Critical Intersection Signal Optimization During Urban Evacuation Utilizing Dynamic Programming

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National Evacuation Conference
February 3-5 2010
New Orleans

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Overview

- Introduction
- Problem Statement
- Literature Review
- Objectives/Methodology
- Case study
- Calibration
- Result/Discussion
- Conclusion
- Further Work

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Introduction: Catastrophic Events

- Natural Disasters
  - Hurricanes
  - Floods
  - Land Slides
  - Tsunamis
  - Wild Fires
  - Earthquakes

Introduction: Catastrophic Events

- Man Made Disasters
  - Terrorist Attacks
  - Nuclear Explosions
  - Chemical Releases
  - Biological Warfare

Problem Statement

- Major cities throughout the world rely on pre-timed signal control settings
- During emergency evacuation most Metropolitan planning organizations (MPO) rely solely on Peak Time Hours
- Pre-timed signals for evacuation could be developed

Literature Review

Signal Timing and Urban Evacuation

- (Fang, 2004)
  - Used Dynamic Programming for adaptive control of a diamond interchange
  - Utilized forward recursion
  - Found DP greatly reduced delay time and increased overall network performance
- (Chen, 2005)
  - Studied signal timing for no-notice evacuation in urban areas
  - Found a trade off exist between long cycle length which can ultimately reduce total delay time
  - Used microscopic modeling tools for his evaluation

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Literature Review

Simulation and Evacuation

- (Lui et al., 2008)
  - Examines various critical issues of planning and operations during evacuation.
  - Developed optimum routing and signal timings during evacuation
  - Utilized macroscopic modeling techniques for traffic analysis

- (Noh et al.,2009)
  - Reviewed modeling demand during evacuation.
  - Found that socio-economic data is accurate for trip generation in evacuation

Literature Review

- There exist a gap between research in the field of traffic operations and emergency evacuation.
- Many tools have been developed to assist in traffic control but few have been used to assist in emergency evacuation planning.

Objective

- The objective of this research is to define a methodology for utilization dynamic programming to development optimum pre-timed signal controls in the case of an urban evacuation

www.msnbc.msn.com

Methodology

- Origin Destination Matrixes created from trip generation and distribution
- A micro-simulation model was developed for an urban corridor
- Optimum Pre-Timed signal settings were developed using dynamic programming
- These settings were compared to the PM Peak hour signal timing provided by the MPO

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Trip Generation

$$G_i = E_i B_i \left(1 - \frac{L_i}{2} - \frac{\gamma_i}{3.5}\right) + U_i P_i (1 - V_i) + \sum_{t=0}^{T} \sum_{j=1}^{J} C_{j,i} - \sum_{t=0}^{T} \sum_{j=1}^{J} C_{i,t} \qquad \forall i$$

- Where,
  - G_i=vehicles generated from i
  - E_i=employment in i
  - B_i= percent vehicular commuters
  - L_i=car pool percent with two riders
  - γ_i=car pool percent with 3 or more
  - U_i=unemployment rate in i
  - P_i=population in i
  - V_i=percent of people with vehicles in i
  - C_{ij}=vehicles leaving i to j
  - C_{ji}=vehicles on entering i from j

Trip Distribution

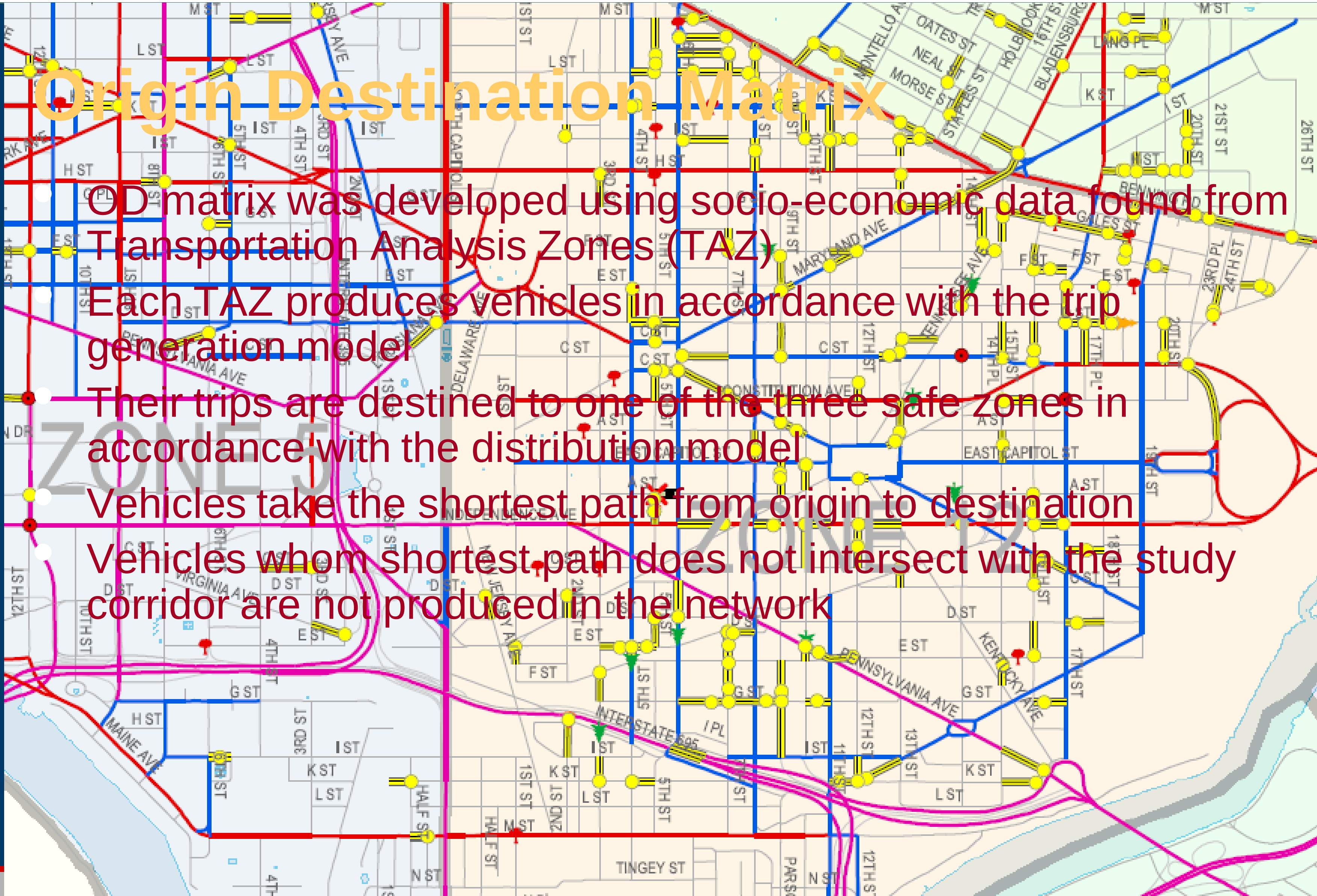
$$\varepsilon_{i,j} = \rho_{i,j} G_i \qquad \forall i, j$$

$$\rho_{i,j} = \frac{W_j \frac{1}{d_{i,j}}}{\sum_{j=1}^{J} W_j \frac{1}{d_{i,j}}} \qquad \forall i, j$$

- Where,
  - $\varepsilon_{i,j}$=vehicles produced from i to j
  - $P_{i,j}$=probability of a trip from i to j
- Where,
  - Wj=perceived benefit of destination j
  - d_{ij}=minimum travel distance from i to j

(Equations from "regional Evacuation Modeling : A State-of-art Review)

Origin Destination Matrix



- OD matrix was developed using socio-economic data found from Transportation Analysis Zones (TAZ)
- Each TAZ produces vehicles in accordance with the trip generation model
- Their trips are destined to one of the three safe zones in accordance with the distribution model
- Vehicles take the shortest path from origin to destination
- Vehicles whom shortest path does not intersect with the study corridor are not produced in the network

Study Area


N
Chevy Chase
Takoma Park
Hyattsville
Riverdale Park
Mount Rainier
Cheverly
Arlington
Alexandria
Daingerfield Island
Temple Hills
Forest Heights
NW F St
NW 7 St
SW Maryland Ave
Google

Case Study: Washington DC

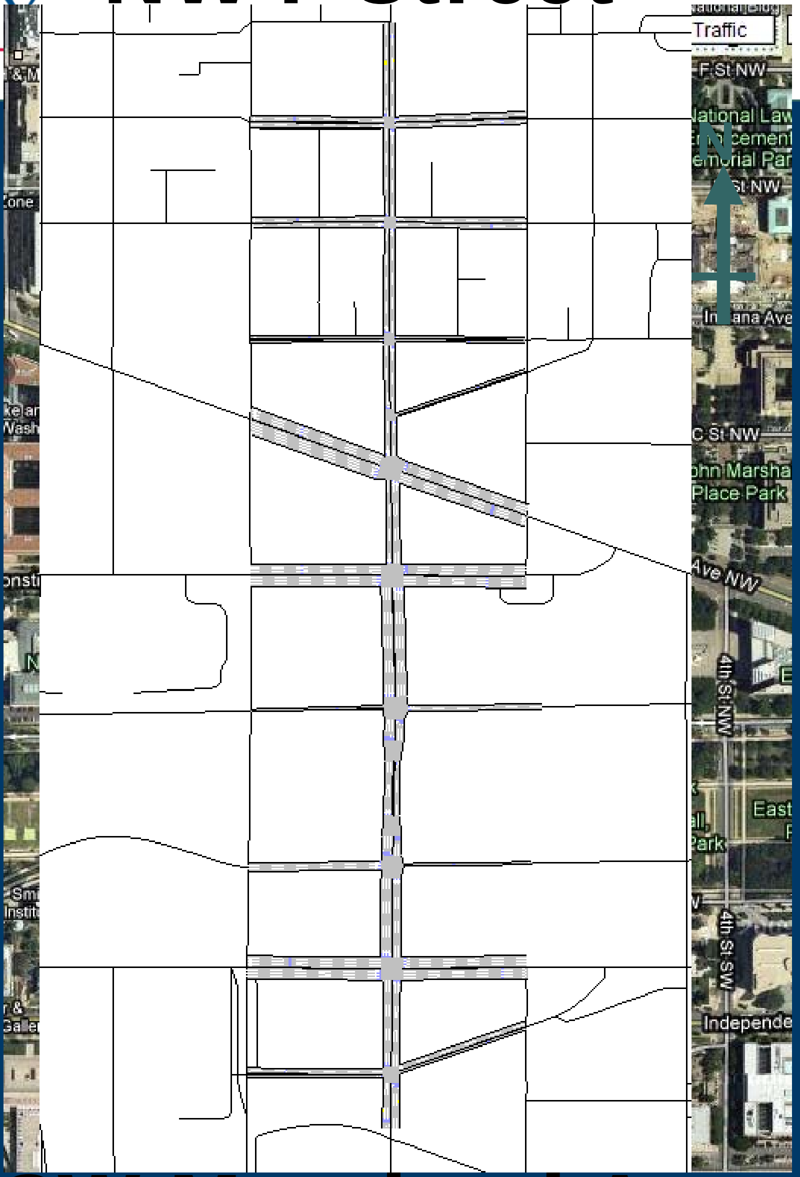
- The case study will consist of a 10 intersection corridor of downtown Washington DC, on NW 7th St from Maryland Ave to NW F st
- The perceived threat is a “dirty bomb” terrorist attack at L’enfant Plaza metro station at the beginning of the PM Peak

Study Area

Evacuation Corridor is:
NW 7 ST

- **From SW Maryland Ave**
- **To NW F Street**

NW F Street



SW Maryland Ave

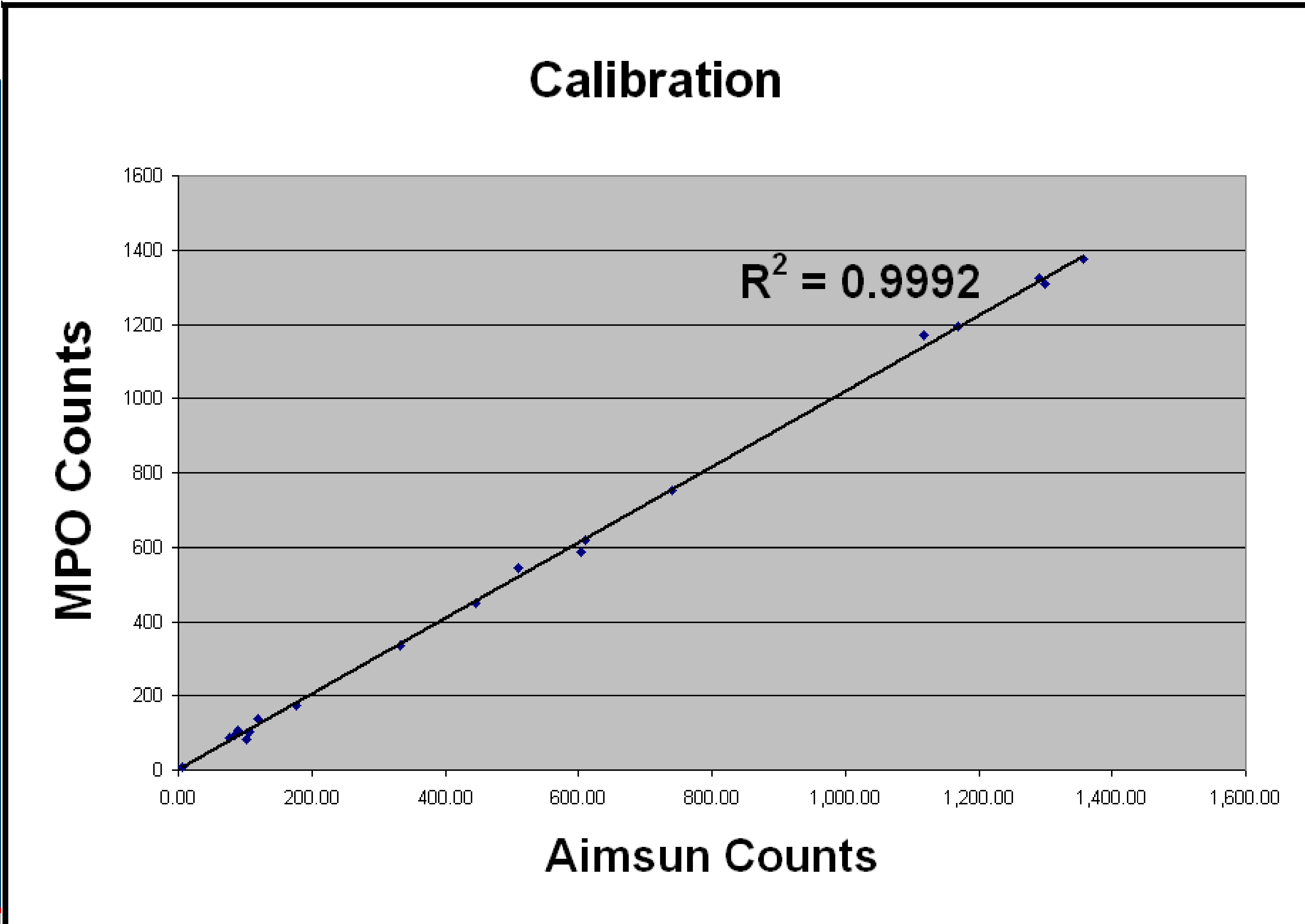
Micro-Simulation

- The study area was developed using AIMSUN NG 6.1 professional edition;

  a micro - meso simulation platform
- Additionally, Synchro 7 was used to developed traffic signal timings

Calibration

- Because collecting field data for this research was not practical, the network calibration was done using traffic data provided by the MPO in the form of a traffic model (Synchro 7).
- Traffic counts from 19 segments were collected and used for calibration
- The calibration was done so that the research model match the MPO model, not necessarily the actual traffic conditions


Calibration
1600
1400
1200
1000
800
600
400
200
0
R2 = 0.9992
0.00
200.00
400.00
600.00
800.00
1,000.00
1,200.00
1,400.00
1,600.00
MPO Counts
Aimsun Counts

Scenario

- A “dirty bomb” is detonated at L’enfant plaza metro station at 16:50
- All people within a half mile of the station must evacuate asap
- Citizens are direct to three possible shelters: International trade center, Convention Center, and I-395 North
- Evacuates are directed to avoid the out fall (vehicles do not travel past the metro station)

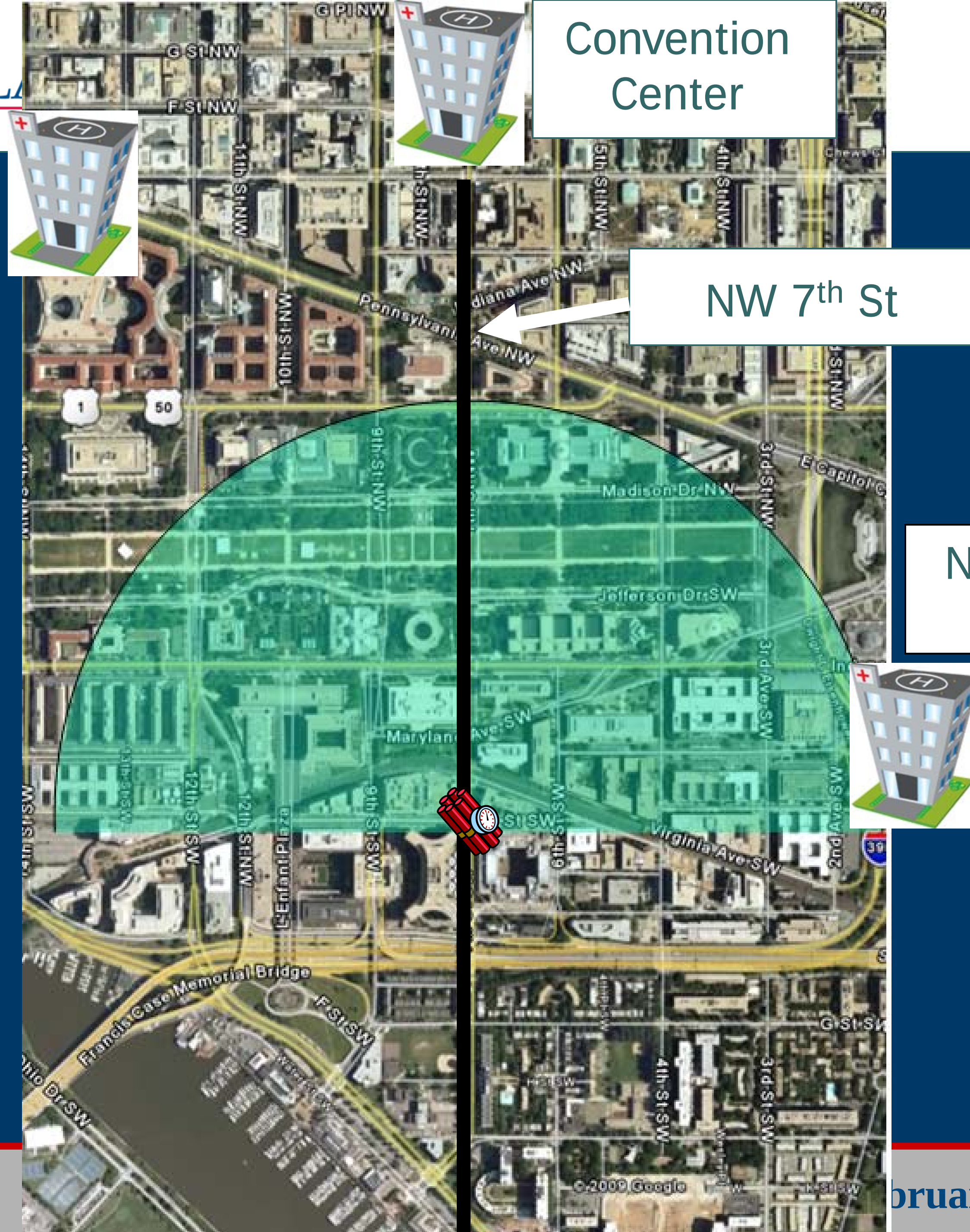
Trade Center

Convention Center

NW 7th St

Northbound I-395

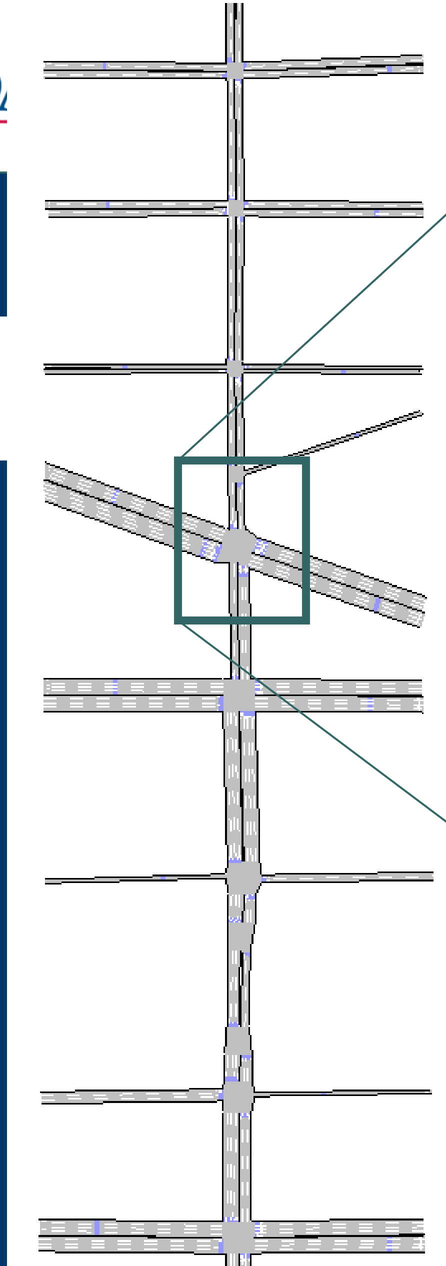
N

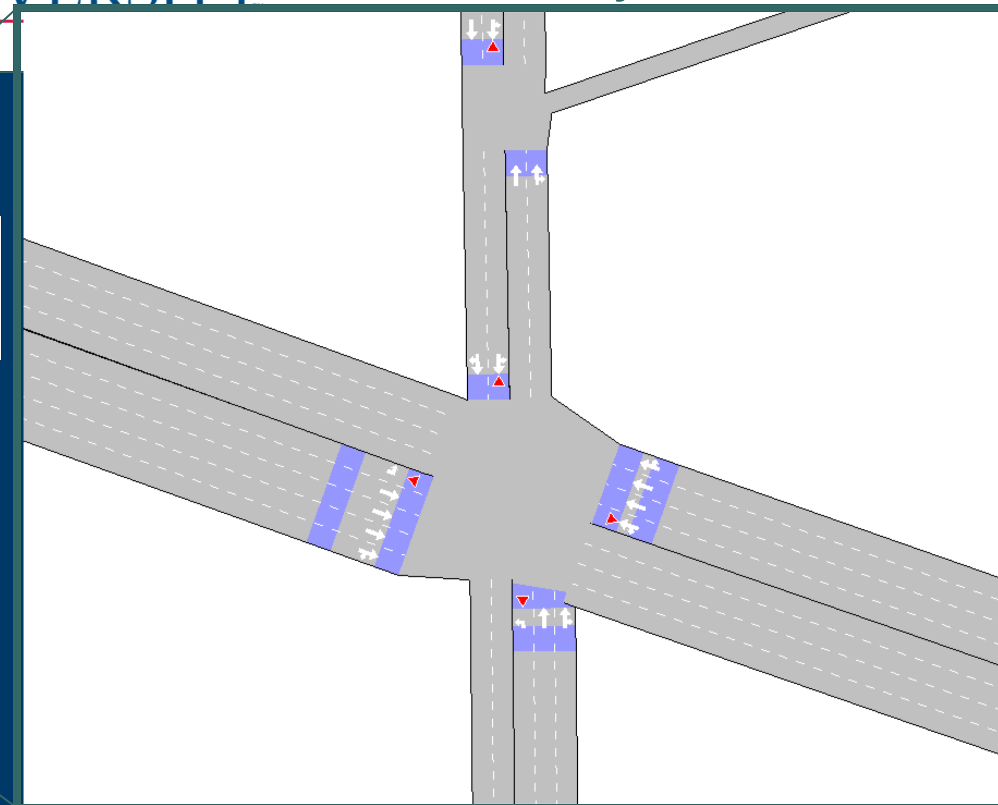


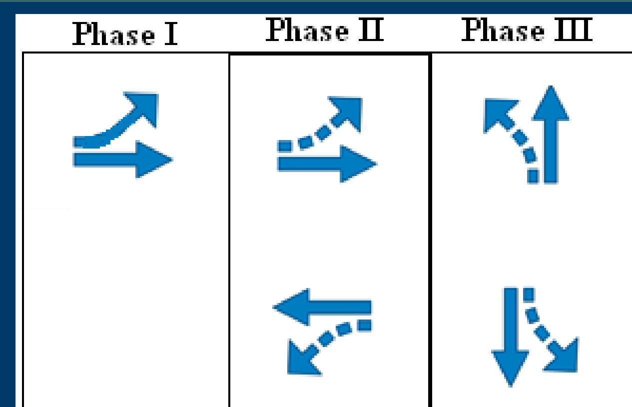
Dynamic Programming

- The critical intersection in the corridor was used (Nw 7 st and Pennsylvania) for DP analysis
- Each turning of the intersection was given the same green time
- These green times increased from 0-240 in 10 second intervals
- The simulation ran the evacuation traffic demand for one hour
- Traffic counts per lane were than used to create the DP matrix using time as the stages and the phases as the state

NW 7th St and Pennsylvania Ave







DP Matrix

- To calculate the traffic count per lane for each phase the average of 3 simulations were used (total of 72 runs)
- Because the DP had 24 stages and 3 state variables the DP was solved using advanced solver software

Maximize: $$P = \sum_{i=1}^{I} \beta_i$$

Subject to: $$\beta_i = \sum_{t=0}^{T} \alpha_{i,t} \frac{V_{i,t}}{l_i} \qquad \forall i$$

$$\sum_{t=0}^{T} \alpha_{i,t} \leq 1 \qquad \forall i$$

$$\sum_{i=1}^{I} \alpha_{i,t} \leq I \qquad \forall t$$

$$\alpha_{i,t} \in \{0, 1\}$$

$$\sum_{i=1}^{I} \alpha_{i,t} \delta_t = 240 \qquad \forall t$$

$$\delta_t = \{0; 10; 20; \ldots T\}$$

Phase Length	Phase I P	Phase II P
10	100	150
20	200	200

Phase Length	Alpha I	Alpha II	
10	0	0	Sum <2
20	0	0	sum <2
	Sum ≤ 1	Sum ≤ 1	

Cycle Length Must = 30 Sec

Phase Length	P*Alpha	P*Alpha
10	0	150
20	200	0

DP Results

With 100 Sec Cycle Length

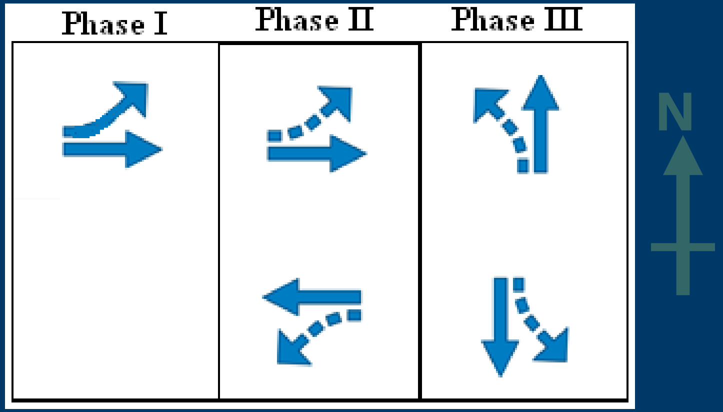
Phase	Length	Payoff
Phase I	20 sec	270
Phase II	50 sec	466
Phase III	50 sec	373
Total	100 sec	1108

Without Cycle Length Constraints

Phase	Length	Payoff
Phase I	200 sec	383
Phase II	50 sec	466
Phase III	190 sec	390
Total	440 sec	1239

With 240 Sec Cycle Length

Phase	Length	Payoff
Phase I	100 sec	357
Phase II	90 sec	373
Phase III	50 sec	466
Total	240 sec	1196



Evacuation Simulation

- DP solution were placed into simulation and run for the entire evacuation time
- Results were compared to PM-Peak hour timing

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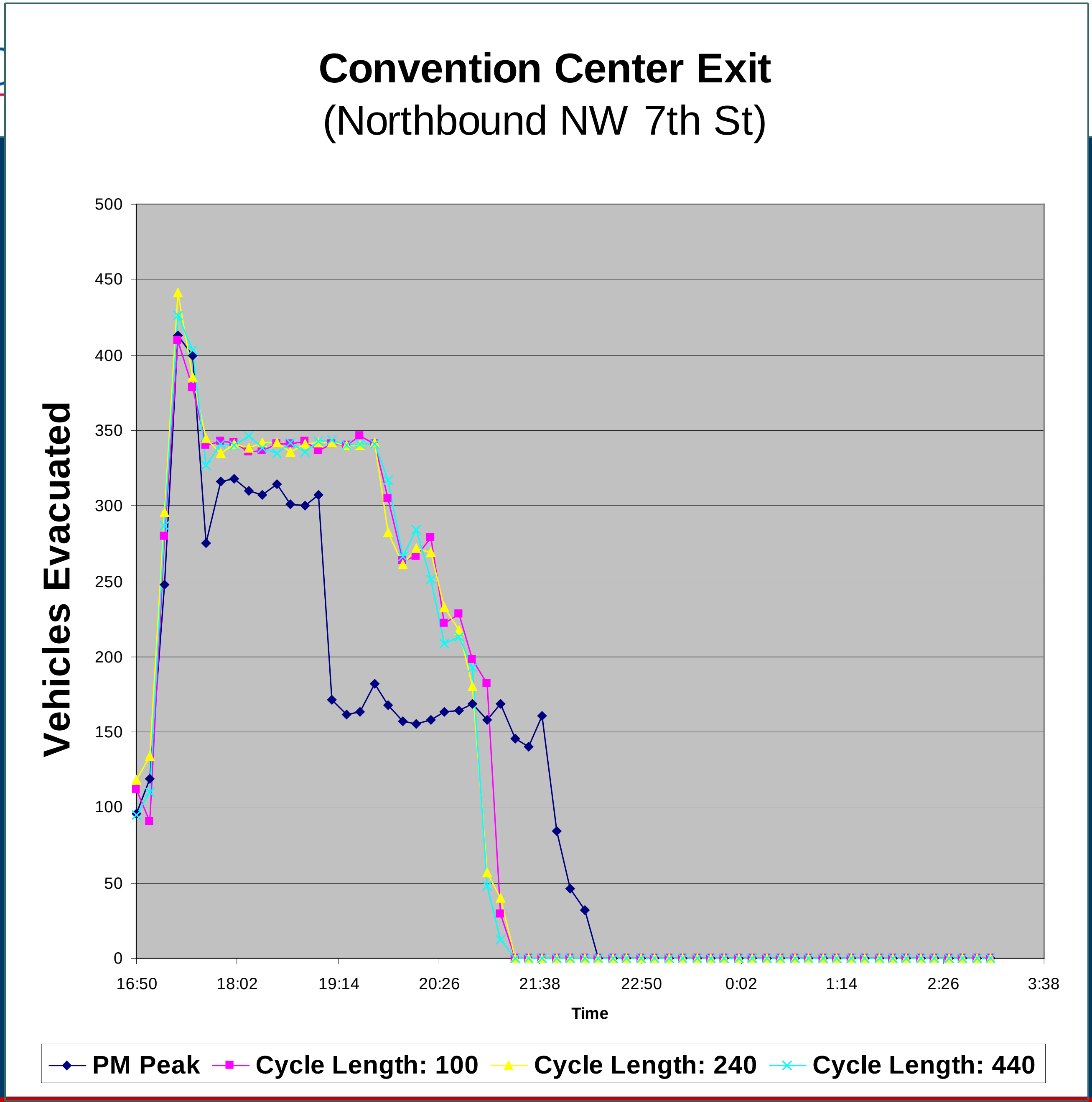

Convention Center Exit
(Northbound NW 7th St)
Vehicles Evacuated
500
450
400
350
300
250
200
150
100
50
0
16:50
18:02
19:14
20:26
21:38
22:50
0:02
1:14
2:26
3:38
Time
PM Peak
Cycle Length: 100
Cycle Length: 240
Cycle Length: 440

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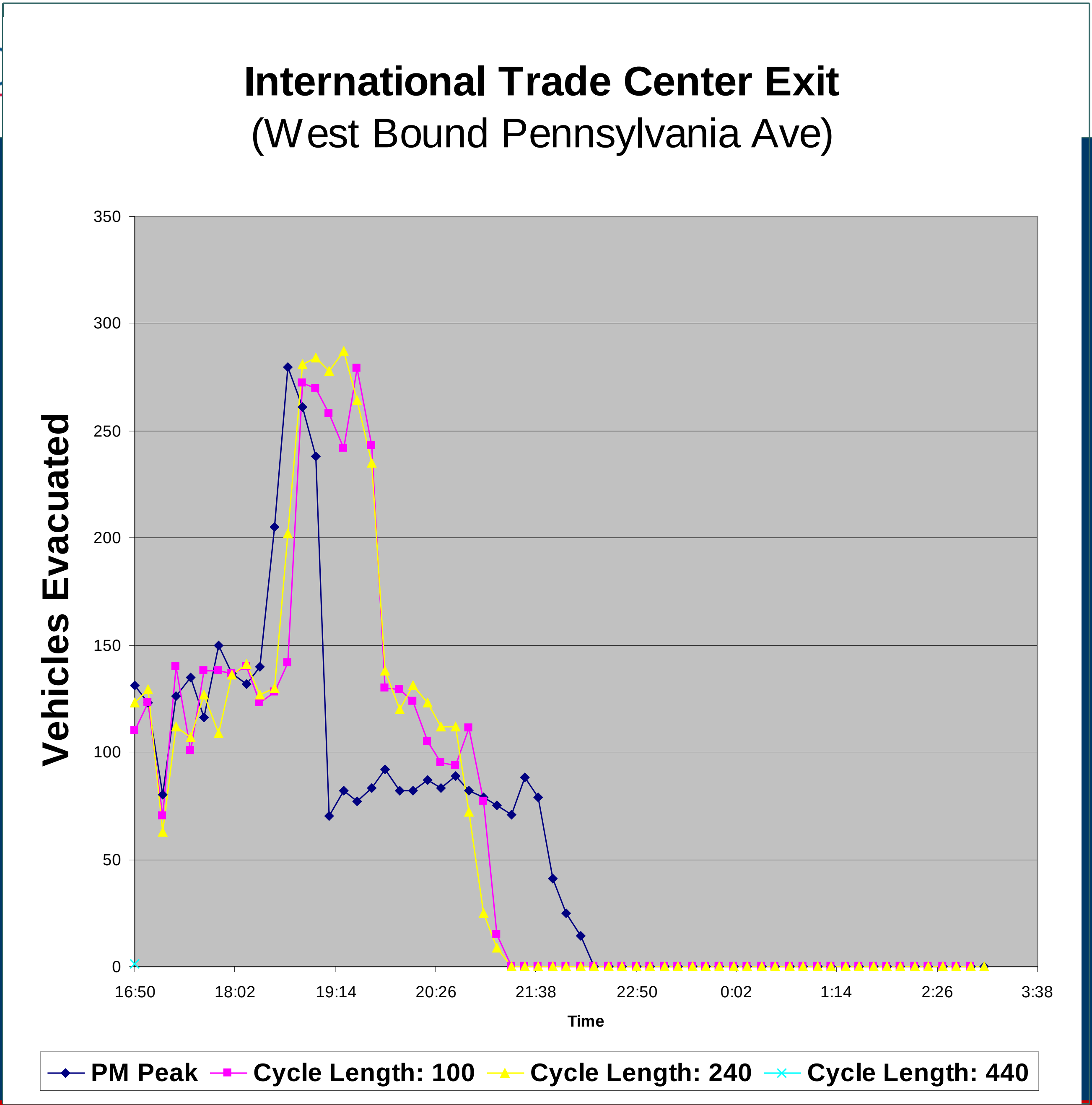
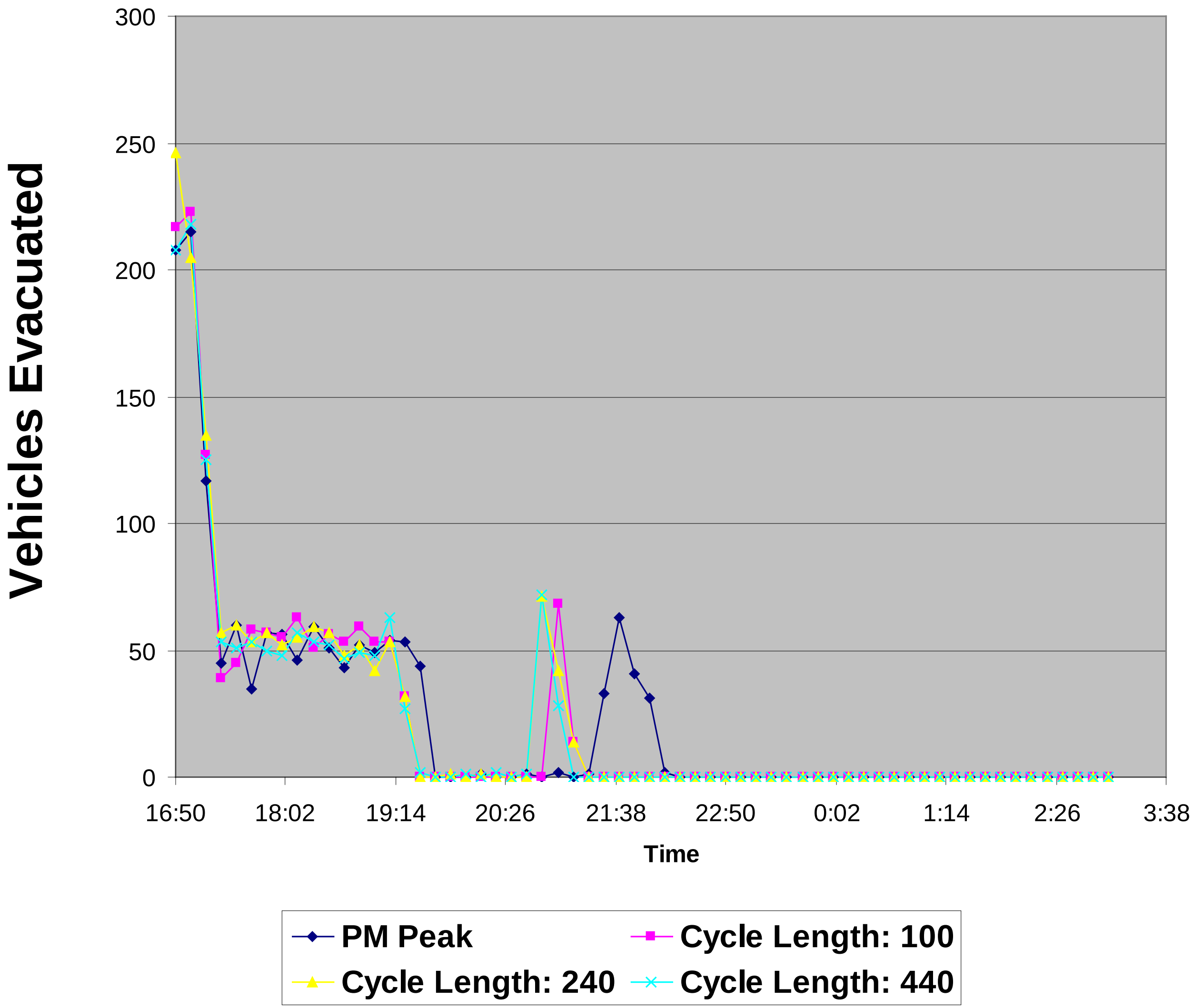


International Trade Center Exit
(West Bound Pennsylvania Ave)
Vehicles Evacuated
350
300
250
200
150
100
50
0
16:50
18:02
19:14
20:26
21:38
22:50
0:02
1:14
2:26
3:38
Time
PM Peak
Cycle Length: 100
Cycle Length: 240
Cycle Length: 440

North Bound I-395 Exit
(Eastbound Independence Exit)



Conclusion

- The DP yields better results than that of the PM Peak hour
- Optimizing the splits of a single critical intersection reduced clearance time by one hour regardless of cycle length

Further Work

- This methodology can be further researched to run in tandem with the simulation platform to better optimize results

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Thank you

- Questions?

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