Evacuation Route Planning: A Scientific Approach

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Project Details at http://www.cs.umn.edu/~shekhar/talk/evacuation.html

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Homeland Defense & Evacuation Planning

- Preparation of response to an attack
- Plan evacuation routes and schedules
- Help public officials to make important decisions
- Guide affected population to safety

PLANNING SCENARIOS

Executive Summaries

Created for Use in National, Federal, State, and Local Homeland Security Preparedness Activities

The Homeland Security Council
David Howe, Senior Director for Response and Planning

July 2004

(Images from www.fortune.com)
Example – Monticello Nuclear Power Plant

Nuclear Power Plants in Minnesota
Monticello Emergency Planning Zone

Emergency Planning Zone (EPZ) is a 10-mile radius around the plant divided into sub areas.

Monticello EPZ
Subarea Population
2  4,675
5N  3,994
5E  9,645
5S  6,749
5W  2,236
10N  391
10E  1,785
10SE  1,390
10S  4,616
10SW  3,408
10W  2,354
10NW  707
Total  41,950

Estimate EPZ evacuation time:
Summer/Winter (good weather): 3 hours, 30 minutes
Winter (adverse weather): 5 hours, 40 minutes

Data source: Minnesota DPS & DHS
Web site: http://www.dps.state.mn.us
http://www.dhs.state.mn.us
Existing Evacuation Routes (Handcrafted)

Destination
Monticello Power Plant
Our algorithms reduce evacuation time!

Total evacuation time:
- Existing Routes: 268 min.
- New Routes: 162 min.

Congestion is likely in old plan near evacuation destination due to capacity constraints. Our plan has richer routes near destination to reduce congestion and total evacuation time.
Case Study 2 - Metropolitan Wide Evacuation Planning

**Mandate - DHS Requirement**

**Objectives**

- Coordinate evacuation plans of individual communities
- Reduce conflicts across component plans
  - due to the use of common highways

**Timeframe:** January – November 2005
Why avoid conflicts among local plans?

- No coordination among local plans means
  - Traffic congestions on all highways
  - e.g. 100 mile congestion in Texas (2005)

- Great confusions and chaos

"We packed up Morgan City residents to evacuate in the a.m. on the day that Andrew hit coastal Louisiana, but in early afternoon the majority came back home. **The traffic was so bad that they couldn't get through Lafayette.**"
Mayor Tim Mott, Morgan City, Louisiana
(http://i49south.com/hurricane.htm)
Acknowledgements

• **Sponsors**
  - CTS, MnDOT

• **Key Individuals**
  - Univ. of Minnesota - Sangho Kim, Qingsong Lu, and Betsy George
  - MnDOT - Sonia Pitt, Robert Vasek, Cathy Clark
  - URS - Daryl Taavola, Tait Swanson, Erik Seiberlich

• **Participating Organizations**
  - DPS, MEMA, Mpls./St. Paul Emergency Mgmt.
  - Dept. of Public Safety, DOE, DOH, DO Human Services
  - Coast Guard, FHWA, TSA, Mn National Guard, UMN
  - 9 Counties, 4 Cities, Metropolitan Council, Metro Transit
  - 3 Fire Depts., 7 Law Enforcements
Advisory Board

MEMA/Hennepin Co. - Tim Turnbull, Judith Rue
Dakota Co. (MEMA) - David Gisch
Minneapolis Emergency Mgt. - Rocco Forte, Kristi Rollwagen
St. Paul Emergency Mgt. - Tim Butler
Minneapolis Fire - Ulie Seal
DPS HSEM - Kim Ketterhagen, Terri Smith
DPS Special Operations - Kent O’Grady
DPS State Patrol - Mark Peterson

Workshops

Over 100 participants from various local, state and federal govt.
Workshop Participants

**Federal, State, County, City**
- Gerald Liibbe, Federal Highway Administration (FHWA)
- Katie Belmore, Representing Wisconsin Department of Transportation

**Airports**
- George Condon, Metropolitan Airports Commission

**Businesses**
- Chris Terzich, Minnesota Information Sharing and Analysis Center
- Barry Gorelick, Minnesota Security Board

**Communications and Public Information**
- Kevin Gutknecht, Mn/DOT
- Lucy Kender, Mn/DOT
- Andrew Terry, Mn/DOT

**Dispatch**
- Keith Jacobson, Mn/DOT

**Education**
- Bob Fischer, Minnesota Department of Education
- Dick Guevremont, Minnesota Department of Education

**Emergency Management**
- Bruce Wojack, Anoka County Emergency Management
- Tim Walsh, Carver County Emergency Management
- Jim Halstrom, Chisago County Emergency Management
- David Gisch, Dakota County Emergency Preparedness
- Tim O'Laughlin, Scott County Sheriff – Emergency Management
- Tim Turnbull, Hennepin County Emergency Preparedness
- Judith Rue, Hennepin County Emergency Preparedness
- Rocco Forte, Minneapolis Fire Department – Emergency Preparedness
- Kristi Rollwagen, Minneapolis Fire Department – Emergency Preparedness
- William Hughes, Ramsey County Emergency Management and Homeland Security
- Tim Butler, St. Paul Fire and Safety Services
- Deb Paige, Washington County Emergency Management
- Kim Ketterhagen, Department of Public Safety (DPS) HSEM
- Sonia Pitt, Mn/DOT HSEM
- Bob Vasek, Mn/DOT HSEM

**Fire**
- Gary Sigfrinius, Forest Lake Fire Department

**Health**
- Debrah Ehret, Minnesota Department of Health

**Hospitals**
- Dan O'Laughlin, Metropolitan Hospital Compact

**Human Services**
- Glenn Olson, Minnesota Department of Human Services

**Law Enforcement**
- Brian Johnson, Hennepin County Sheriff
- Jack Nelson, Metro Transit Police Department
- David Indrehus, Metro Transit Police Department
- Otto Wagenpfeil, Minneapolis Police Department
- Kent O'Grady, Minnesota State Patrol
- Mark Peterson, Minnesota State Patrol
- Chuck Walerus, Minnesota State Patrol
- Douglas Biehn, Ramsey County Sheriff's Office
- Mike Morehead, St. Paul Police

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- Dan Schacht, Ramsey County

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- Paul Pettit, Transportation Security Administration

**Transit**
- Dana Rude, Metro Mobility
- Steve McLaird, Metro Transit
- Christy Bailly, Metro Transit
- David Simoneau, SouthWest Metro Transit

**Traffic**
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- Jon Wertjes, City of Minneapolis
- Bernie Arseneau, Mn/DOT
- Amr Jabr, Mn/DOT
- Eil Kwon, Mn/DOT
- Paul St. Martin, City of St. Paul

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**University**
- Dan Johnson Powers, University of Minnesota Emergency Management

**Volunteer Organizations**
- Gene Borochoff, Minnesota Volunteer Organization active in Disaster
Task-structure

Metro Evacuation Plan

- Identify Stakeholders
- Establish Steering Committee
- Perform Inventory of Similar Efforts and Look at Federal Requirements
- Evacuation Route Modeling
- Finalize Project Objectives
- Agency Roles
- Regional Coordination and Information Sharing
- Evacuation Routes and Traffic Mgt. Strategies
- Stakeholder Interviews and Workshops
- Issues and Needs
- Preparedness Process
- Final Plan

Metro Evacuation Plan

Stakeholders: Identify Stakeholders

Establish Steering Committee

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Evacuation Route Modeling

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Agency Roles

Regional Coordination and Information Sharing

Evacuation Routes and Traffic Mgt. Strategies

Stakeholder Interviews and Workshops

Issues and Needs

Preparedness Process

Final Plan
Given

- A transportation network, a directed graph $G = (N, E)$ with
  - Capacity constraint for each edge and node
  - Travel time for each edge
- Number of evacuees and their initial locations
- Evacuation destinations

Output

- Evacuation plan consisting of a set of origin-destination routes and a scheduling of evacuees on each route.

Objective

- Minimize evacuation time
- Minimize computational cost

Constraints

- Edge travel time observes FIFO property
- Limited computer memory
A Note on Objective Functions

- Why minimize evacuation time?
  - Reduce exposure to evacuees
  - Since harm due to many hazards increase with exposure time!

- Why minimize computation time?
  - During Evacuation
    - Unanticipated events
      - Bridge Failure due to Katrina, 100-mile traffic jams due to Rita
      - Plan new evacuation routes to respond to events
        - Contra-flow based plan for Rita
  - During Planning
    - Explore a large number of scenarios Based on
      - Transportation Modes
      - Event location and time

Plans are nothing; planning is everything.-- Dwight D. Eisenhower
Limitations of Related Works

Linear Programming Approach
- Optimal solution for evacuation plan
- e.g. EVACNET (U. of Florida), Hoppe and Tardos (Cornell University).

**Limitation:**
- High computational complexity
- Cannot apply to large transportation networks

<table>
<thead>
<tr>
<th>Number of Nodes</th>
<th>50</th>
<th>500</th>
<th>5,000</th>
<th>50,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVACNET Running Time</td>
<td>0.1 min</td>
<td>2.5 min</td>
<td>108 min</td>
<td>&gt; 5 days</td>
</tr>
</tbody>
</table>

Capacity-ignorant Approach
- Simple shortest path computation
- e.g. EXIT89 (National Fire Protection Association)

**Limitation:**
- Do not consider capacity constraints
- Very poor solution quality
Proposed Approach

• Existing methods can not handle large urban scenarios
  • Communities use manually produced evacuation plans

• Key Ideas in Proposed Approach
  • Generalize shortest path algorithms
  • Honor road capacity constraints
  • Capacity Constrained Route Planning (CCRP)
Performance Evaluation

Effect of Network Size

Setup: fixed number of evacuees = 5000, fixed number of source nodes = 10 nodes, number of nodes from 50 to 50,000.

- CCRP produces high quality solution, solution quality increases as network size grows.
- Run-time of CCRP is scalable to network size.

Figure 1 Quality of solution

Figure 2 Run-time
Scalability Test: Large Scenario

Evacuation Zone:
Source Radius: 10 mile
Dest. Radius: 10 mile

Number of Evacuees:
1.37 Million (Est. Daytime)

Transportation mode:
single occupancy vehicles

- Evacuation Zone
- TP+ network
- MnDOT basemap
Finding: Our algorithms scale to large scenarios!

- **Large Scenario:** 1.3 million evacuees
  - Within 494-694 circle (314 Square mile area)
  - Comparable to Rita evacuation in Houston

Evacuation Planning System for Twin Cities Metro Area
Step 3 of 3: Evacuation Route Plan  (go home)

**Scenario Name:**
- User Defined

**Evacuation Radius**
- Src Radius: 10.0 mile
- Dist Radius: 10.0 mile

**Population Estimate**
- Original Estimate: 1370286  (details)
- Adjusted Estimate: 1370286

**Time of Day:** Daytime

**Analysis Result**
- Number of destinations: 58
- Evacuation Time: 9 hr(s) 12 min
1. TP+ (Tranplan) road network for Twin Cities Metro Area

   Source: Met Council TP+ dataset
   Summary:
   - Contain freeway and arterial roads with road capacity, travel time, road type, area type, number of lanes, etc.
   - Contain virtual nodes as population centroids for each TAZ.
   Limitation: No local roads (for pedestrian routes)

2. MnDOT Basemap

   Source: MnDOT Basemap website (http://www.dot.state.mn.us/tda/basemap)
   Summary: Contain all highway, arterial and local roads.
   Limitation: No road capacity or travel time.
Demographic Datasets

1. Night time population
   • Census 2000 data for Twin Cities Metro Area
   • Source: Met Council Datafinder (http://www.datafinder.org)
   • Summary: Census 2000 population and employment data for each TAZ.
   • Limitation: Data is 5 years old; day-time population is different.

2. Day-time Population
   • Employment Origin-Destination Dataset (Minnesota 2002)
   • Source: MN Dept. of Employment and Economic Development
     - Contain work origin-destination matrix for each Census block.
     - Need to aggregate data to TAZ level to obtain:
       Employment Flow-Out: # of people leave each TAZ for work.
       Employment Flow-In: # of people enter each TAZ for work.
   • Limitation: Coarse geo-coding => Omits 10% of workers
   • Does not include all travelers (e.g. students, shoppers, visitors).
Defining A Scenario

State Fairgrounds, Daytime, 1 Mile Src - 2 Mile Dst,

Evacuation Planning System for Twin Cities Metro Area
Step 2 of 3: Adjust Scenario Settings (go home)

Scenario Name:
User Defined Refinery

Evac. Zone Adjustment
Source Radius: 1 mile
Destination Radius: 2 mile

Transportation Mode
Driving: 100%
Walking: 0%

Apply Parameters
(If any values of above parameters change, click 'Apply Parameters' button again. The Estimated value may decrease a little by applying parameters due to assignment)

Execute Planning Calculation
Run

Set source to 1 mile and destination to 2 mile
Click 'Apply Parameters' and wait for a while
If population estimate is shown, click 'run'.
Reviewing Resulting Evacuation Routes

State Fairgrounds, Daytime, 1 Mile Src - 2 Mile Dst,

Evacuation Planning System for Twin Cities Metro Area
Step 3 of 3: Evacuation Route Plan  

<table>
<thead>
<tr>
<th>Scenario Name:</th>
<th>User Defined</th>
</tr>
</thead>
</table>
| Evacuation Radius | Src Radius: 1 mile  
                     Dst Radius: 2 mile |
| Population Estimate | Original Estimate: 14431 (details)  
                       Adjusted Estimate: 14431 |
| Time of Day | Daytime |
| Analysis Result | Number of destinations: 45  
                   Evacuation Time: 3 hr(s) 16 min |

- Web-based
  - Easy Installation
  - Easy Maintenance
  - Advanced Security

- Simple Interface
  - User friendly and intuitive

- Comparison on the fly
  - Changeable Zone Size
  - Day vs. Night Population
  - Driving vs. Pedestrian Mode
  - Capacity Adjustment

- Visualized routes

Results with routes
Common Usage of the tool

- Current Usage: Compare options
  - Ex.: transportation modes
    - Walking may be better than driving for 1-mile scenarios
  - Ex.: Day-time and Night-time needs
    - Population is quite different

- Potential Usage: Identify bottleneck areas and links
  - Ex.: Large gathering places with sparse transportation network
  - Ex.: Bay bridge (San Francisco),

- Potential: Designing / refining transportation networks
  - Address evacuation bottlenecks
  - A quality of service for evacuation, e.g. 4 hour evacuation time
Finding: Pedestrians are faster than Vehicles!

Five scenarios in metropolitan area
Evacuation Zone Radius: 1 Mile circle, daytime

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Population</th>
<th>Vehicle</th>
<th>Pedestrian</th>
<th>Ped / Veh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario A</td>
<td>143,360</td>
<td>4 hr 45 min</td>
<td>1 hr 32 min</td>
<td>32%</td>
</tr>
<tr>
<td>Scenario B</td>
<td>83,143</td>
<td>2 hr 45 min</td>
<td>1 hr 04 min</td>
<td>39%</td>
</tr>
<tr>
<td>Scenario C</td>
<td>27,406</td>
<td>4 hr 27 min</td>
<td>1 hr 41 min</td>
<td>38%</td>
</tr>
<tr>
<td>Scenario D</td>
<td>50,995</td>
<td>3 hr 41 min</td>
<td>1 hr 20 min</td>
<td>36%</td>
</tr>
<tr>
<td>Scenario E</td>
<td>3,611</td>
<td>1 hr 21 min</td>
<td>0 hr 36 min</td>
<td>44%</td>
</tr>
</tbody>
</table>
Finding: Pedestrians are faster than Vehicles!

If number of evacuees > bottleneck capacity of network

<table>
<thead>
<tr>
<th># of Evacuees</th>
<th>200</th>
<th>2,000</th>
<th>10,000</th>
<th>20,000</th>
<th>100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving</td>
<td>4 min</td>
<td>14 min</td>
<td>57 min</td>
<td>108 min</td>
<td>535 min</td>
</tr>
<tr>
<td>Walking</td>
<td>18 min</td>
<td>21 min</td>
<td>30 min</td>
<td>42 min</td>
<td>197 min</td>
</tr>
<tr>
<td>Drv / Wlk</td>
<td>0.22</td>
<td>0.67</td>
<td>1.90</td>
<td>2.57</td>
<td>2.72</td>
</tr>
</tbody>
</table>

Driving / Walking Evacuation Time Ratio with regard to # of Evacuees

Small scenario – 1 mile radius circle around State Fairground
Key finding 2 – Finding hard to evacuate places!

- Scenario C is a difficult case
  - Same evacuation time as A, but one-fourth evacuees!
  - Consider enriching transportation network around C?
Summary Messages

• Evacuation Planning is critical for homeland defense
• Existing methods can not handle large urban scenarios
  • Communities use hand-crafted evacuation plans
• New Methods from Our Research
  • Can produce evacuation plans for large urban area
  • Reduce total time to evacuate!
  • Improves current hand-crafted evacuation plans
  • Ideas tested in the field
Who cares about evacuation planning?

- **Goal** - minimize loss of life and/or harm to public
  - First Responders
    - Which routes minimize evacuation time?
      - Respond to unanticipated events, e.g. Bridge failure, Accidents
  - Policy Makers, Emergency Planners
    - What transportation mode to use during evacuation?
      - Example, Walking, Private vehicles, Public transportation, …
    - Which locations take unacceptably long to evacuate?
      - Should one enrich transportation network to reduce evacuation time?
    - Should contra-flow strategy be used?
      - Texas Governor called for contra-flow on second day!
    - Should one used phased evacuation?

- **Goal** – Reduce loss of productivity due to congestion
  - Viking’s game, major conventions, … – **move parking 1 mile away?**
  - Long weekends – Fishing opener, July 4th - ?contra-flow (I-94 or Hwy 10)

*Plans are nothing; planning is everything.* -- Dwight D. Eisenhower
Current Limitations & Future Work

- **Evacuation time estimates**
  - Approximate and optimistic
  - Assumptions about available capacity, speed, demand, etc.
  - No model for public transportation, bikes, etc.

- **Quality of input data**
  - Population and road network database age!
    - Ex.: Rosemount scenario – an old bridge in the roadmap!
  - Data availability
    - Pedestrian routes (links, capacities and speed)

- **On-line editing capabilities**
  - Taking out a link (e.g. New Orleans bridge flooding)!
Future funding will ...

- Help the nation in the critical area of evacuation planning!
  - Save lives and reduce injuries by reducing evacuation time
  - Reduce productivity loss due to congestion at events (e.g. conventions, professional sports, long weekends such as 4th of July, Memorial day, Fishing opener etc.)

- Mature the research results into tools for first responders
  - Help them use explore many evacuation scenarios
  - Help them compare alternate evacuation routes, transportation modes, etc.
  - Identify hot-spots (e.g. places which take too long to evacuate)
  - Improve transportation networks to address hot-spots

- Develop new scientific knowledge
  - When to use each mode (e.g. public transportation, pedestrian, SOVs) ?
  - How to plan multi-modal evacuation routes and schedules?
  - How to model capacities, speed and flow-rate for public transportation, pedestrians?
  - Panic management
Acknowledgements

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  • Univ. of Minnesota - Sangho Kim, Qingsong Lu, and Betsy George
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  •                Mike Sobolesky, Eil Kwon
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