Metropolitan Evacuation Planning and Operations – Tool and Methodology

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Agenda

• Background
• Objective
• Tool
• Methodology
• Case Study Analysis
• Conclusion
What We Learned from the Past

- Disaster scenario difficult to predict
- Oversaturated evacuation routes
  - Too few routes
  - Too much flow appear simultaneously
- Uncoordinated evacuees
  - Destinations, departure times and routes
- Under-preparedness of gas stations, triages or shelters
  - Too much circulating traffic
  - Spillbacks to freeways
  - Vehicle breakdown due to congestion and overheat
- Decisions in contra-flow was not based on system-wide impact assessment
  - Traffic spillbacks caused by contra-flow lanes

Scenario-based preconceived plans at best relevant for initial response, at worst useless

An optimal analysis platform is key in analyzing, planning and implementing possible strategies in case of evacuation
Challenges of Emergency Evacuation

- Emergency evacuation is complex:
- Hazardous event dependent
  - Lead times (e.g. no-notice vs. short-notice)
  - Impact areas
  - Extent of the evacuations, ...
- Evacuee and driver behavior unknown
- Challenges in communicating with and coordinating evacuees and responders
- Needs multiple and flexible response strategies

The Objective

- To develop a methodology integrating dynamic traffic assignment (DTA) approaches for evacuation modeling
- The major operation decisions to make
  - Where? – Optimal destinations
  - When? – Phased evacuation times
  - Which route? – Optimal evacuation routes
  - How many at what time? – Optimal traffic assignment
Cell Transmission Model

- Carlos F. Daganzo (1994):
  - proposed hydrodynamic macroscopic traffic flow simulation model called Cell Transmission Model (CTM)
  - Used CTM to formulate the SO DTA problem as a Linear Program (LP)

\[
\sum_{i \in I} \sum_{t \in T} C_{i} S_{i} x_{i}^{s} - x_{i}^{d} = 0 \quad \forall i \in C, \forall t \in D (1)
\]

\[
x_{i}^{s} - \chi_{i}^{s} \leq 0, \quad \chi_{i}^{s} \leq Q_{i} \quad \forall (i,j) \in B_{u}, \forall t \in D (2)
\]

\[
x_{i}^{s} - \chi_{i}^{t} \leq 0, \quad \chi_{i}^{t} \leq Q_{i} \quad \forall (i,j) \in B_{v}, \forall t \in D (3)
\]

\[
\sum_{i \in I} \chi_{i}^{s} \leq 0, \quad \sum_{i \in I} \chi_{i}^{t} \leq Q_{i} \quad \forall i \in C_{u}, \forall t \in D (4)
\]

\[
\sum_{i \in I} \chi_{i}^{s} \leq Q_{i}, \quad \sum_{i \in I} \chi_{i}^{t} \leq Q_{i} \quad \forall i \in C_{v}, \forall t \in D (5)
\]

\[
x_{i}^{s} - \chi_{i}^{s} + \sum_{i \in I} \chi_{i}^{s} \leq d_{i}^{s} \quad \forall i \in I \cup \{0\}, \forall t \in D (6)
\]

\[
\sum_{i \in I} \chi_{i}^{s} = 0 \quad \forall (i,j) \in B, \forall t \in D (7)
\]

\[
\chi_{i}^{s} = 0 \quad \forall i \in C, \forall t \in D (8)
\]

\[
\chi_{i}^{d} = 0 \quad \forall i \in C, \forall t \in D (9)
\]

\[
x_{i}^{d} \geq 0 \quad \forall i \in I \cup \{0\}, \forall t \in D (10)
\]

\[
\chi_{i}^{d} \geq 0 \quad \forall (i,j) \in B, \forall t \in D (11)
\]

\[
\chi_{i}^{s} \geq 0 \quad \forall i \in C, \forall t \in D (12)
\]

\[
\chi_{i}^{d} \geq 0 \quad \forall (i,j) \in B, \forall t \in D (13)
\]
Cell Transmission Model

Basic Characteristics of CTM

\[ q = \min \left\{ k, q_{\text{max}}, w\{k - j\} \right\} \text{ for } 0 \leq k \leq k_j \]  

Equation of State

Flow-Density Curve

Single Destination Evacuation Modeling Concept

Node Arc to CTM Network Transformation

LP model in the Standard form:

Minimize \( C^T X \)

s.t.

\( AX = b \)
**El Paso and Dallas Fort Worth Network in CTM**

**Case Study**

**Transformed Network:**
- 18 nodes, 32 links
- 5 origins, 3 destinations, 2 shelters
- 1 super-sink
- Demand = 160 (node1 = 100, others = 15)
- One way links with max flow 4320 vph

**Cell Network:**
- 108 cells, 138 connectors
- 5 origins cells, 3 destinations cells
- 2 shelter cells (capacity 20 veh. in each)
- 1 super-sink cell
- One clock tick = 5 secs.
Case Study

- Rolling Horizon = 30 steps
- within 20 steps veh. reached shelter cells; in capacity
- within 28 steps all veh. reached the dest.
- Dest. 15 received 43.3% of flow units
- Dest 17 – 37.5 %
- Dest 16 – 19.2 %

Flow distribution at origins

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<th>Nodes</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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</table>

Dallas Ft. Worth – CTM and Dynasmart-P

The Network:
13 Zones
200 Nodes and 445 links

Scenario:
82 origin nodes
2 destination nodes
Demand = 525 flow units
Super-sink Node = 201

Flow distribution at origins
Dallas Ft. Worth- CTM

Cell Network:
1953 Cells, 3084 Connectors
82 origin cells
2 destination cells
1 super-sink cell

One clock tick (step) = 6 secs.
Rolling Horizon = 70 steps

Flow units reached the destinations in 53 steps
(5.3 minutes)
### Dallas Ft. Worth: CTM and Dynasmart-P

#### CTM and Dynasmart-P – Dallas Ft. Worth

<table>
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<th>SN</th>
<th>Dynasmart – P</th>
<th>CTM</th>
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<tr>
<td>1</td>
<td>Maximum number of iterations</td>
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<td>2</td>
<td>Current iterations</td>
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<td>3</td>
<td>Total Vehicles</td>
<td>525</td>
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<td>4</td>
<td>Max simulation intervals</td>
<td>900</td>
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<td>5</td>
<td>Actual simulation intervals</td>
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<td>6</td>
<td>Total Travel times (Hrs)</td>
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<td>7</td>
<td>Average travel times (mins)</td>
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<td>Total trip times (including entry queue time)</td>
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<td>Avg. trip times (including entry queue time) (mins)</td>
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<td>Total entry queue times (Hrs)</td>
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<td>Avg. entry queue time (mins)</td>
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<td>Total trip distance (miles)</td>
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<tr>
<td>13</td>
<td>Avg. trip distance (miles)</td>
<td>2.5830</td>
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Conclusion

• The concept of single destination (super-sink) has been successful for solving the evacuation related problems.

• Optimal solutions give the Emergency Management Agency (EMA) an evacuation GOAL to target at, instead of using trial-and-error approach

• Future research includes generating computationally efficient tools for solving large networks

Open Forum