Evacuation Route Planning

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Evacuation Worskhop
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Note: Many of the results presented in these slides are summarized in the following paper:
Evacuation Planning: A Spatial Network Database Approach, *IEEE* Data Eng. Bulletin, 33(2): 26-31 (2010).
(http://sites.computer.org/debull/A10june/Shashi.pdf).

Transportation Motivation

- CONGESTION: increasingly congested facilities across all modes;
- ENERGY, ENVIRONMENT, AND CLIMATE CHANGE: extraordinary challenges;
- INFRASTRUCTURE: enormous, aging capital stock to maintain;
- FINANCE: inadequate revenues;
- EQUITY: burdens on the disadvantaged;
- EMERGENCY PREPAREDNESS, RESPONSE, AND MITIGATION: vulnerability to natural disasters and terrorist

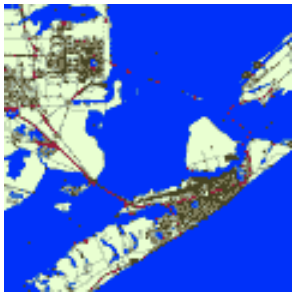
The slow and ineffective evacuations from Hurricanes Katrina and Rita in 2005 pointed to the importance of having plans that can be executed and of ensuring that intergovernmental collaborations are effective. In addition, the evacuations highlighted the need to plan and provide for transportation facilities that are adequate for response to, and recovery from, terrorist attacks and natural disasters.

ions mismatched to

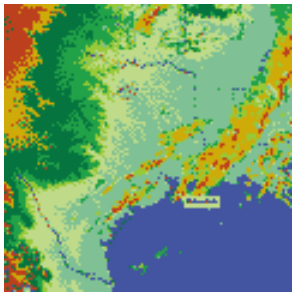
AL: inadequate

Homeland Defense & Evacuation Planning

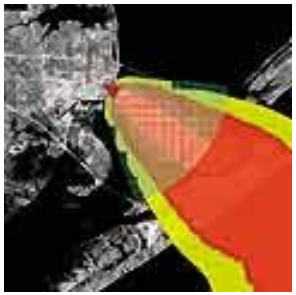
- Preparation of response to an attack
- Plan evacuation routes and schedules
- Help public officials to make important decisions
- Guide affected population to safety



Base Map



Weather Data

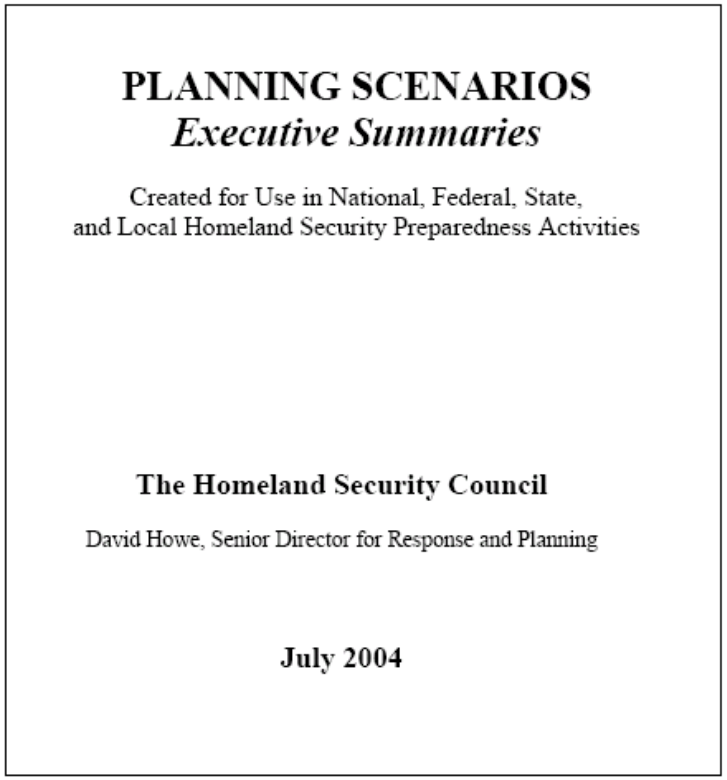


Plume Dispersion

Demographics Information

Transportation Networks

(*Images from www.fortune.com*)



PLANNING SCENARIOS
Executive Summaries

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

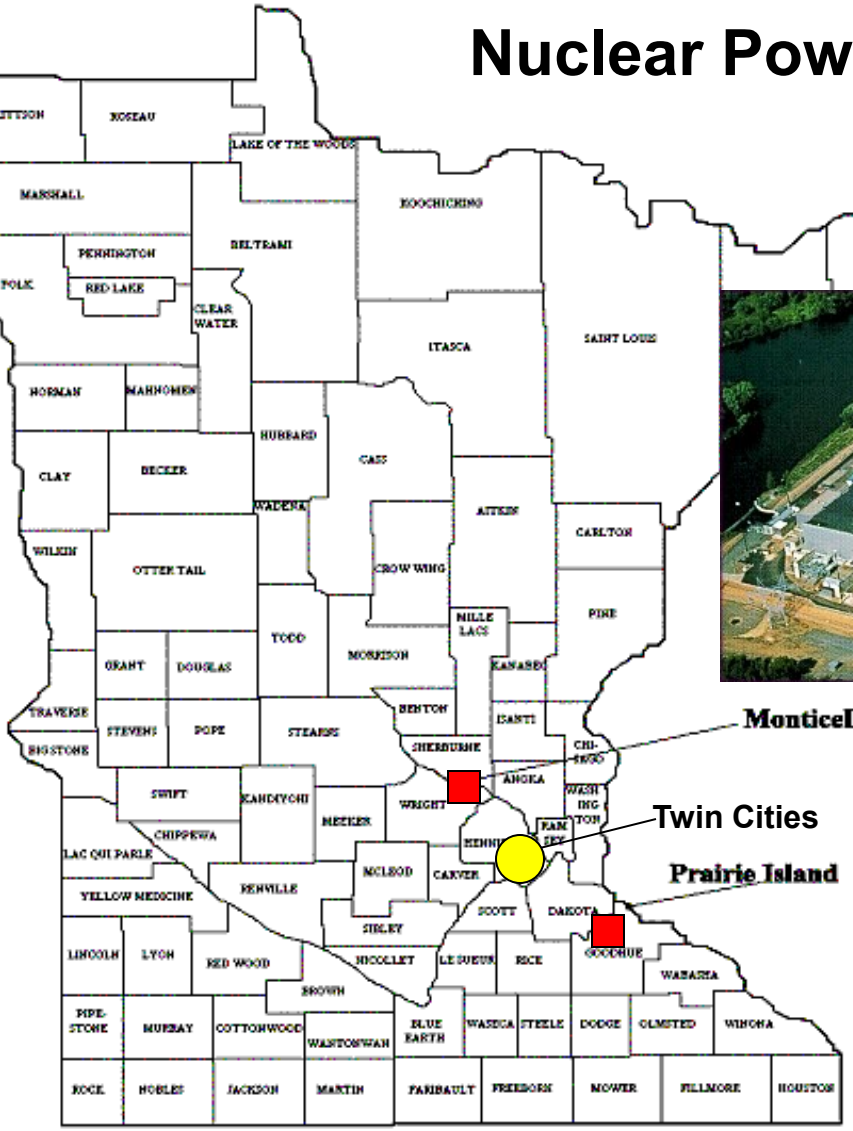
The Homeland Security Council

David Howe, Senior Director for Response and Planning

July 2004

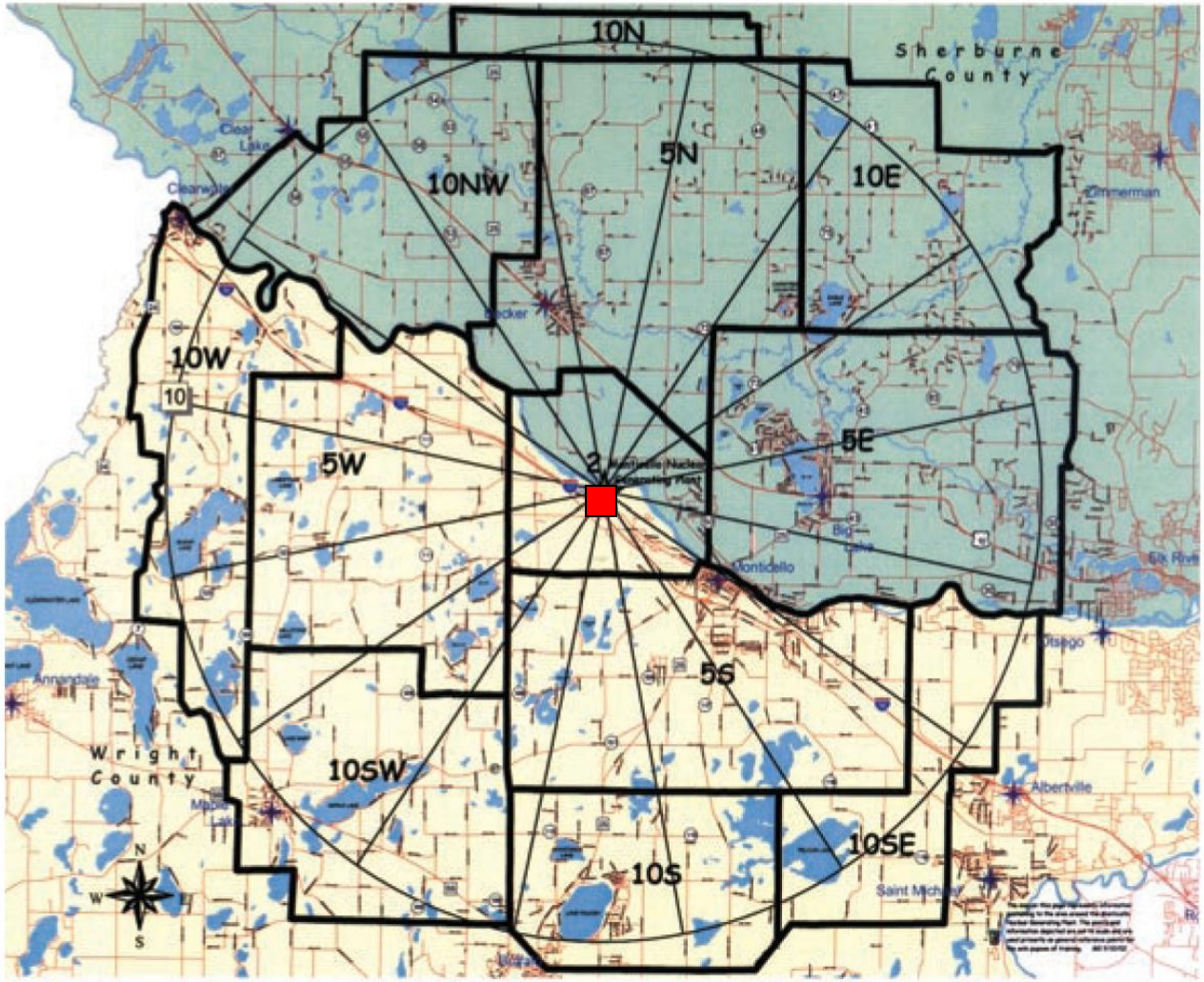
Example – Monticello Nuclear Power Plant

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.



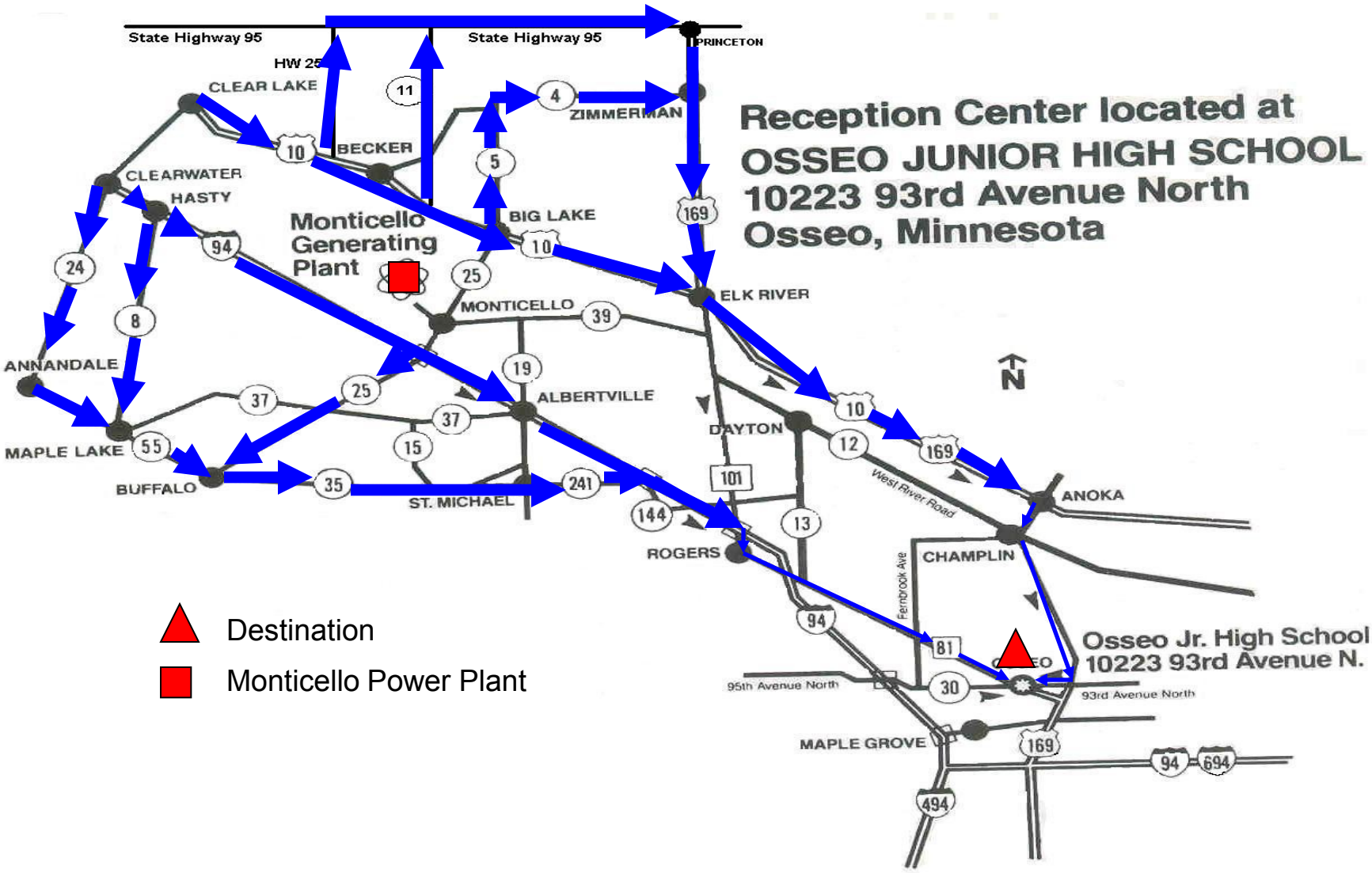
Monticello EPZ

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

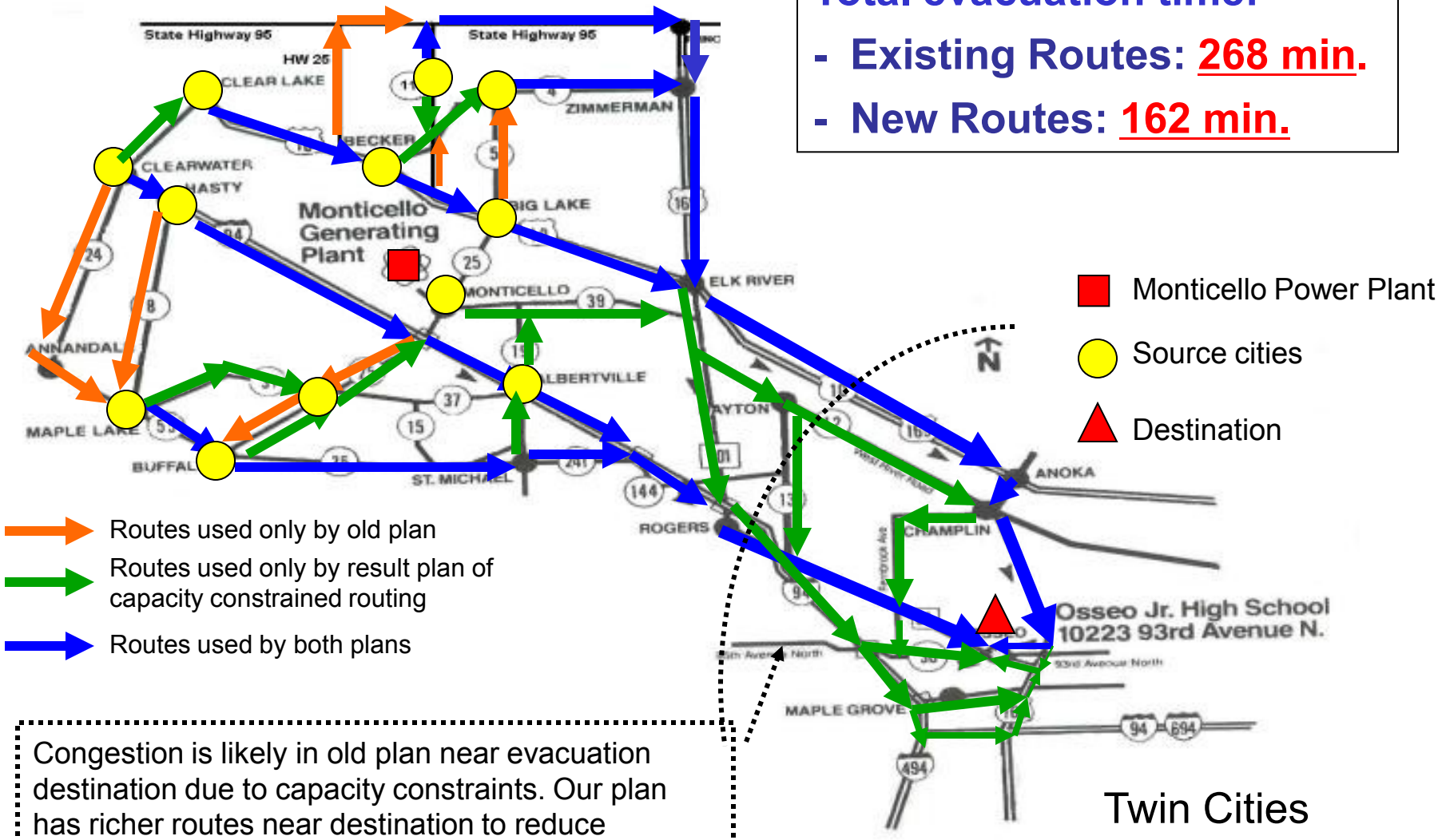
Existing Evacuation Routes (Handcrafted)



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 – US-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

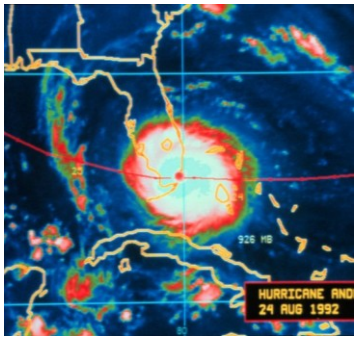
Why avoid conflicts among local plans?

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

- Great confusions and chaos

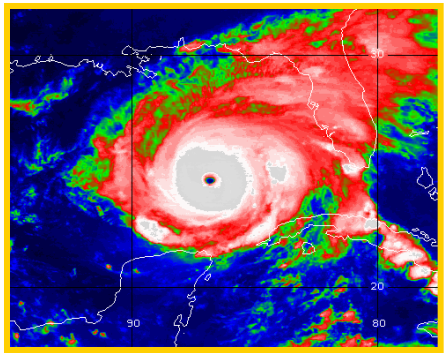
"We packed up Morgan City residents to evacuate in the a.m. on the day that Andrew hit coastal Louisiana, but in early afternoon the majority came back home. **The traffic was so bad that they couldn't get through Lafayette**."
Mayor Tim Mott, Morgan City, Louisiana
(http://i49south.com/hurricane.htm)

Florida, Lousiana (Andrew, 1992)



(National Weather Services)

Houston (Rita, 2005)



(National Weather Services)

(www.washingtonpost.com)

I-45 out of Houston

(FEMA.gov)

Acknowledgements

- **Sponsors**
  - CTS, MnDOT
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  - MnDOT - Sonia Pitt, Robert Vasek, Cathy Clark
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- **Participating Organizations**
  - MN-DPS – Minnesota Department of Public Safety
  - MEMA – Minnesota Emergency Management Association
  - Mpls./St. Paul Emergency Mgmt.
  - MN: 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

Metropolitan Wide Evacuation Planning - 2

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

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Dick Guevremont, Minnesota Department of Education

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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

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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 Walerius, Minnesota State Patrol
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Mike Morehead, St. Paul Police

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Dan Schacht, Ramsey County

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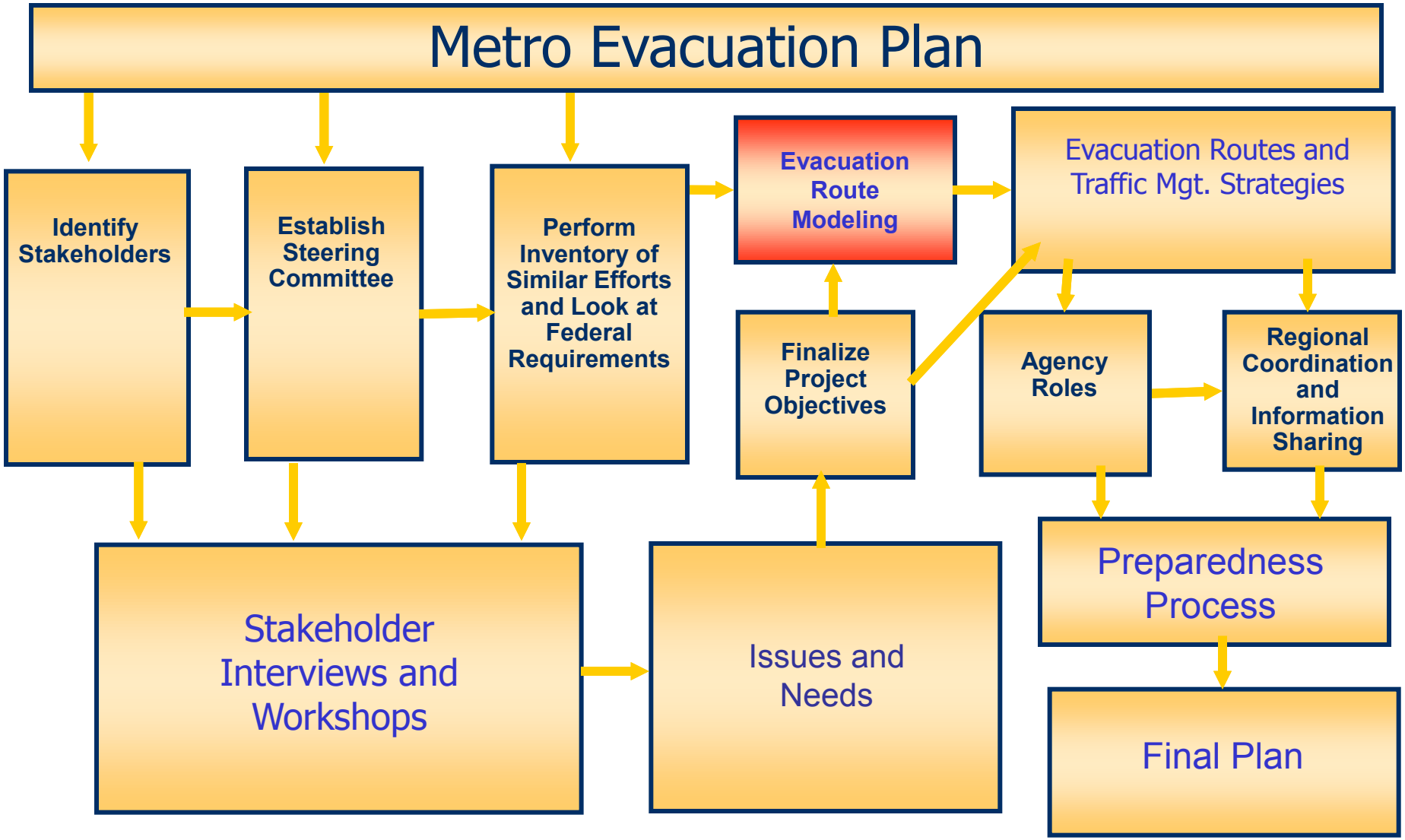
Bernie Arseneau, Mn/DOT
Amr Jabr, Mn/DOT
Eil Kwon, Mn/DOT
Paul St. Martin, City of St. Paul

Trucking
John Hausladen, Minnesota Trucking Association

University
Dan JohnsonPowers,
University of Minnesota Emergency Management

Volunteer Organizations
Gene Borochoff, MinnesotaVolunteer Organization active in Disaster

Task-structure



Problem Definition

Given

- A transportation network, a directed graph $G = (N, E)$ with
  - Travel time for each edge (a.ka. Link)
  - Capacity constraint for each edge and node
- 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

Number of Nodes	50	500	5,000	50,000
EVACNET Running Time	0.1 min	2.5 min	108 min	> 5 days

Commuter Traffic Simulation Approach

- Game Theory: Wadrop Equilibrium among commuters over a few weeks
- e.g. DYNASMART, TRANSIM, …

Limitation:

- Requires a lot of data, e.g. traffic signal timing
- Does not scale, Needs tremendous amount of computing

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 (e.g. Google Map)
  - 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.

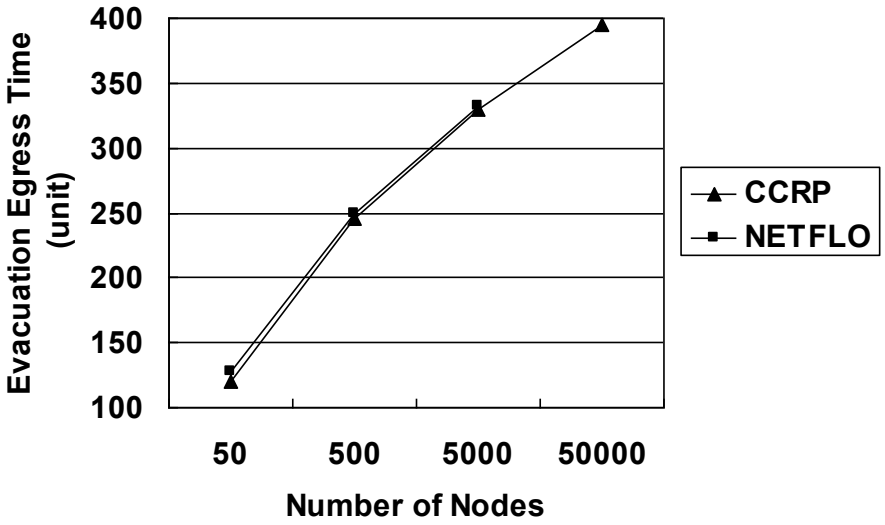
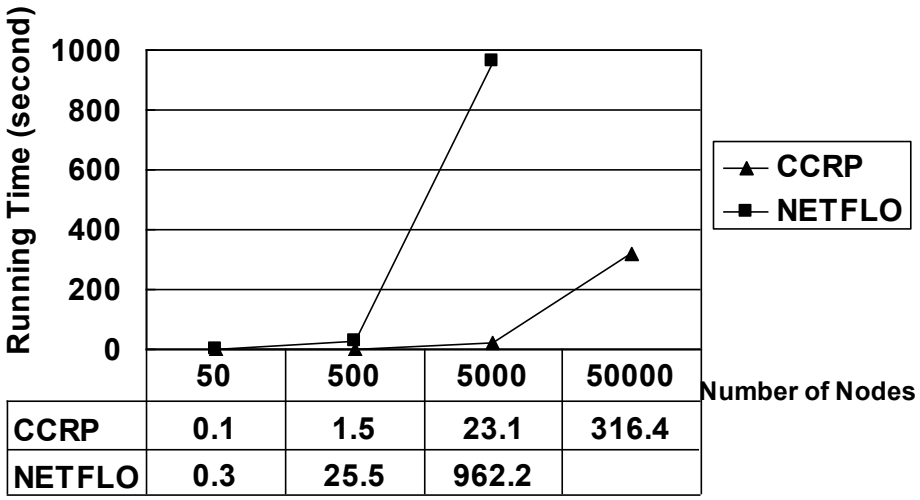


Figure 1 Quality of solution



	50	500	5000	50000
CCRP	0.1	1.5	23.1	316.4
NETFLO	0.3	25.5	962.2	

Figure 2 Run-time

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

Performance Evaluation : Effect of Number of Evacuees

Setup: fixed network size = 5000 nodes, fixed number of source nodes = 2000 nodes, number of evacuees from 5,000 to 50,000.

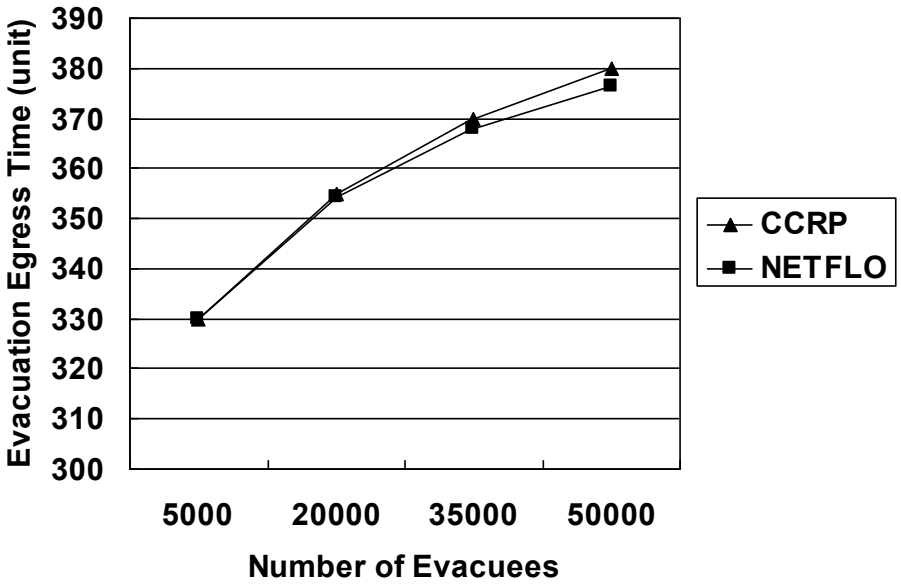


Figure 1 Quality of solution

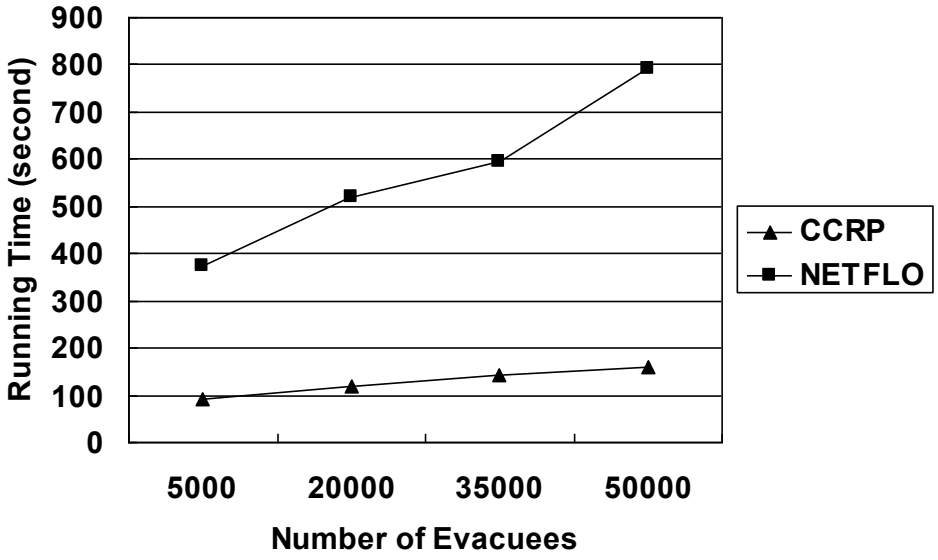


Figure 2 Run-time

- CCRP produces high quality solution, solution quality drops slightly as number of evacuees grows.
- Run-time of CCRP is less than 1/3 that of NETFLO.
- CCRP is scalable to the number of evacuees.

Road Networks

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

Population Adjustment

Original Estimate: 14431 (details)

Adjusted Estimate: 14431

Change time of day: Daytime / Nighttime

Transportation Mode

Driving: 100 %

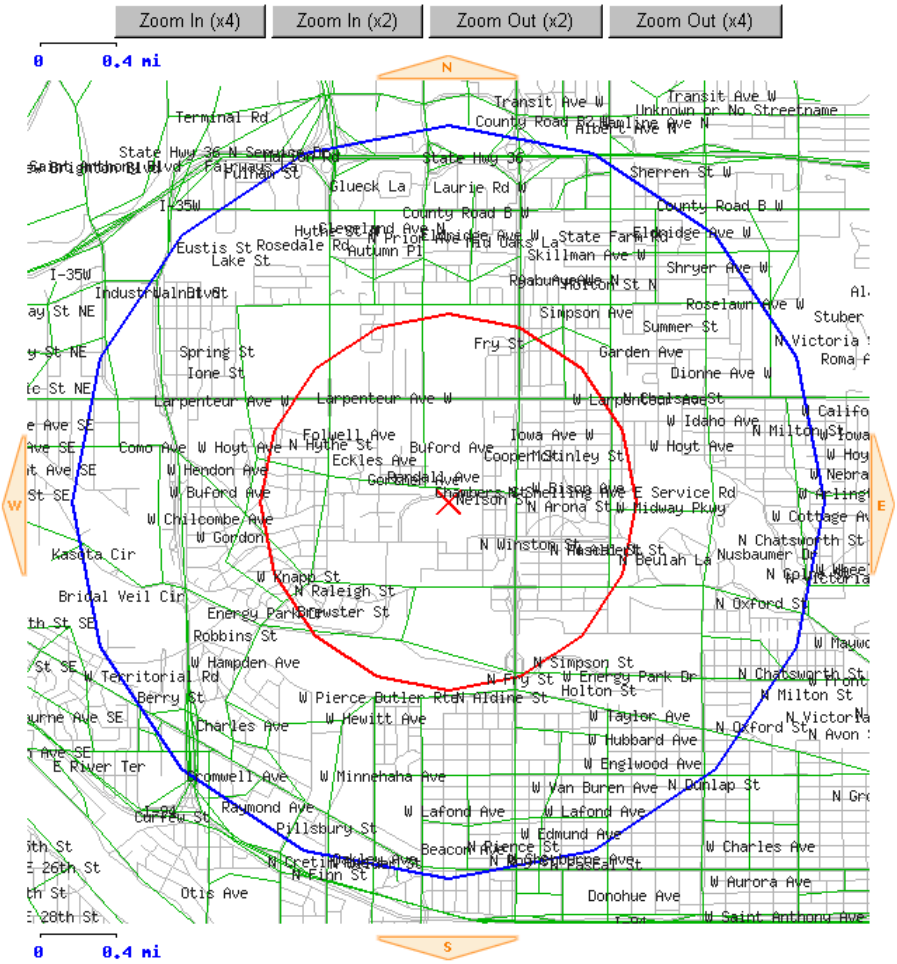
Walking: 0 %

Apply Parameters

(if some values of above parameters change, always click 'Apply Parameters' button again.)
(Adjusted Estimate value may decrease a little after 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 (go home)

Scenario Name:

User Defined

Evacuation Radius

Src Radius: 1 mile
Dst Radius: 2 mile

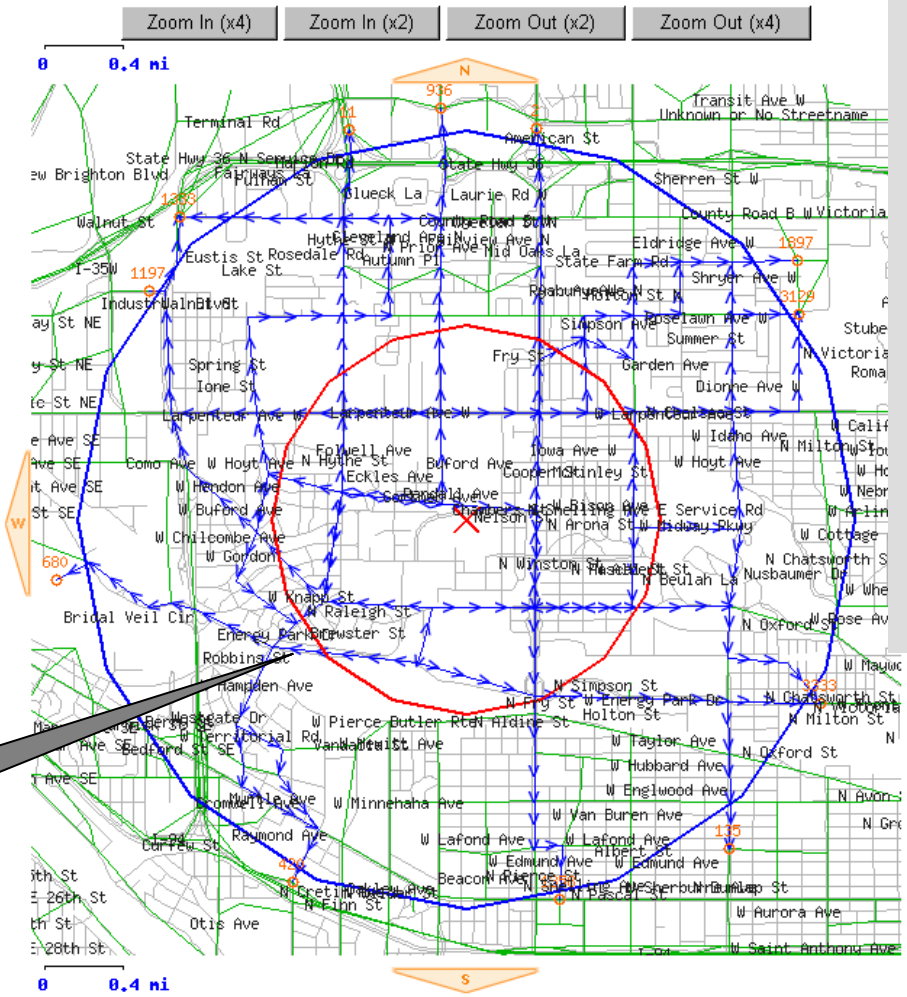
Population Estimate

Original Estimate: 14431 (details)
Adjusted Estimate: 14431

Time of Day: Daytime

Analysis Result

Number of destinations: 45
Evacuation Time: 3 hr(s) 16 min



Results with routes

- **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**

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

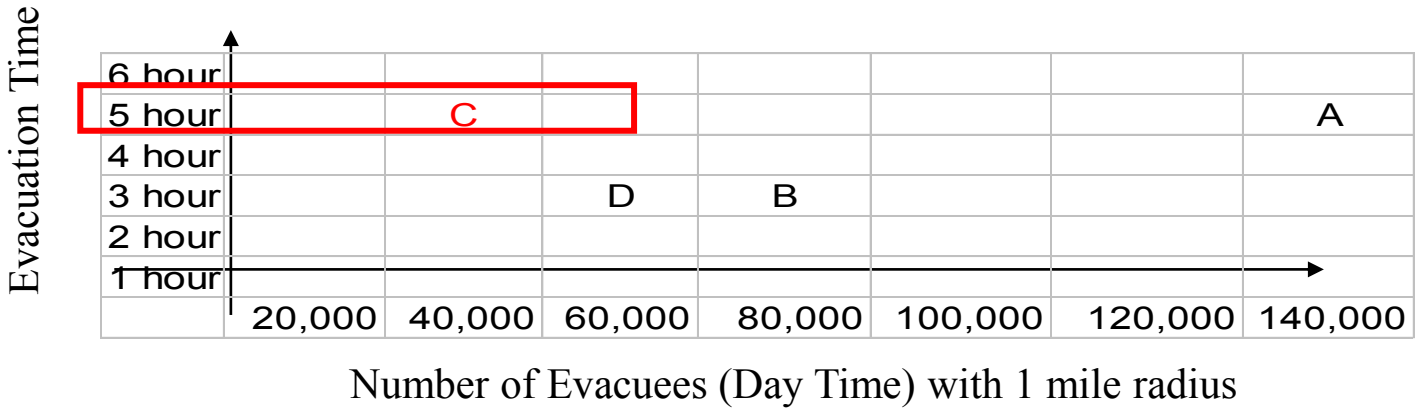
Finding: Pedestrians are faster than Vehicles!

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

Scenario	Population	Vehicle	Pedestrian	Ped / Veh
Scenario A	**143,360**	**4 hr 45 min**	**1 hr 32 min**	**32%**
Scenario B	**83,143**	**2 hr 45 min**	**1 hr 04 min**	**39%**
Scenario C	**27,406**	**4 hr 27 min**	**1 hr 41 min**	**38%**
Scenario D	**50,995**	**3 hr 41 min**	**1 hr 20 min**	**36%**
Scenario E	**3,611**	**1 hr 21 min**	**0 hr 36 min**	**44%**

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

- CCRP is better than hand-crafted plans because
  - It provide better routes to reduce evacuation time
  - It can identify bottlenecks
  - It facilitates frequent revisions
- CCRP is better than Google Map
  - It accounts for capacity constraints to reduce congestion
- CCRP is better than Commuter simulation & Math. Programming
  - It needs less data
  - It is (orders of magnitude) faster
    - Usable during emergency response
    - Scales up to larger scenarios, large number of scenarios
  - It has been field tested by emergency managers

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) !

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- **Key Individuals**

  - Univ. of Minnesota - Sangho Kim, Qingsong Lu, and Betsy George
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