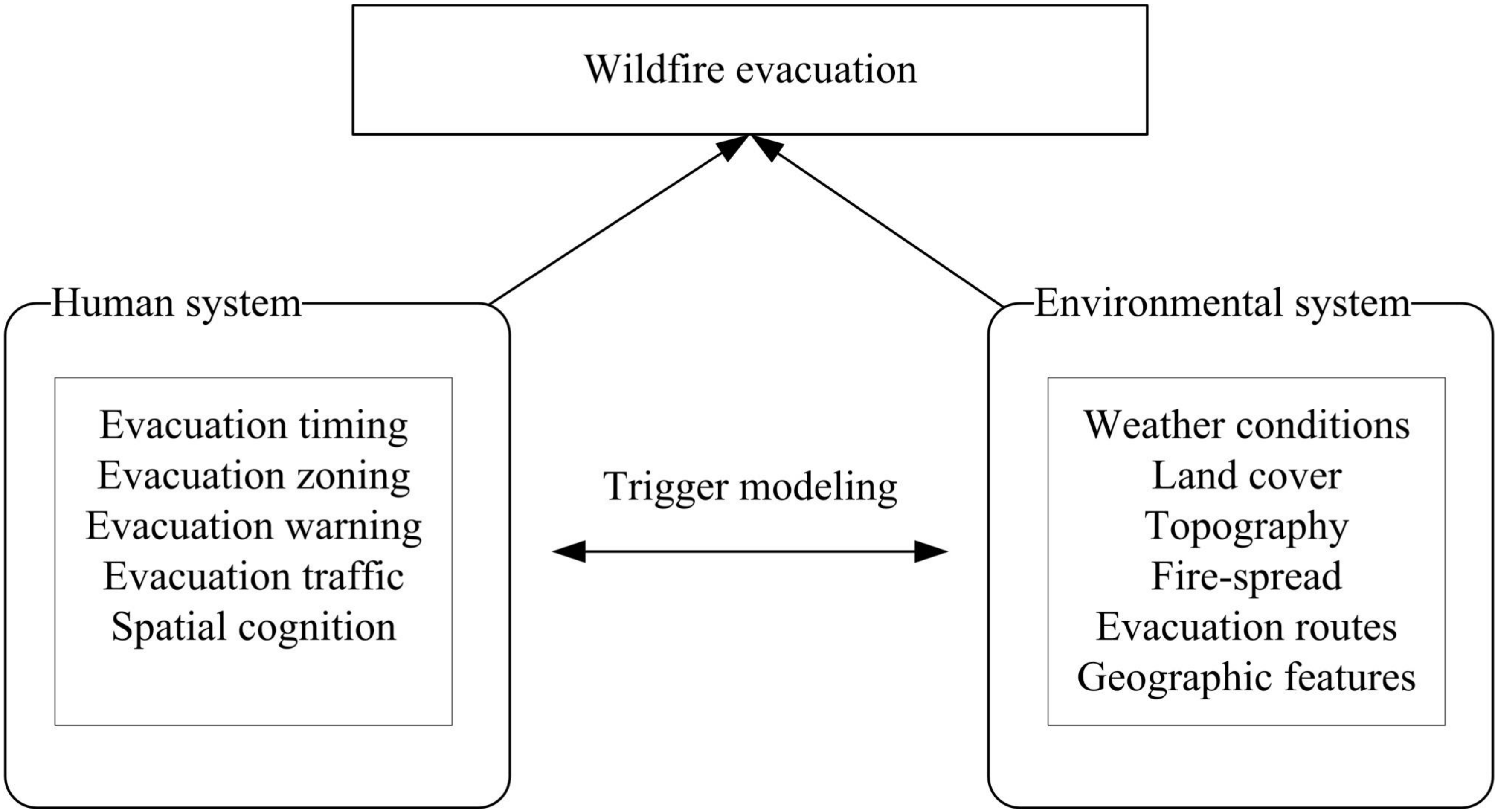
- Evacuation traffic simulation (Southworth, 1991)
- Wildfire evacuation traffic simulation (Cova & Johnson, 2002)
- Recent trends
  - System coupling (Beloglazov et al., 2016; Cova et al., 2017)
  - Interdisciplinary collaboration (Trainor et al., 2012)

Triggers in environmental hazards

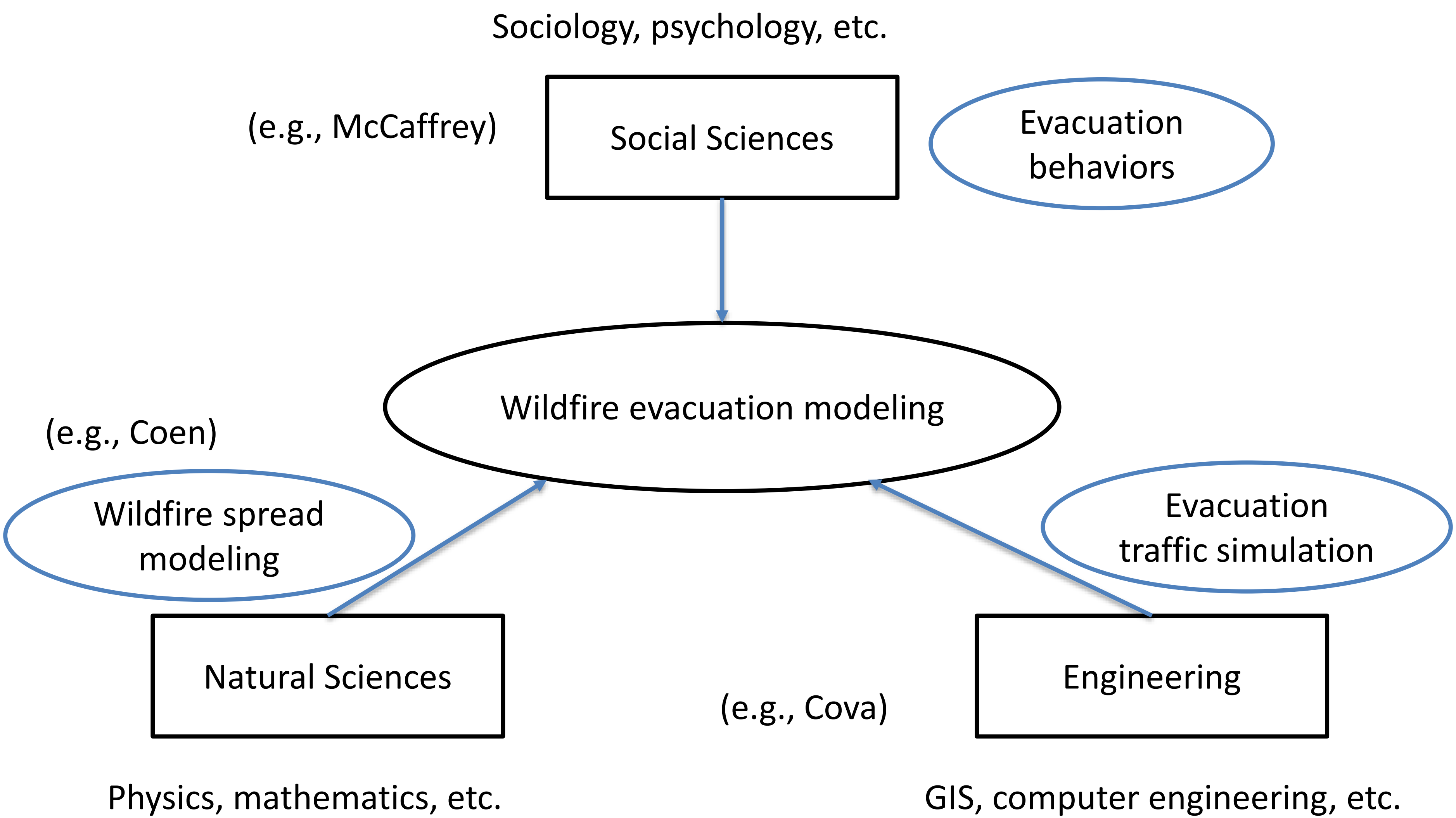


(Cova et al., 2017)

System coupling in wildfire evacuation



Interdisciplinary collaboration



Trigger modeling

- Wildfire evacuation trigger-points (Cova et al., 2005)
- Wildfire evacuation trigger modeling

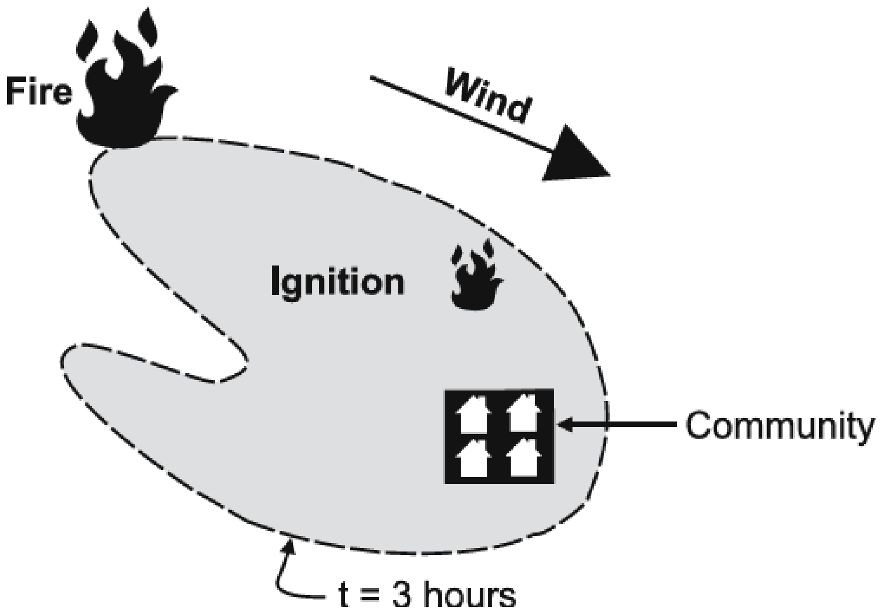
Trigger modeling

➢Fire spread

➢Evacuation timing

➢Evacuation warning

➢Communication

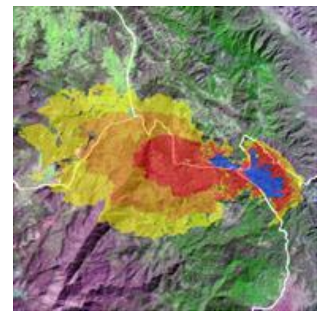


(Dennison et al., 2007)

System coupling in wildfire evacuation modeling

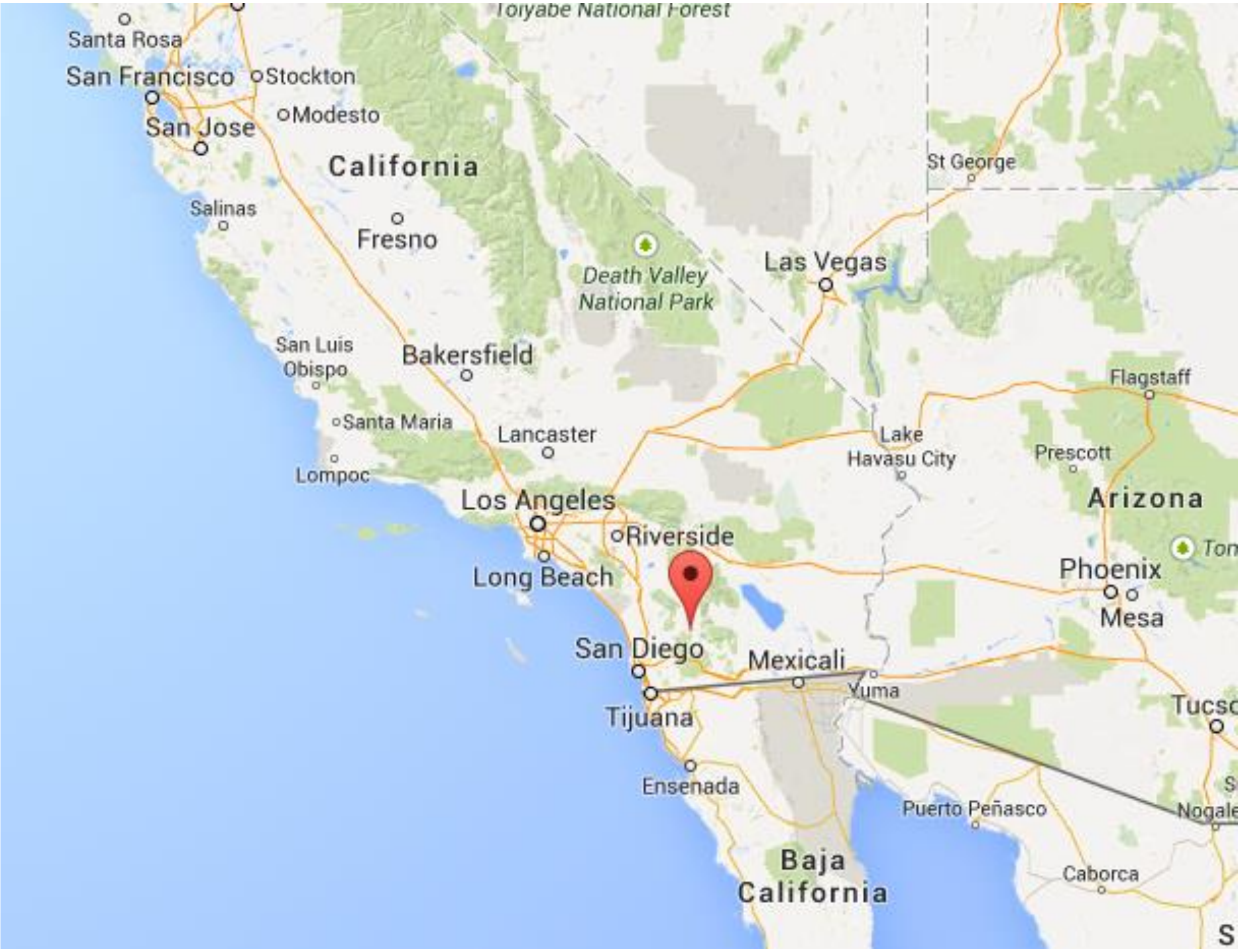
Evacuation traffic

Fire spread

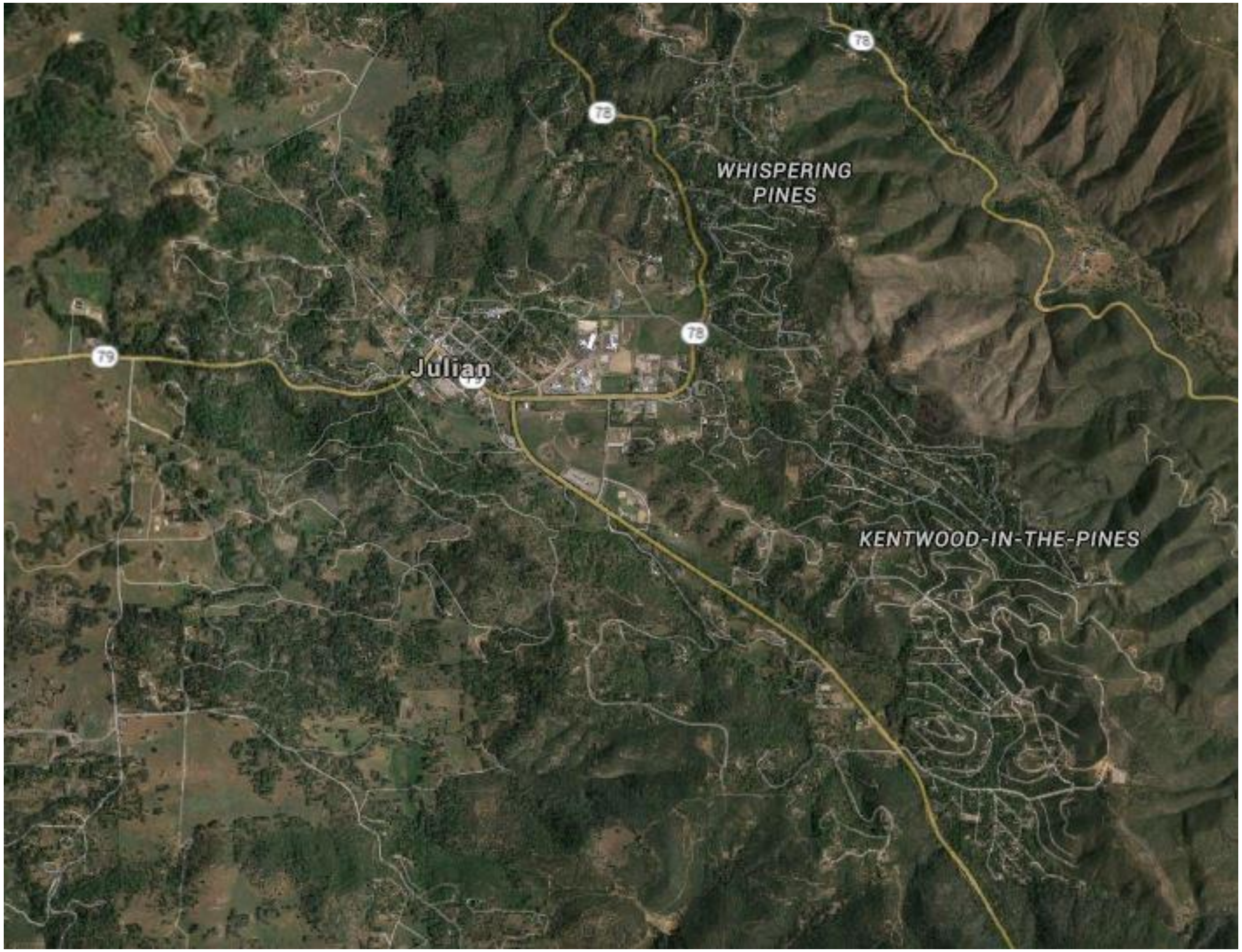


Evacuation timing and warning

Study site: Julian, California

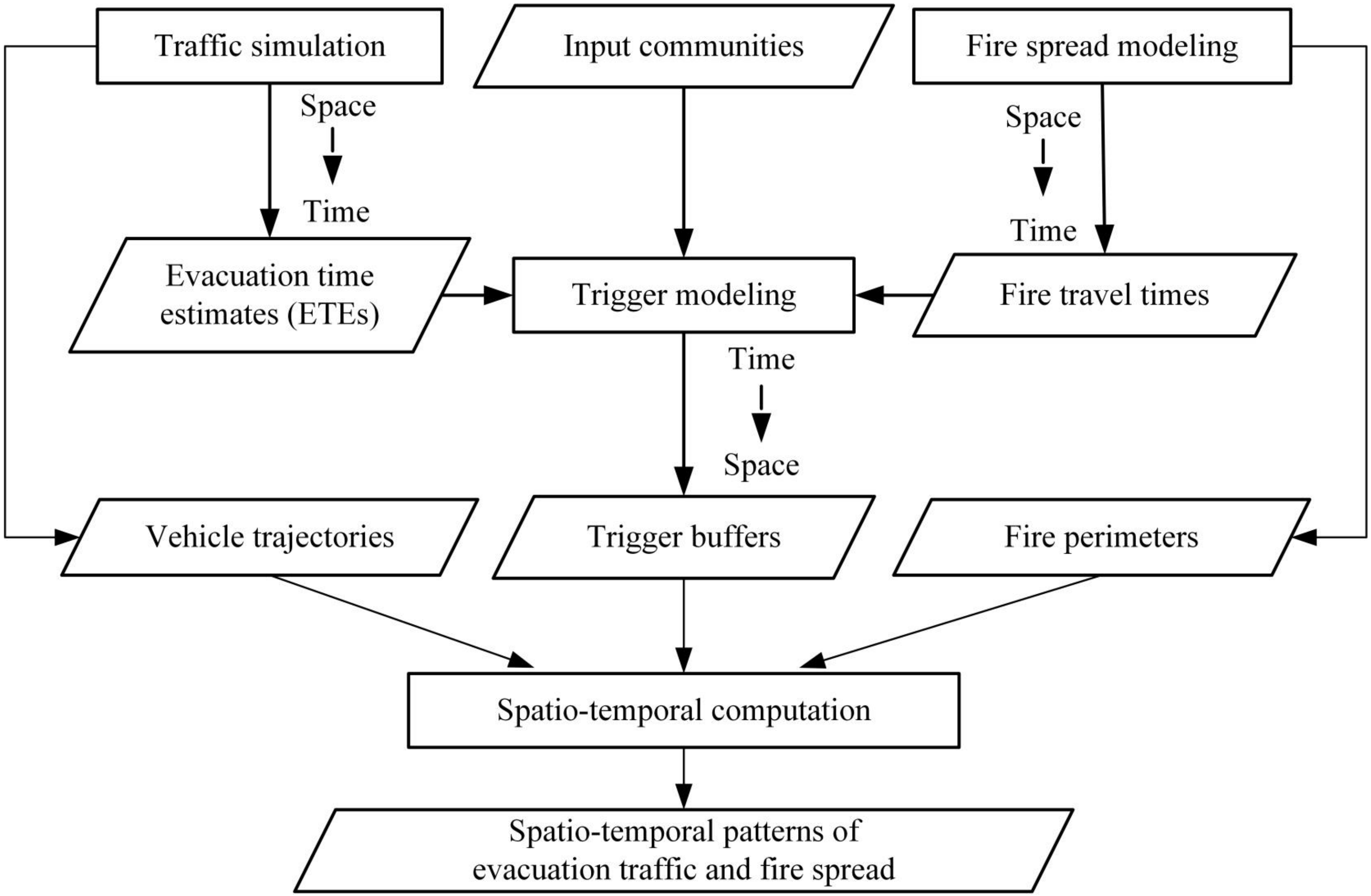


Study site: Julian, California



Pictures taken by Dapeng Li on 8/9/2015 in Julian, California

Setting wildfire evacuation triggers by coupling fire and traffic simulation models



(Li, Cova, & Dennison, in press)

Step 1: estimate evacuation times using traffic simulation

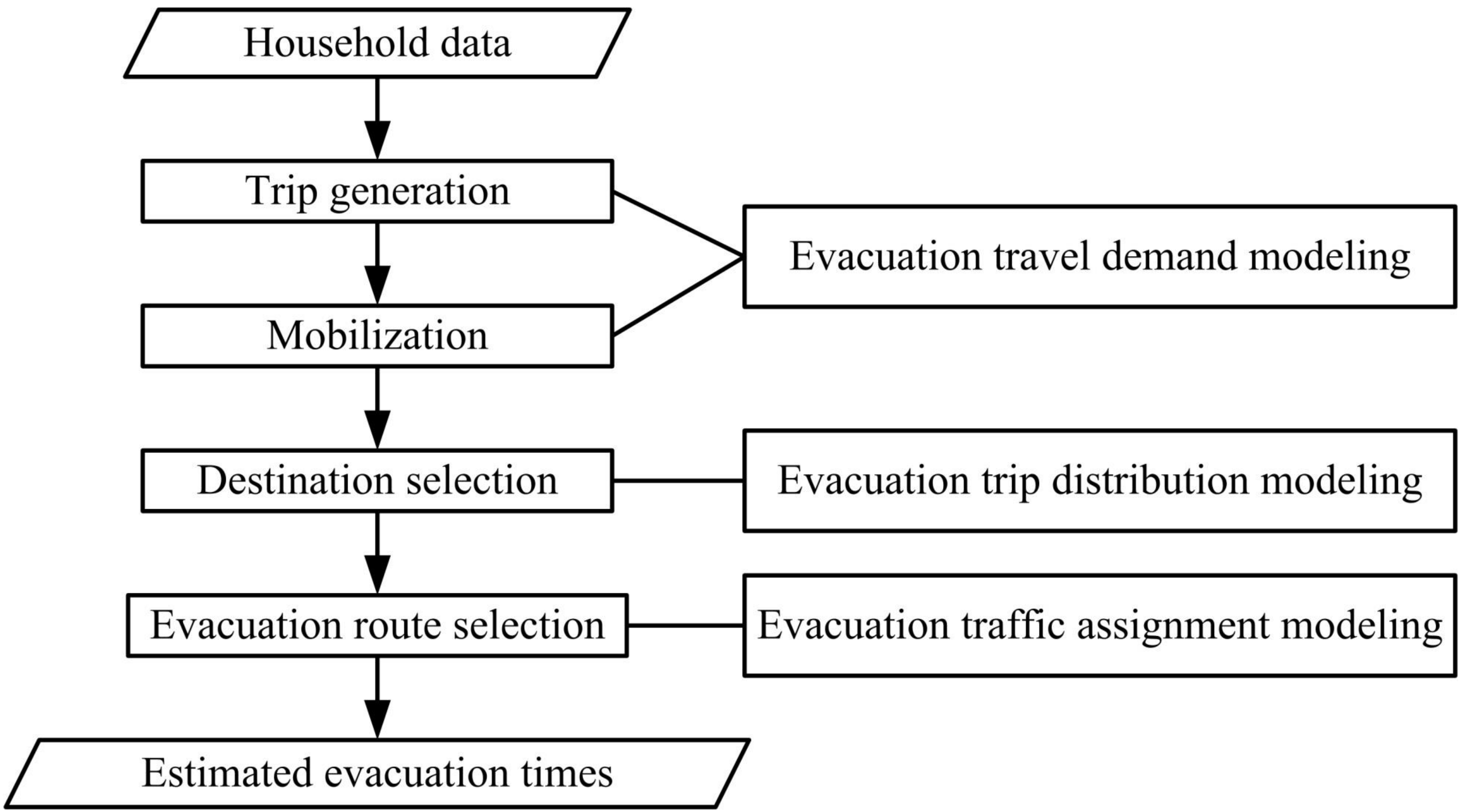
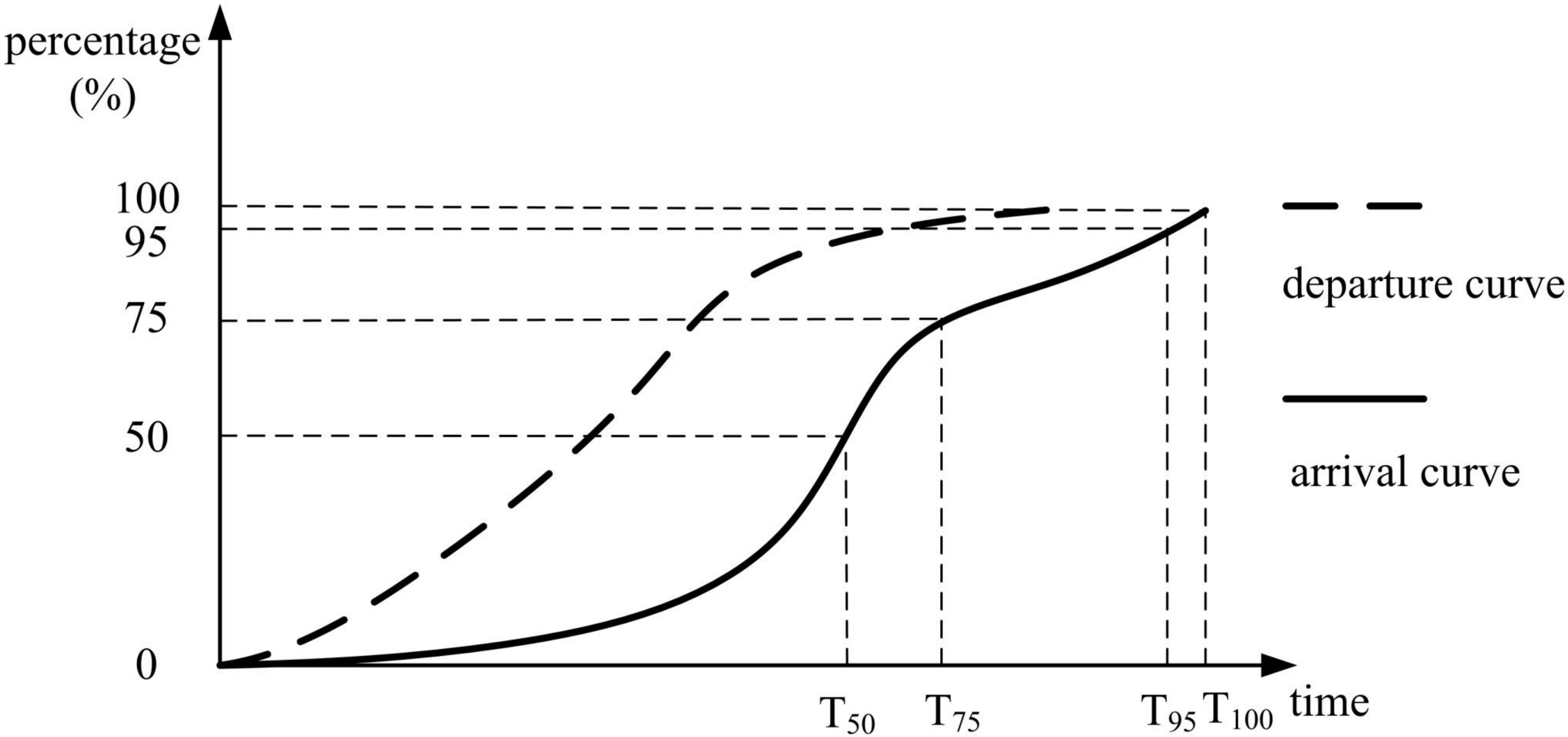


Illustration of the four estimated evacuation times



Step 2: create probability-based trigger buffers

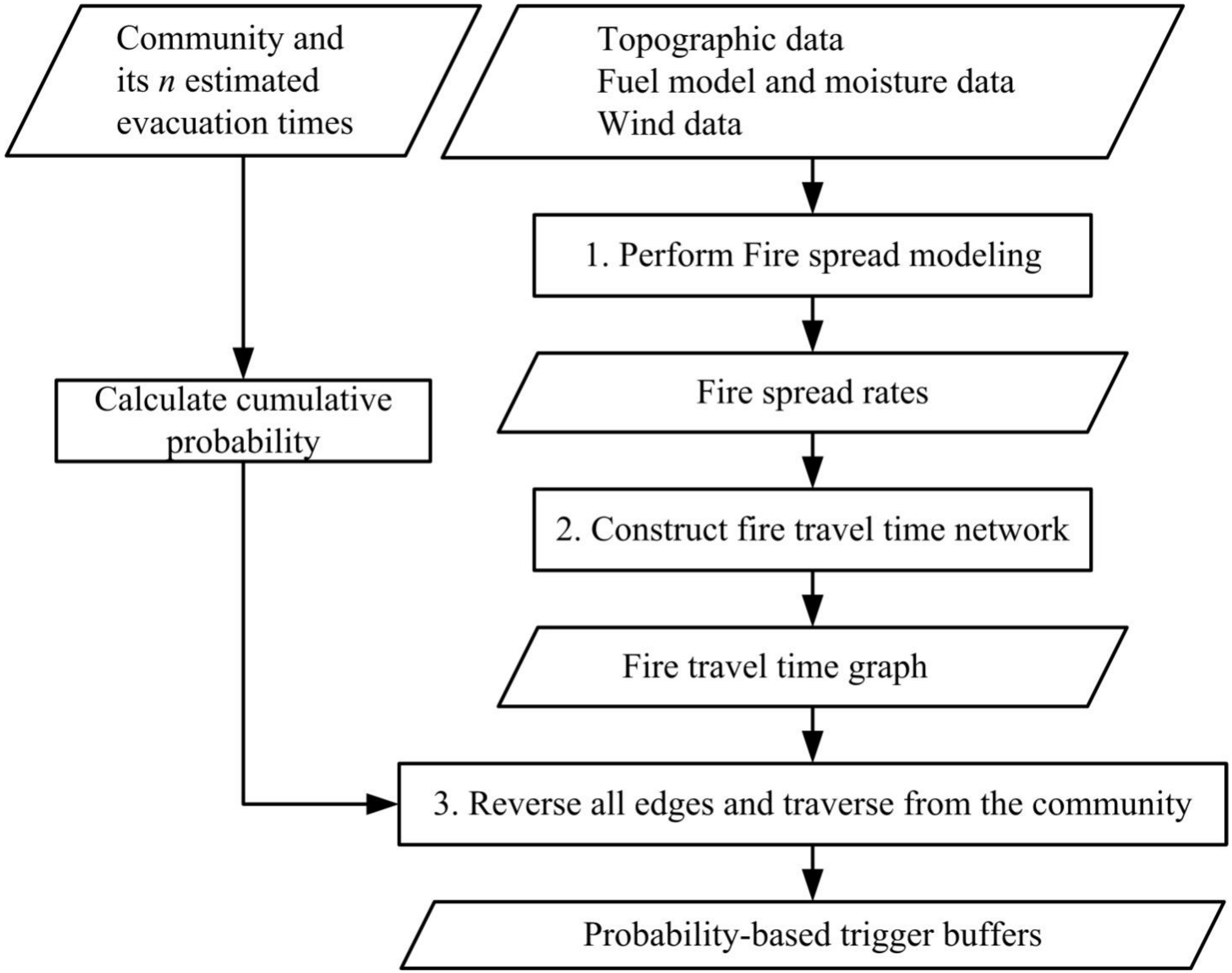
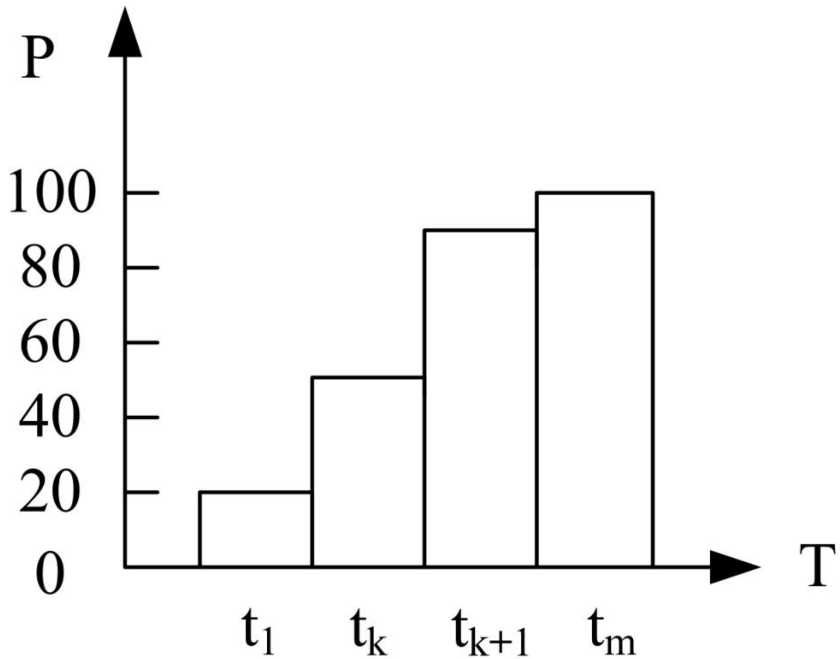
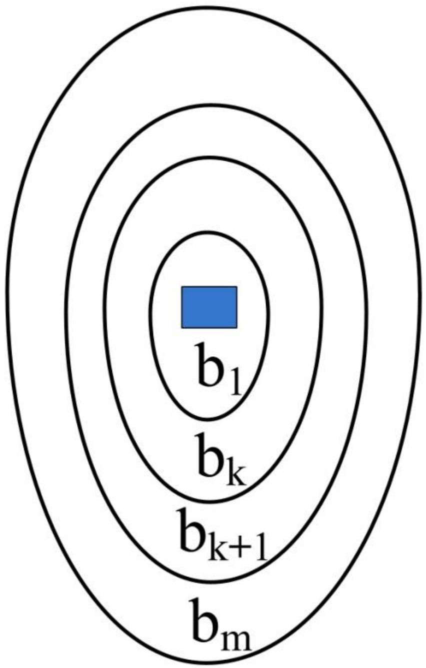


Illustration of probability-based trigger buffers

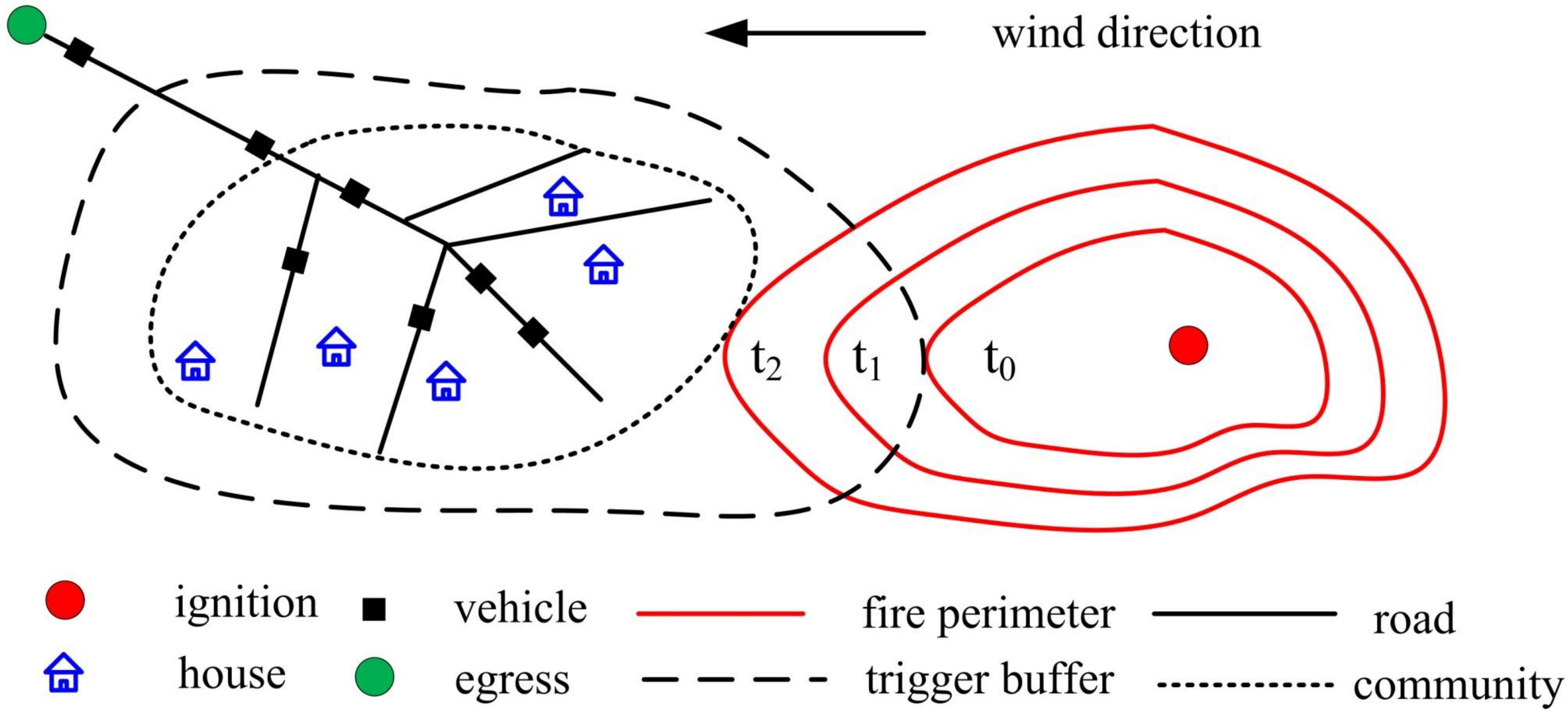


(a) Cumulative probability



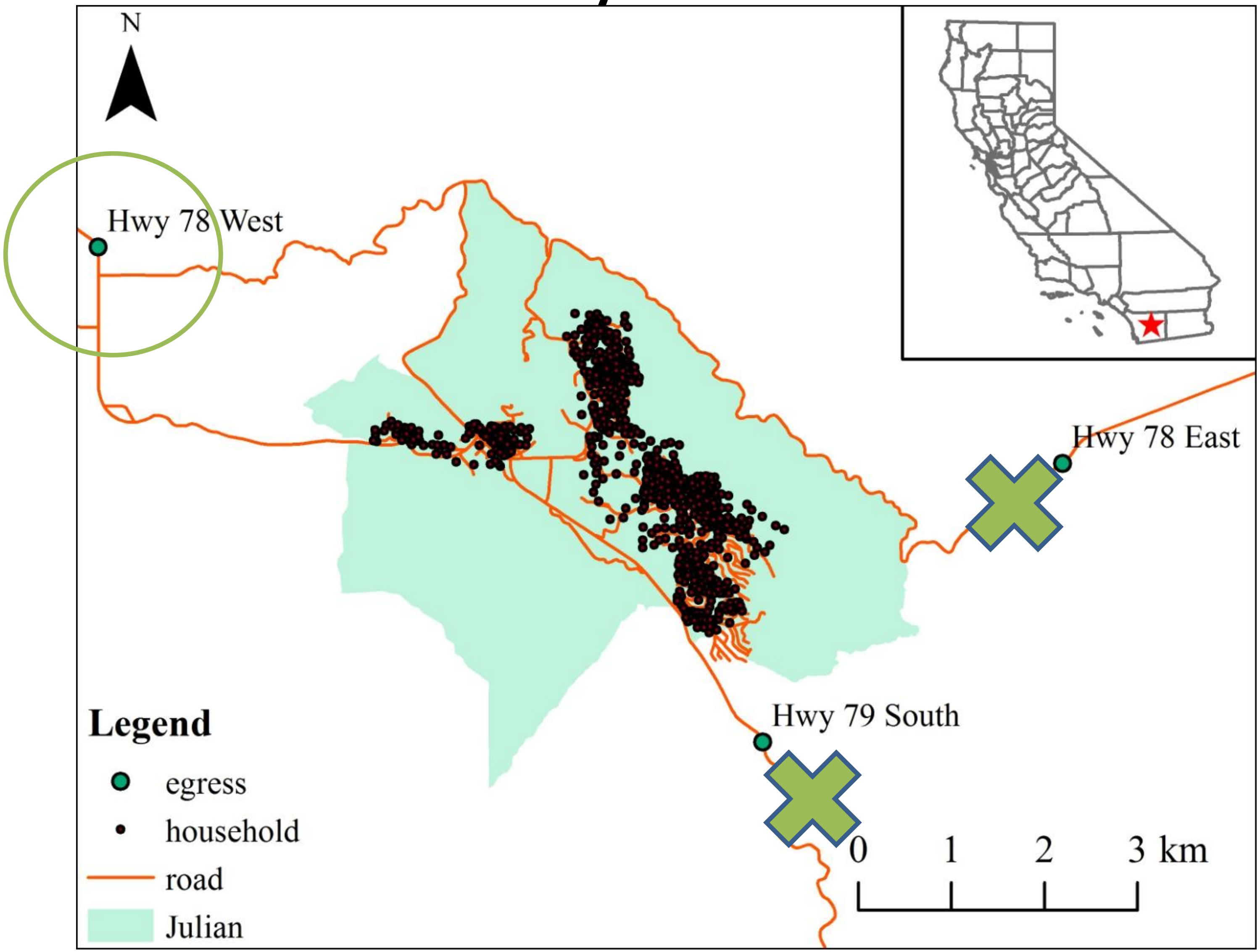
(b) Probability-based trigger buffers

Step 3: Conceptual diagram of the evaluation procedure



Person-threat distance (Beloglazov, Almashor, Abebe, Richter, and Steer, 2016)
Spatio-temporal computation and visualization

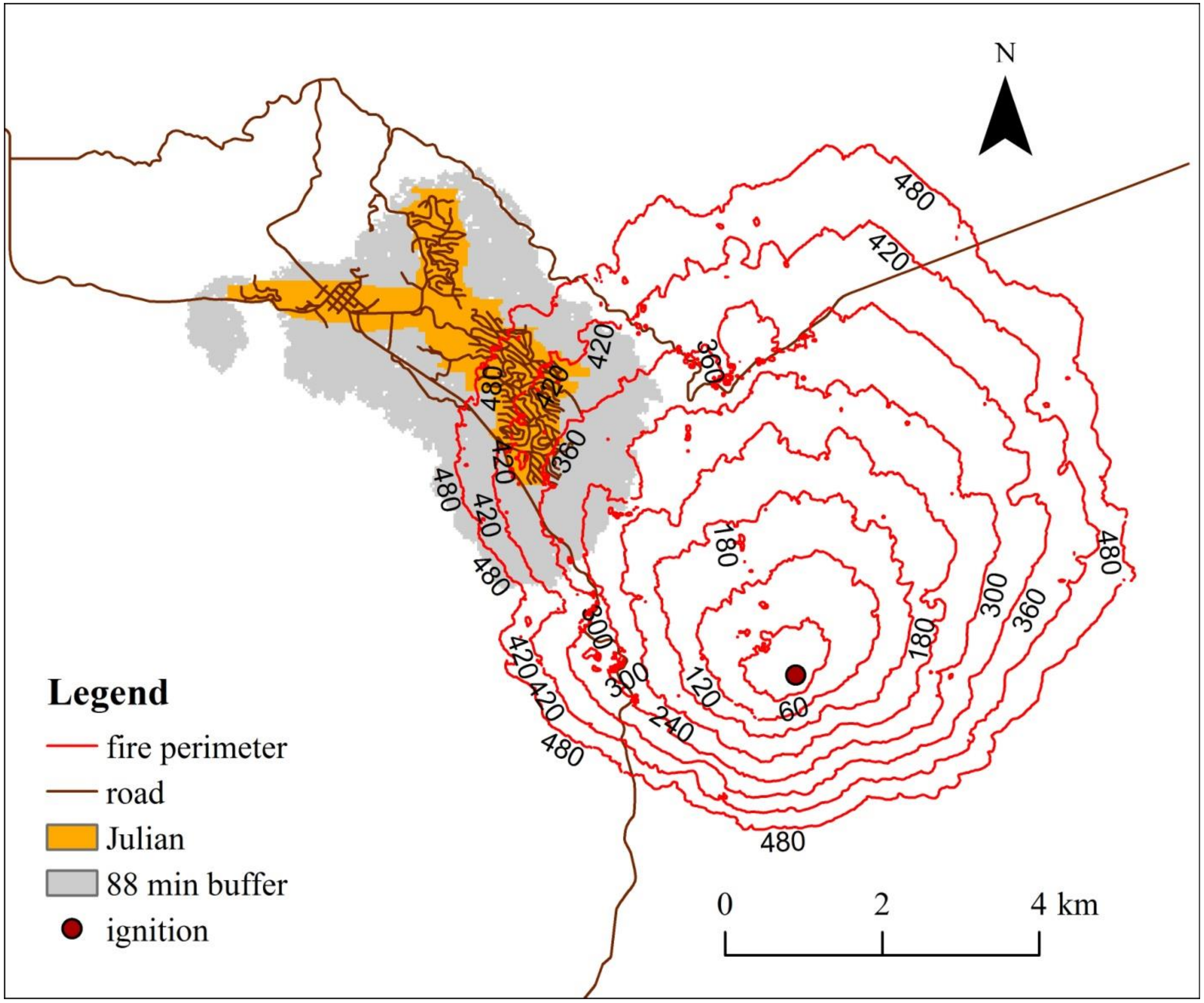
Households and the evacuation route system



MATSim: Agent-based microscopic traffic simulation

- An open-source agent-based microscopic traffic simulator
- Trips from the origin to the destination
  - The number of “persons” from each household
  - A Poisson distribution
- Agents will choose the shortest path
- Departure times
  - A normal distribution: $N(\mu, \sigma)$
- Calculate the evacuation times taken when 25%, 50%, 75%, and 95% of the evacuees have arrived at the safe areas ($T_{25}T_{50}, T_{75}, T_{95}$)

Fire perimeters from wildfire simulation



Wind direction	Wind speed (km/h)	Dead fuel moisture (%)			Live fuel moisture (%)	
		1 h	10 h	100 h	Wood	Herbaceous
South	16	5	5	5	65	65

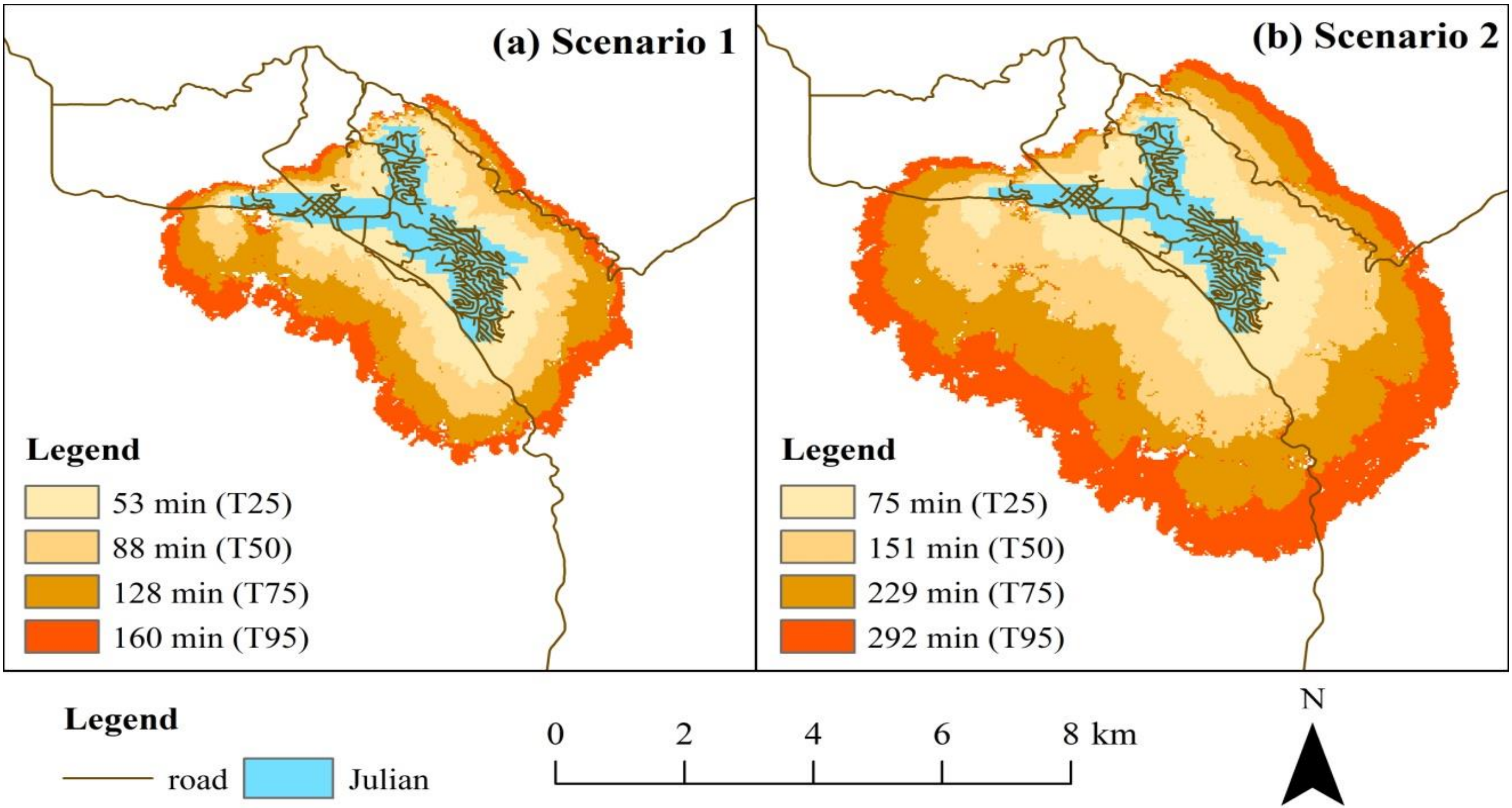
Two evacuation scenarios

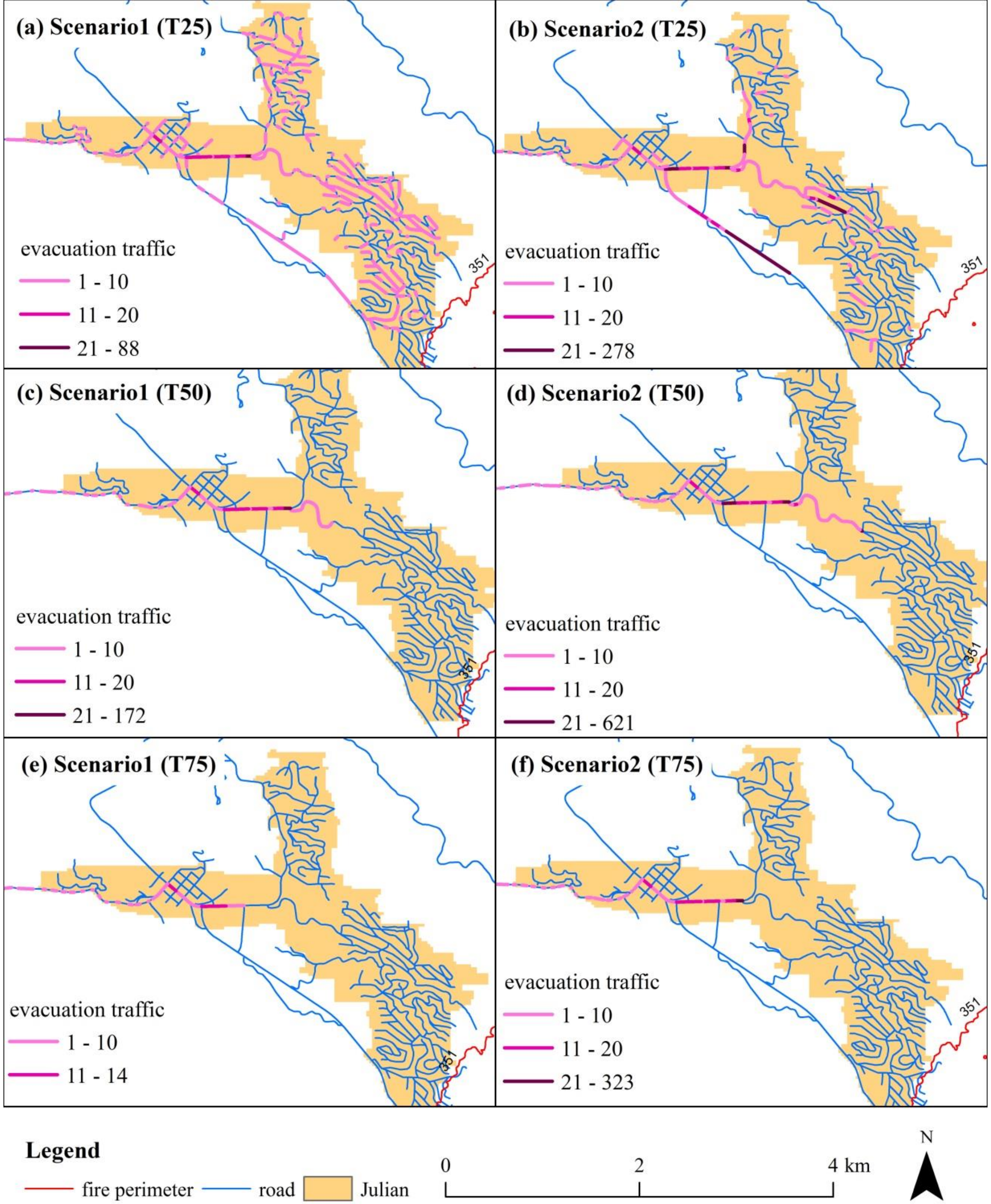
Table 1 Parameters for different evacuation scenarios

Scenario	λ	μ (min)	σ (min)	earliest (min)	latest (min)
1	2	40	20	0	80
2	4	40	20	0	80

Scenario		T_{25}	T_{50}	T_{75}	T_{95}
1	min	45 (1%)	78 (4%)	113 (2%)	141 (2%)
	mean	49 (64%)	82 (56%)	119 (56%)	149 (58%)
	max	53 (100%)	88 (100%)	128 (100%)	160 (100%)
	sd	1.5	2.4	3.4	4.2
2	min	69 (4%)	139 (2%)	210 (1%)	268 (1%)
	mean	72 (74%)	144 (55%)	219(63%)	278 (57%)
	max	75 (100%)	151 (100%)	229 (100%)	292 (100%)
	sd	1.3	2.7	4.0	4.2

Trigger buffers generated using 100% evacuation times

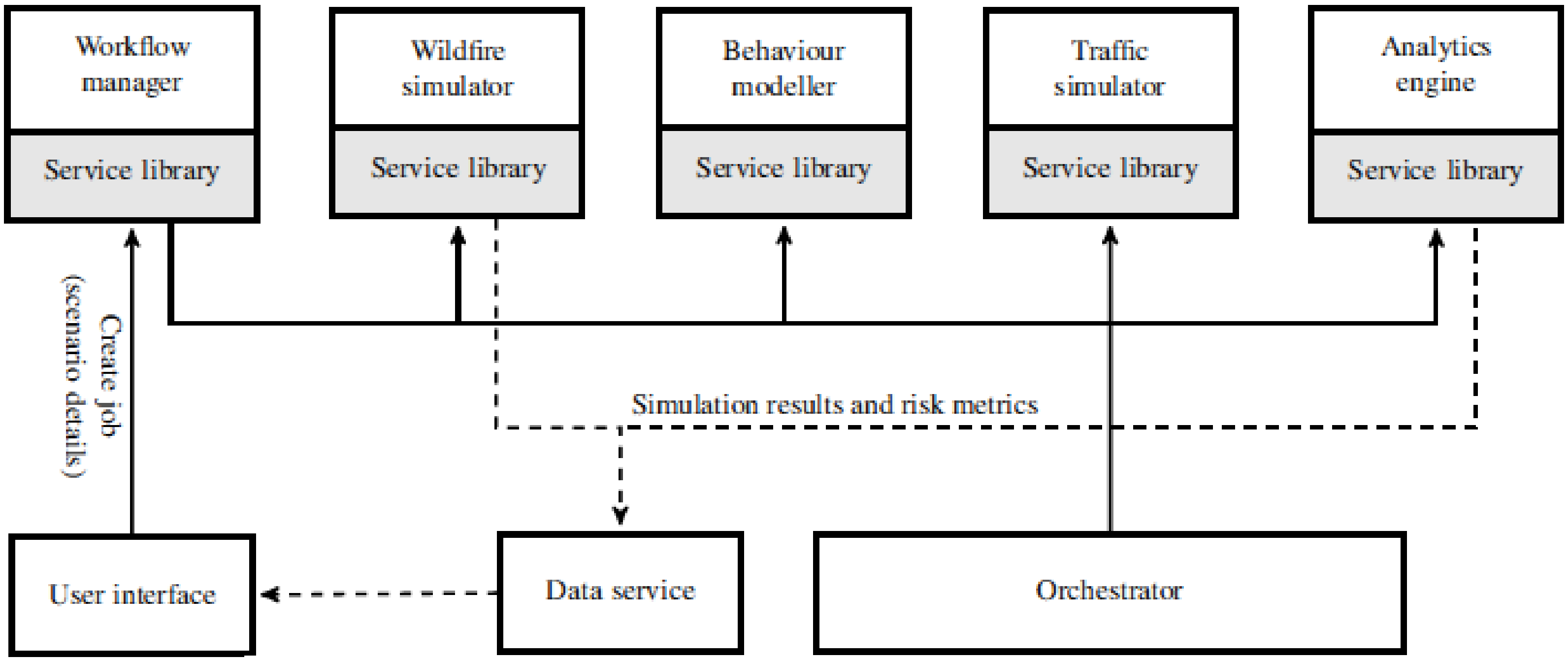



(a) Scenario1 (T25)
evacuation traffic
1 - 10
11 - 20
21 - 88
(b) Scenario2 (T25)
evacuation traffic
1 - 10
11 - 20
21 - 278
(c) Scenario1 (T50)
evacuation traffic
1 - 10
11 - 20
21 - 172
(d) Scenario2 (T50)
evacuation traffic
1 - 10
11 - 20
21 - 621
(e) Scenario1 (T75)
evacuation traffic
1 - 10
11 - 14
(f) Scenario2 (T75)
evacuation traffic
1 - 10
11 - 20
21 - 323
351
Legend
fire perimeter
road
Julian
0
2
4 km
N

Summary

- System coupling
  - Fire spread and trigger modeling, traffic simulation
  - Spatiotemporal modeling
- Agent-based modeling and simulation
  - Household-level evacuation warning
  - Agent-based evacuation traffic simulation
- Research and Development (R&D)
  - Object-oriented design/programming (OOD/P)
  - C/C++, Python, Java, R
  - Various GIS tools

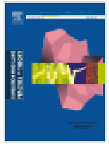
IBM Research's work on wildfire evacuation modeling and simulation



ELSEVIER

Simulation Modelling Practice and Theory

Volume 60, January 2016, Pages 144–159



Simulation of wildfire evacuation with dynamic factors and model composition

Anton Beloglazov[a], Mahathir Almashor[a], Ermyas Abebe[a], Jan Richter[a, 1], Kent Charles Barton Steer[a, b],

Ongoing work:
Open wildfire evacuation trigger modeling

Wildfire spread module → Trigger modeling module

Future work

- Cloud-based wildfire evacuation modeling
  - Cloud computing
- Household-level evacuation warning systems
  - Mobile computing
  - Location-based services (LBS)
- Wildfire evacuation planning
  - High-performance computing
- House loss in wildfires
  - Information needs
  - Notification systems

Li, D., Cova, T.J. & Dennison, P.E. Fire Technol. (2018). https://doi.org/10.1007/s10694-018-0771-6

Reference

- Beloglazov, A., Almashor, M., Abebe, E., Richter, J., & Steer, K. C. B. (2016). Simulation of wildfire evacuation with dynamic factors and model composition. Simulation Modelling Practice and Theory, 60, 144-159.
- Cova, T.J., Dennison, P.E., Li, D., Siebeneck, L.K., Drews, F.A., Lindell, M.K. (2017). “Warning triggers in environmental hazards: who should be warned to do what and when?” Risk Analysis.
- Cova, T. J., & Johnson, J. P. (2002). Microsimulation of neighborhood evacuations in the urban-wildland interface. Environment and Planning A, 34(12), 2211-2230.
- Dennison, P. E., Cova, T. J., & Mortiz, M. A. (2007). WUIVAC: a wildland-urban interface evacuation trigger model applied in strategic wildfire scenarios. Natural Hazards, 41(1), 181-199.
- Li, D. “Geocoding and reverse geocoding”. (2018). In Cova, T.J. & Tsou, M. (Eds.), Comprehensive Geographic Information Systems. Vol. 1, Elsevier.
- Li, D., Cova, T. J., & Dennison, P. E. (2015). A household-level approach to staging wildfire evacuation warnings using trigger modeling. Computers, Environment and Urban Systems, 54, 56-67.
- Li, D., Cova, T. J., & Dennison, P. E. (2017). Using reverse geocoding to identify prominent wildfire evacuation trigger points. *Applied Geography*, *87*, 14-27.
- Li, D., Cova, T.J. & Dennison, P.E . (2018). *Fire Technology*. https://doi.org/10.1007/s10694-018-0771-6
- Southworth, F. (1991). Regional evacuation modeling: A state-of-the-art review. Oak Ridge, TN, USA: Oak Ridge National Laboratory.
- Trainor, J. E., Murray-Tuite, P., Edara, P., Fallah-Fini, S., & Triantis, K. (2012). Interdisciplinary approach to evacuation modeling. Natural Hazards Review, 14(3), 151-162.

Q & A

Dapeng Li, Ph.D.
Department of Geography, South Dakota State University
Email: dapeng.li@sdstate.edu
Website: http://lidapeng.github.io
GitHub: https://github.com/lidapeng

South Dakota State University