Coupling fire and traffic simulation models to set wildfire evacuation triggers

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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

Wildfire evacuation in the western U.S.

2012 Wildfire Evacuation Map in the Western U.S.

Waldo Canyon Fire
6/23/2012~7/20/2012
Caused the evacuation of over 32,000 residents
Two deaths, approximately 346 homes were destroyed
The most expensive fire in Colorado state history (more than $352.6 million)
<table>
<thead>
<tr>
<th>FIRE NAME (CAUSE)</th>
<th>DATE</th>
<th>COUNTY</th>
<th>ACRES</th>
<th>STRUCTURES</th>
<th>DEATHS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TUBBS (Under Investigation)</td>
<td>October 2017</td>
<td>Sonoma</td>
<td>36,807</td>
<td>5,643</td>
<td>22</td>
</tr>
<tr>
<td>TUNNEL - Oakland Hills (Rekindle)</td>
<td>October 1991</td>
<td>Alameda</td>
<td>1,600</td>
<td>2,900</td>
<td>25</td>
</tr>
<tr>
<td>CEDAR (Human Related)</td>
<td>October 2003</td>
<td>San Diego</td>
<td>273,246</td>
<td>2,820</td>
<td>15</td>
</tr>
<tr>
<td>VALLEY (Electrical)</td>
<td>September 2015</td>
<td>Lake, Napa &amp; Sonoma</td>
<td>76,067</td>
<td>1,955</td>
<td>4</td>
</tr>
<tr>
<td>WITCH (Powerlines)</td>
<td>October 2007</td>
<td>San Diego</td>
<td>197,990</td>
<td>1,650</td>
<td>2</td>
</tr>
<tr>
<td>NUNS (Under Investigation)</td>
<td>October 2017</td>
<td>Sonoma</td>
<td>54,382</td>
<td>1,355</td>
<td>2</td>
</tr>
<tr>
<td>THOMAS (Under Investigation)</td>
<td>December 2017</td>
<td>Ventura &amp; Santa Barbara</td>
<td>281,893</td>
<td>1,063</td>
<td>1</td>
</tr>
<tr>
<td>OLD (Human Related)</td>
<td>October 2003</td>
<td>San Bernardino</td>
<td>91,281</td>
<td>1,003</td>
<td>6</td>
</tr>
<tr>
<td>JONES (Undetermined)</td>
<td>October 1999</td>
<td>Shasta</td>
<td>26,200</td>
<td>954</td>
<td>1</td>
</tr>
<tr>
<td>BUTTE (Powerlines)</td>
<td>September 2015</td>
<td>Amador &amp; Calaveras</td>
<td>70,868</td>
<td>921</td>
<td>2</td>
</tr>
<tr>
<td>ATLAS (Under Investigation)</td>
<td>October 2017</td>
<td>Napa &amp; Solano</td>
<td>51,624</td>
<td>781</td>
<td>6</td>
</tr>
<tr>
<td>PAINT (Arson)</td>
<td>June 1990</td>
<td>Santa Barbara</td>
<td>4,900</td>
<td>641</td>
<td>1</td>
</tr>
<tr>
<td>FOUNTAIN (Arson)</td>
<td>August 1992</td>
<td>Shasta</td>
<td>63,960</td>
<td>636</td>
<td>0</td>
</tr>
<tr>
<td>SAYRE (Misc.)</td>
<td>November 2008</td>
<td>Los Angeles</td>
<td>11,262</td>
<td>604</td>
<td>0</td>
</tr>
<tr>
<td>CITY OF BERKELEY (Powerlines)</td>
<td>September 1923</td>
<td>Alameda</td>
<td>130</td>
<td>584</td>
<td>0</td>
</tr>
<tr>
<td>HARRIS (Under Investigation)</td>
<td>October 2007</td>
<td>San Diego</td>
<td>90,440</td>
<td>548</td>
<td>8</td>
</tr>
<tr>
<td>REDWOOD VALLEY (Under Investigation)</td>
<td>October 2017</td>
<td>Mendocino</td>
<td>36,523</td>
<td>544</td>
<td>9</td>
</tr>
<tr>
<td>BEL AIR (Undetermined)</td>
<td>November 1961</td>
<td>Los Angeles</td>
<td>6,090</td>
<td>484</td>
<td>0</td>
</tr>
<tr>
<td>LAGUNA (Arson)</td>
<td>October 1993</td>
<td>Orange</td>
<td>14,437</td>
<td>441</td>
<td>0</td>
</tr>
<tr>
<td>ERSKINE (Under Investigation)</td>
<td>June 2016</td>
<td>Kern</td>
<td>46,684</td>
<td>386</td>
<td>2</td>
</tr>
</tbody>
</table>

***"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
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

Wildfire evacuation

Human system
- Evacuation timing
- Evacuation zoning
- Evacuation warning
- Evacuation traffic
- Spatial cognition

Environmental system
- Weather conditions
- Land cover
- Topography
- Fire-spread
- Evacuation routes
- Geographic features

Trigger modeling
Interdisciplinary collaboration

Wildfire evacuation modeling

Social Sciences

- Sociology, psychology, etc. (e.g., McCaffrey)

Natural Sciences

- Wildfire spread modeling (e.g., Coen)

Engineering

- Evacuation traffic simulation (e.g., Cova)

GIS, computer engineering, etc.

Physics, mathematics, etc.
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

- Household data
  - Trip generation
    - Mobilization
      - Destination selection
        - Evacuation route selection
          - Estimated evacuation times
            - Evacuation travel demand modeling
            - Evacuation trip distribution modeling
            - Evacuation traffic assignment modeling
Illustration of the four estimated evacuation times
Step 2: create probability-based trigger buffers

- Community and its $n$ estimated evacuation times
- Topographic data
  - Fuel model and moisture data
  - Wind data

1. Perform Fire spread modeling
2. Construct fire travel time network
3. Reverse all edges and traverse from the community

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

<table>
<thead>
<tr>
<th>Wind direction</th>
<th>Wind speed (km/h)</th>
<th>Dead fuel moisture (%)</th>
<th>Live fuel moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 h</td>
<td>10 h</td>
</tr>
<tr>
<td>South</td>
<td>16</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
## Two evacuation scenarios

### Table 1 Parameters for different evacuation scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>$\lambda$</th>
<th>$\mu$ (min)</th>
<th>$\sigma$ (min)</th>
<th>earliest (min)</th>
<th>latest (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>40</td>
<td>20</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>40</td>
<td>20</td>
<td>0</td>
<td>80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario</th>
<th>$T_{25}$</th>
<th>$T_{50}$</th>
<th>$T_{75}$</th>
<th>$T_{95}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>min</td>
<td>45 (1%)</td>
<td>78 (4%)</td>
<td>113 (2%)</td>
<td>141 (2%)</td>
</tr>
<tr>
<td>mean</td>
<td>49 (64%)</td>
<td>82 (56%)</td>
<td>119 (56%)</td>
<td>149 (58%)</td>
</tr>
<tr>
<td>max</td>
<td>53 (100%)</td>
<td>88 (100%)</td>
<td>128 (100%)</td>
<td>160 (100%)</td>
</tr>
<tr>
<td>sd</td>
<td>1.5</td>
<td>2.4</td>
<td>3.4</td>
<td>4.2</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>min</td>
<td>69 (4%)</td>
<td>139 (2%)</td>
<td>210 (1%)</td>
<td>268 (1%)</td>
</tr>
<tr>
<td>mean</td>
<td>72 (74%)</td>
<td>144 (55%)</td>
<td>219 (63%)</td>
<td>278 (57%)</td>
</tr>
<tr>
<td>max</td>
<td>75 (100%)</td>
<td>151 (100%)</td>
<td>229 (100%)</td>
<td>292 (100%)</td>
</tr>
<tr>
<td>sd</td>
<td>1.3</td>
<td>2.7</td>
<td>4.0</td>
<td>4.2</td>
</tr>
</tbody>
</table>
Trigger buffers generated using 100% evacuation times

(a) Scenario 1

(b) Scenario 2

Legend
- 53 min (T25)
- 88 min (T50)
- 128 min (T75)
- 160 min (T95)

Legend
- 75 min (T25)
- 151 min (T50)
- 229 min (T75)
- 292 min (T95)

Legend
- road
- Julian

0 2 4 6 8 km
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

Simulation of wildfire evacuation with dynamic factors and model composition

Anton Beloglazov\textsuperscript{a}, Mahathir Almahmor\textsuperscript{b}, Ernyas Abebe\textsuperscript{c}, Jan Richter\textsuperscript{d, e}, Kent Charles Barton Steer\textsuperscript{a, b}

\textsuperscript{a}IBM Research

Simulation Modelling Practice and Theory
Volume 60, January 2016, Pages 144–159

ELSEVIER
Ongoing work:
Open wildfire evacuation trigger modeling

Wildfire spread module → Trigger modeling module

Bringing advanced geospatial technologies to the world
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
Reference


Q & A

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