The application of GIScience to Search and Rescue in Yosemite National Park

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NSF #1031914
What is a Park Ranger?

- NPS Mission: conserve the scenery, the natural and historic objects, and the wildlife, and to provide for the public's enjoyment of these features in a manner that will leave them unimpaired for the enjoyment of future generations.

- Protect: the Park from people, people from the Park, people from each other.

What is Search and Rescue? (SAR)

- Locate
- Stabilize
- Extract
- Prevention?

Action occurs at a *time* and a *place*
Framework

• If Search and Rescue is an inherently spatial process, then:
  – The application of GISystems should enhance the likelihood of desirable outcomes – rescue/prevent
  – The study of SAR in a spatio-temporal context can contribute to GIScience
GIScience topics

- Probabilistic time geography
- Dynamic GIS
- Geographic one-class data
- Spatial uncertainty, data quality, and innovative uses of human geography
Yosemite Search and Rescue (YOSAR)
12,000 sq miles, 95% wilderness, 800 miles of hiking trails
Yosemite National Park

- Annually
  - +3.5 million visitors
  - +200 SARs
- How do we find and rescue them?
- Where and when do they get rescued?

Table 1. Most common injuries and illnesses needing SAR services (n = 2077)

<table>
<thead>
<tr>
<th>Type of Injury or Illness</th>
<th>N</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture</td>
<td>416</td>
<td>20.0</td>
</tr>
<tr>
<td>Sprain/strain</td>
<td>290</td>
<td>14.0</td>
</tr>
<tr>
<td>Unspecified</td>
<td>253</td>
<td>12.2</td>
</tr>
<tr>
<td>Dehydration/hypovolemia/hunger</td>
<td>172</td>
<td>8.3</td>
</tr>
<tr>
<td>Contusion</td>
<td>157</td>
<td>7.6</td>
</tr>
<tr>
<td>Laceration</td>
<td>143</td>
<td>6.9</td>
</tr>
<tr>
<td>Cold injury/hypothermia/frostbite</td>
<td>95</td>
<td>4.6</td>
</tr>
<tr>
<td>Abrasion</td>
<td>91</td>
<td>4.4</td>
</tr>
<tr>
<td>Nausea/vomiting</td>
<td>63</td>
<td>3.0</td>
</tr>
<tr>
<td>Dislocation</td>
<td>50</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Table 2. Most common activities victims were participating in at time of incident (n = 2327)*

<table>
<thead>
<tr>
<th>Activity</th>
<th>N</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hiking/snowshoeing</td>
<td>1208</td>
<td>52.0</td>
</tr>
<tr>
<td>Rock climbing/scrambling</td>
<td>442</td>
<td>19.0</td>
</tr>
<tr>
<td>Driving</td>
<td>139</td>
<td>6.0</td>
</tr>
<tr>
<td>Skiing</td>
<td>130</td>
<td>5.6</td>
</tr>
<tr>
<td>Leisure/working</td>
<td>101</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Hung et al 2007
What is Search and Rescue? (SAR)

• Locate
• Stabilize
• Extract
• Prevention?
When location is known

Notification:
- In Person
- Radio
- Cell-phone (Enhanced-911)
- S.E.N.D. (SPOT)
When location is unknown

- Point Last Seen (PLS)
- Last Known Point (LKP)
- Witnesses
- Itinerary
- Clues

Are they missing or overdue?
Campsite where last seen, 0830h
Planning

- Probability of Area (POA)
- Probability of Detection (POD)

Probability of Success = POA x POD

Small Search Area = Low POA  
Large Search Area = Low POD

X = last known point
O = current location

***Probabilistic time geography***
### Lost Person Behavior Statistics for the Hiker Category (ISRID)

**Mobility (hours)**

<table>
<thead>
<tr>
<th></th>
<th>Temperate</th>
<th>Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>232</td>
<td>112</td>
</tr>
</tbody>
</table>

**Dispersal Angle (degrees)**

<table>
<thead>
<tr>
<th></th>
<th>Temperate</th>
<th>Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>134</td>
<td>28</td>
</tr>
</tbody>
</table>

**Find Location (%)**

<table>
<thead>
<tr>
<th></th>
<th>Temp</th>
<th>Dry</th>
<th>Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>312</td>
<td>196</td>
<td>17</td>
</tr>
</tbody>
</table>

**Scenario (%)**

<table>
<thead>
<tr>
<th></th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avalanche</td>
<td>2242</td>
</tr>
</tbody>
</table>

**Survivability**

<table>
<thead>
<tr>
<th>Survivability</th>
<th>Wilderness</th>
<th>Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uninjured</td>
<td>78%</td>
<td>59%</td>
</tr>
<tr>
<td>Injured</td>
<td>16%</td>
<td>24%</td>
</tr>
<tr>
<td>Fatality</td>
<td>6%</td>
<td>12%</td>
</tr>
<tr>
<td>No Trace</td>
<td>6%</td>
<td>6%</td>
</tr>
</tbody>
</table>

**Track Offset (meters)**

<table>
<thead>
<tr>
<th></th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40</td>
</tr>
</tbody>
</table>

**Elevation (vertical) Change from the IPP (feet)**

<table>
<thead>
<tr>
<th></th>
<th>Temperate</th>
<th>Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>32%</td>
<td>52%</td>
</tr>
</tbody>
</table>

**Horizontal Change from IPP (miles) for Mtn Terrain**

<table>
<thead>
<tr>
<th></th>
<th>Temperate</th>
<th>Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>58</td>
<td>131</td>
</tr>
</tbody>
</table>

**Scenario (%)**

<table>
<thead>
<tr>
<th></th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lost</td>
<td>68%</td>
</tr>
</tbody>
</table>

**Scenario (%)**

<table>
<thead>
<tr>
<th></th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical</td>
<td>2%</td>
</tr>
<tr>
<td>Drowning</td>
<td>2%</td>
</tr>
<tr>
<td>Overdue</td>
<td>16%</td>
</tr>
<tr>
<td>Stranded</td>
<td>4%</td>
</tr>
<tr>
<td>Trauma</td>
<td>7%</td>
</tr>
</tbody>
</table>
From Tobler 1993, Miller and Bridwell 2009, Lin and Goodrich 2010
Assignments

• Search Segments
  – Terrain
  – Man-made features
  – Water

• Teams
  – Tracking
  – Ground
  – Dog
  – Helicopter
Integrated Terrain Units

Campsite where last seen, 0830h
Segment the Map

Campsite where last seen, 0830h

- Trailblocks
- HastyTrailSearch
- Search Segments
- Road

Wacom penabled screen
Assigning Segments

Map with different colored segments and labeled areas.
Assignment Maps

Colby Mountain

Campsite where last seen, 0830h

Grand Mountain

Ten Lakes Pass

Large format HP plotter
POD/debrief

- Aerial Tracklogs
- Ground Tracklogs
- Lakes
- Search Segments

Garmin 60Csx
Search Progress – Day 1 and 2
Successful Find
1. Places not seen

2. Planning
   - Digitize search assignments
   - Hazard analyses
   - Print assignment maps
   - Load assignments onto GPS units

3. Briefing
   - Provide Ops and Search Teams with assignment maps

4. Operations
   - Real-time GPS unit tracking
   - Clue logging

5. Debrief
   - GPS unit download, Plot GPS tracks and clues

6. Re-group

* The GISS falls under the Planning Section, working directly for the SITL
What is Search and Rescue? (SAR)

- Locate
- Stabilize
- Extract
- Prevention?
Computer-Aided Dispatch
Common Operational Picture

- Unified cartography
- Real-time tracking
  - GPS enabled radios
  - Smart phones
  - Automated flight following
- Web-GIS
What is Search and Rescue? (SAR)

- Locate
- Stabilize
- Extract
- Prevention?
Types of Extraction

• Ground
  – Walk/crutch-out
  – Litter Carryout
  – Technical Rescue

• Water
  – Shore-based
  – Rescue Swimmer/Technical Rescue

• Air
  – Direct
  – Short-haul
Landing Suitability Model

- **Slope**: Reclassify (expert knowledge) and spatial uncertainty
- **Vegetation (NDVI)**: Reclassify (expert knowledge) and spatial uncertainty
- **Hazards**: Reclassify (expert knowledge) and spatial uncertainty

- **Weighted Overlay**: Raster suitability categories
Expert Model

95% correct classification on test data

Store and Kangas 2001, Malczewski 2004
N = 4000, Kruskal-Wallis $P < 0.001$, Nemenyi test shows separation of all groups.
Machine-learning model

95% correct classification on test data
Maxent – significant relationship with Expert Model using 100 training points

***Geographic one-class data
Philips et al. 2006; Mateo-Tomás and Olea 2010
What is Search and Rescue? (SAR)

• Locate
• Stabilize
• Extract

• Prevention?
Preventative Search and Rescue

• Use our knowledge of past incidents to inform:
  – The visitors
  – The management
  – The rescuers

***Spatial uncertainty, data quality, and innovative use
The big problem:
We do not have spatially explicit incident information and we are losing our institutional knowledge.
What is an *ideal* georeference?

A numerical description of a place that can be mapped and that describes the spatial extent of a locality and its associated uncertainties as well as possible.

*Wieczorek et al 2004; Chapman and Wieczorek 2006, Guo et al 2008; Liu et al 2009*
Put it on a map, do it well, and know how confident you should be

Reference object vs. Target object
## Georeferencing SAR

<table>
<thead>
<tr>
<th>Locality</th>
<th>Description</th>
<th>Example</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F</strong></td>
<td>Feature</td>
<td>“Patient fractured ankle at <strong>Columbia Point</strong>”.</td>
<td><img src="image" alt="Feature" /></td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>Path or linear feature</td>
<td>“Patient twisted knee while on the <strong>Mist Trail</strong> between the <strong>Steps</strong> and the top of <strong>Vernal Falls</strong>”.</td>
<td><img src="image" alt="Path" /></td>
</tr>
<tr>
<td><strong>J</strong></td>
<td>Junction</td>
<td>“Patient was found unconscious at the <strong>junction of the John Muir and Panorama Trail</strong>”.</td>
<td><img src="image" alt="Junction" /></td>
</tr>
<tr>
<td><strong>BF</strong></td>
<td>Between features or paths</td>
<td>“The missing person’s body was located between the <strong>Tioga Road</strong> and <strong>Gaylor Lakes Trail</strong>”.</td>
<td><img src="image" alt="Between" /></td>
</tr>
</tbody>
</table>
834 of 934 incidents from 2006 – 2009 could be georeferenced

Wieczorek et al. 2004 IJGIS
834 of 934 incidents from 2006 – 2009 could be georeferenced.
578 of 834 incidents from 2006 – 2009 were path related
Probability-field method

\[ q_1 p_1(x_0,y_0) + q_2 p_2(x_0,y_0) \]
2006 - 2009 SAR - 164 SARs involved a helicopter
2006 - 2009 SAR - 330 SARs with lone Female patient
2006 - 2009 SAR - 453 SARs with lone Male patient
“As a collector, you may have an intended use for the data you collect but data have the potential to be used in unforeseen ways; therefore, the value of your data is directly related to the fitness of those data for a variety of uses”.

“As data become more accessible, many more uses become apparent”.

Chapman and Wieczorek 2006
GIScience topics

• Probabilistic time geography
• Human geography
• Geographic one-class data
• Machine learning algorithms
• Spatial uncertainty, data quality, and innovative use
Get involved!

Using GIS in SAR for Emergency Responders Google Group

National Alliance for Public Safety GIS
Regional Coordination • Information Clearinghouse • Best Practices Recognition • Political Advocacy

UCMERCED

National Science Foundation
WHERE DISCOVERIES BEGIN

When Every Second Counts
Yosemite uses GIS for coordinating search and rescue operations

By Jesse Theodore, ESRI Writer

GIS has helped the Yosemite Search and Rescue (YOSAR) team improve its methods of operation and has been used successfully in searches for missing persons in Yosemite National Park.

Every year, three million visitors come to Yosemite National Park to enjoy the outdoors. One of the nation's greatest travel destinations, Yosemite provides camping, fishing, hiking, and other activities for guests to enjoy. While most visitors have the time of their lives, a few face the frightening prospect of becoming disoriented or getting injured while hiking the park's many trails.

Each year, Yosemite National Park responds to hundreds of calls reporting missing persons. Most often, a lost hiker or vacationer is found during the first 24 hours. However, when someone is missing for more than 24 hours, multiple search teams are dispatched. Search and rescue operations require a significant, coordinated effort on the ground and in the air. For these incidents, the National Park Service calls on YOSAR, a team of specialists.

YOSAR is a group of park rangers, technical climbers, helicopter pilots, and incident management staff who are directed by Keith Lobber, the emergency services coordinator for Yosemite National Park. These skilled search and rescue operators are known around the world for their ability to make backcountry extractions of injured hikers perform climbing rescues off of "big walls," such as El Capitan; search for missing hikers; and respond to multi-casualty incidents. They work primarily in the park, but are requested by mutual aid management teams throughout the country.

Once activated, YOSAR assembles and deploys ground, technical, canine, and air units and manages the entire incident response process. Managing complex emergency situations requires rapid response capability that ensures a comprehensive, coordinated search is carried out in the fastest possible time frame.

Expanding GIS at Yosemite
Paul Doberty, a park ranger and GIS specialist for the National Park Service, was hired in May 2008 to establish GIS support specifically for search and rescue operations.

"Once I settled in and started working, the GIS needs in the Protection Division were evident and the opportunity to get involved was very exciting," said Doberty.

The National Park Service has successfully used GIS in its Resource Management and Science Division, as well as in its response to wildland fires. Protection Division chief Steve Shackleton envisioned applying the same technology and services to all branches of emergency response (i.e., search and rescue, law enforcement, disaster management, and structural fire) in the park.

Managing a Complex Operation

Missing person incidents are common in Yosemite. When a hiker is missing or overdue, it requires an initial response known as a "hasty search." These searches are carried out in the first 24 hours in the immediate vicinity where the lost person was last seen. Trail blocks are established to interview possible witnesses and gather information on hiking conditions.

If the person is not found quickly, a large search area of 1-40 square miles is drawn on a map. This area is segmented to create smaller search assignments, and a comprehensive search and rescue case is created.

Finding a missing person in the wilderness is a complex process. Maps are at the core of this process. Incident managers and field teams want to know the coordinates where the person was last seen to determine where they should begin the search. They also want to know about the surrounding landscape so they can safely and efficiently locate, stabilize, and extract victims as quickly as possible.

These search and rescue operations, managed under the Incident Command System, can increase in complexity very quickly. YOSAR members are adept at implementing modern search theory as well as using lessons learned from previous searches.
Any questions?

Special thanks to KU Graduate Student Jared Doke for georeferencing 934 incidents this summer.