Metropolitan Evacuation Planning and Operations – Tool and Methodology

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Agenda

- Background
- Objective
- Tool
- Methodology
- Case Study Analysis
- Conclusion

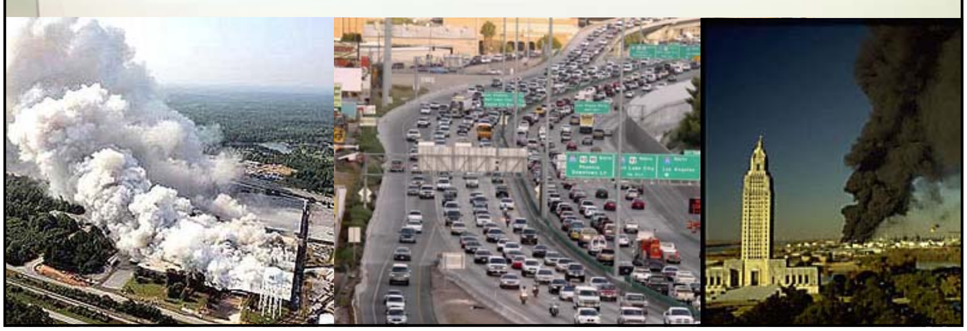
What We Learned from the Past

- 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

What We Learned from the Past

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)
- Athanasios K. Ziliaskopoulos (2000):
  - Used CTM to formulate the SO DTA problem as a Linear Program (LP)

Joint Evacuation Destination-Route-Flow-Departure Time (JEDRFD) Problem

Minimize $\sum_{\forall t \in \Im} \sum_{\forall i \in C \setminus C_s} x_i^t$

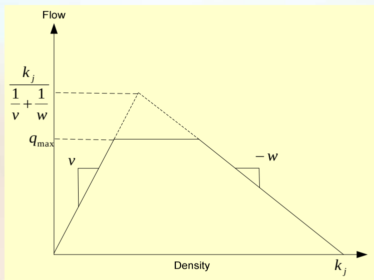
$x_i^t - x_i^{t-1} - \sum_{k \in \Gamma^{-1}(i)} y_{ki}^{t-1} + \sum_{j \in \Gamma(i)} y_{ij}^{t-1} = 0$	$\forall i \in C \setminus \{C_R, C_S\}, \forall t \in \Im$	(1)
$y_{ij}^t - x_i^{t-1} \le 0, y_{ij}^t \le Q_j^t, y_{ij}^t \le Q_i^t, y_{ij}^t + \delta_j^t x_j^t \le \delta_j^t N_j^t$	$\forall (i,j) \in \hbar_O \cup \hbar_R, \forall t \in \Im$	(2)
$y_{ij}^t - x_i^{t-1} \le 0, y_{ij}^t \le Q_j^t$	$\forall (i,j) \in \hbar_S, \forall t \in \Im$	(3)
$y_{ij}^t \le Q_j^t, y_{ij}^t + \delta_j^t x_j^t \le \delta_j^t N_j^t$	$\forall (i,j) \in \hbar_D, \forall t \in \Im$	(4)
$\sum_{j \in \Gamma(i)} y_{ij}^t - x_i^t \le 0, \sum_{j \in \Gamma(i)} y_{ij}^t \le Q_i^t$	$\forall i \in C_D, \forall t \in \Im$	(5)
$y_{ij}^t - x_i^t \le 0, y_{ij}^t \le Q_i^t$	$\forall (i,j) \in \hbar_M, \forall t \in \Im$	(6)
$\sum_{i \in \Gamma^{-1}(j)} y_{ij}^t \le Q_i^t, \sum_{i \in \Gamma^{-1}(j)} y_{ij}^t + \delta_j^t x_j^t \le \delta_j^t N_j^t$	$\forall j \in C_M, \forall t \in \Im$	(7)
$x_i^t - x_i^{t-1} + y_{ij}^{t-1} = d_i^{t-1}$	$\forall j \in \Gamma(i), \forall i \in C_R, \forall t \in \Im,$ $x_i^0 = \xi_i, \forall i \in C$	(8)
$d_i^{t-1} = \begin{cases} \hat{d}_i \\ 0 \end{cases}$	$\forall i \in C_R, \forall t = 1$ $\forall i \in C_R, \forall t > 1$	(9)
$y_{ij}^0 = 0$	$\forall (i,j) \in \hbar$	(10)
$x_i^t = \hat{x}_i$	$\forall i \in C, \forall t = 0$	(11)
$x_i^t \ge 0$	$\forall i \in C, \forall t \in \Im$	(12)
$y_{ij}^t \ge 0$	$\forall (i,j) \in \hbar, \forall t \in \Im$	(13)

Cell Transmission Model

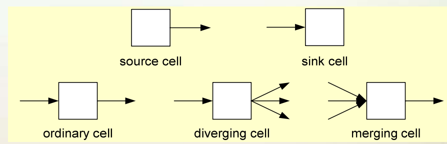
Basic Characteristics of CTM

$$q = \min\{vk, q_{max}, w(k_j - k)\}, \quad for \quad 0 \le k \le k_j \qquad (1)$$

Equation of State



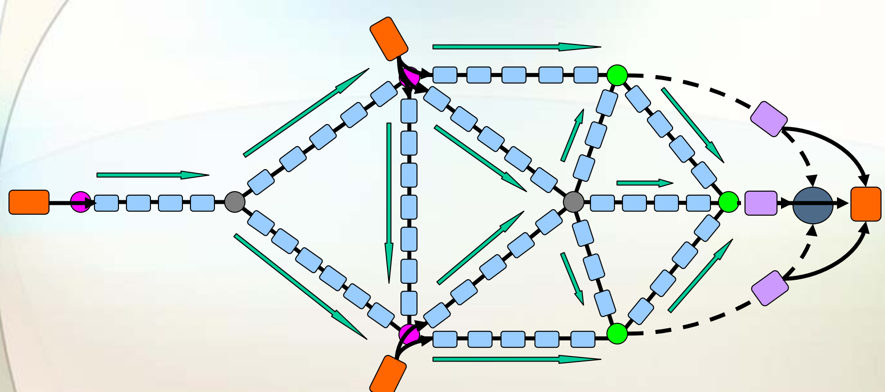
Flow-Density Curve



Various Cell Types used in CTM

Single Destination Evacuation Modeling Concept

Node Arc to CTM Network Transformation



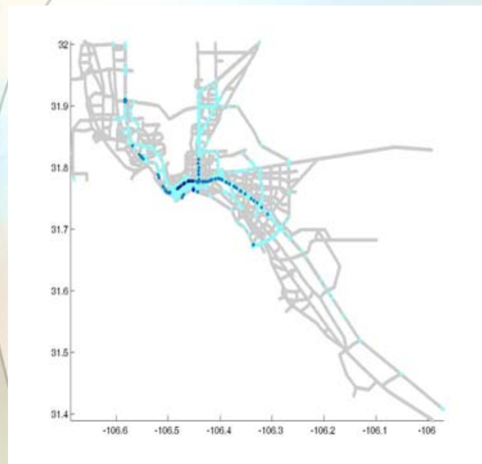
LP model in the Standard form:

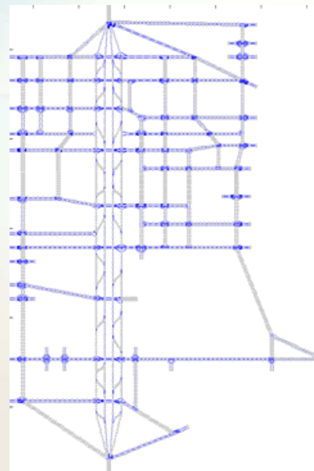
Minimize C^TX

s.t.

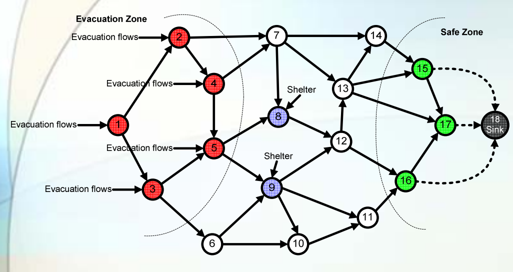
$AX = b$

El Paso and Dallas Fort Worth Network in CTM

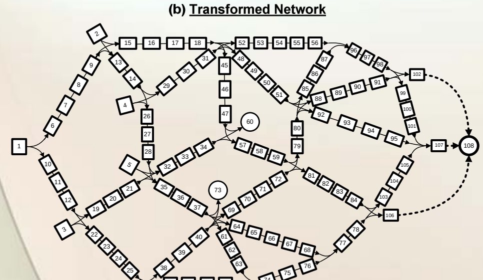




Case Study



(b) Transformed Network



(c) Cell Network

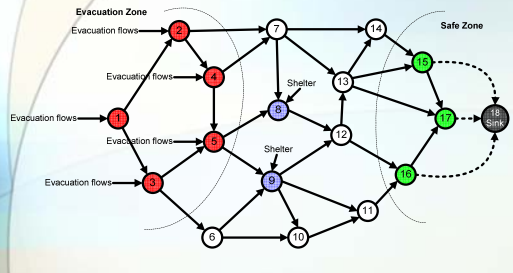
Transformed Network:

- 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:

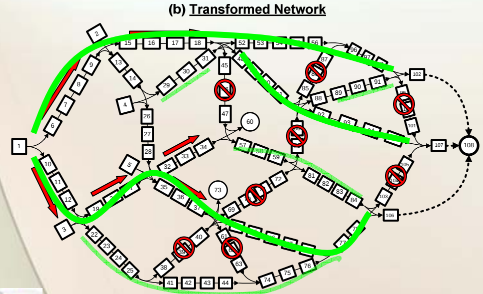
- 108 cells, 138 connectors
- 5 origins cells, 3 destinations cells
- 2 shelter cells (capacity 20 veh. in each)
- 1 super-sink cell
- one clock tick = 5 secs.

Case Study



(b) Transformed Network

- 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 %



(c) Cell Network

Flow distribution at origins

nodes	1	2	3	4	5	6	7	8	9
1		50	50						
2				35			65		
3					55	45			
4					33		77		
5								50	50

Dallas Ft. Worth – CTM and Dynasmart-P

The Network:

13 Zones

200 Nodes and 445 links

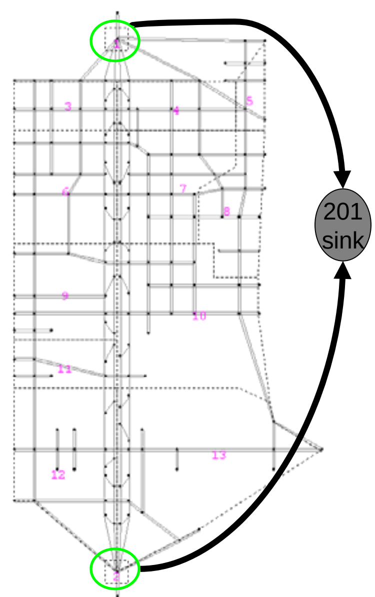
Scenario:

82 origin nodes

2 destination nodes

Demand = 525 flow units

Super-sink Node = 201



Dallas Ft. Worth- CTM

Cell Network:

1953 Cells, 3084 Connectors

82 origin cells

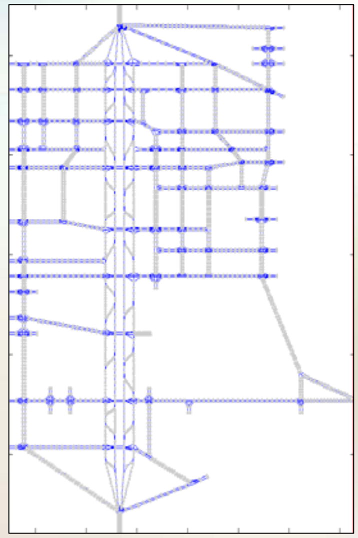
2 destination cells

1 super-sink cell

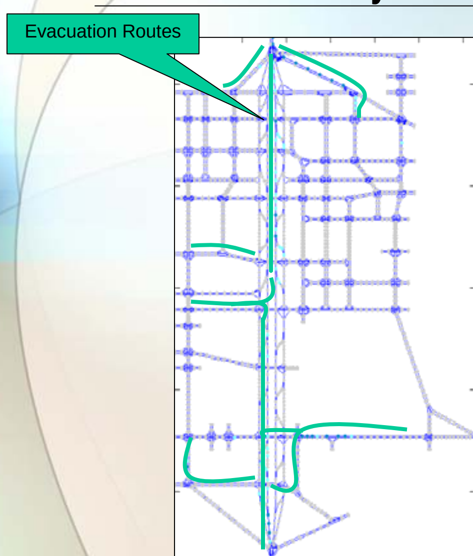
One clock tick (step) = 6 secs.

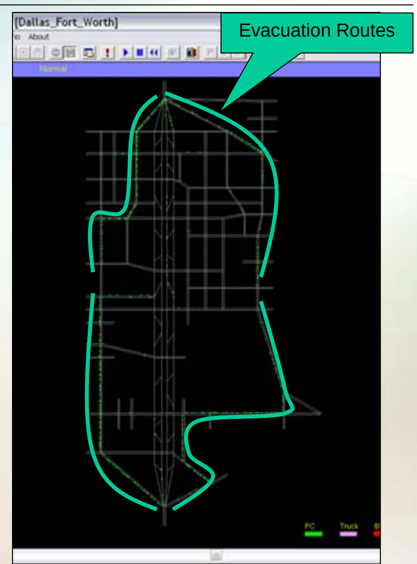
Rolling Horizon = 70 steps

Flow units reached the destinations in 53 steps (5.3 minutes)

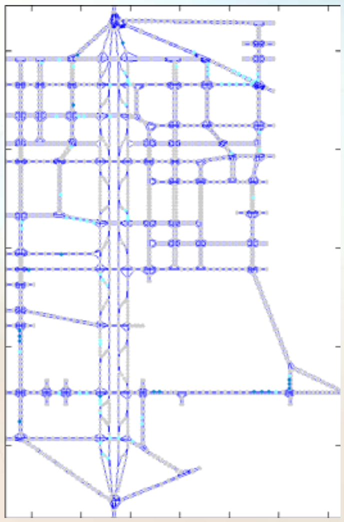


Dallas Ft. Worth- Dynasmart – P and CTM





Dallas Ft. Worth: CTM and Dynasmart-P



CTM and Dynasmart-P – Dallas Ft. Worth

SN		Dynasmart – P	CTM
1	Maximum number of iterations	10	100
2	Current iterations	3	58
3	Total Vehicles	525	525
4	Max simulation intervals	500	70
5	Actual simulation intervals	122	53
6	Total Travel times (Hrs)	36.2698	25.5552
7	Average travel times (mins)	4.1451	2.9205
8	Total trip times (including entry queue time)	37.1165	27.0466
9	Avg. trip times (including entry queue time) (mins)	4.1036	3.0910
10	Total entry queue times (Hrs)	0.8467	1.4914
11	Avg. entry queue time (mins)	0.0968	0.1704
12	Total trip distance (miles)	1356.0784	1170.6767
13	Avg. trip distance (miles)	2.5830	2.2298

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

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