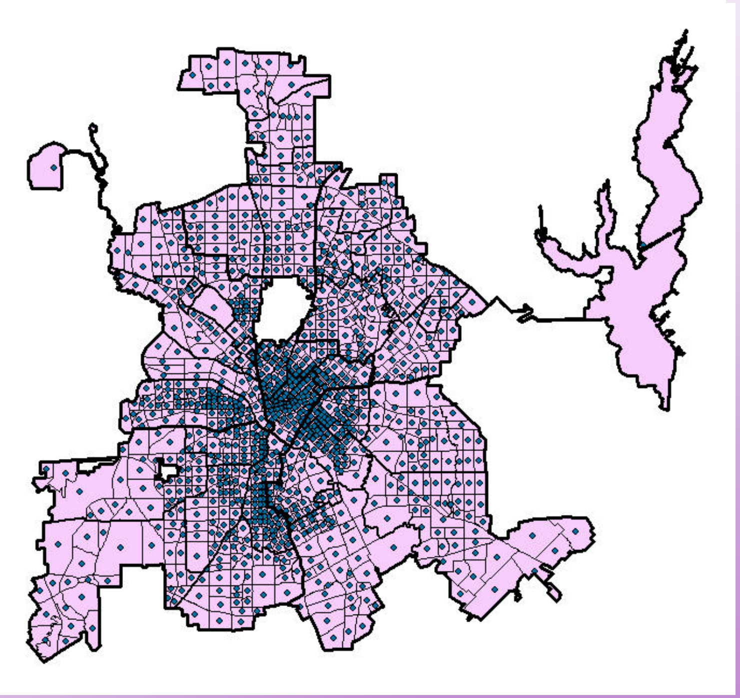
A Family of Models for Determining Optimal Police Deployments

Kevin M. Curtin, PhD
Karen Hayslett-McCall, PhD
Fang Qiu, PhD
University of Texas at Dallas
03/30/07
curtin@utdallas.edu
www.utdallas.edu/~curtin

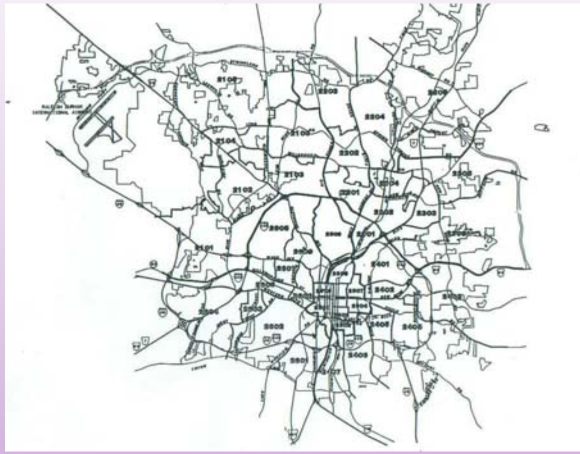
Deployment Strategies

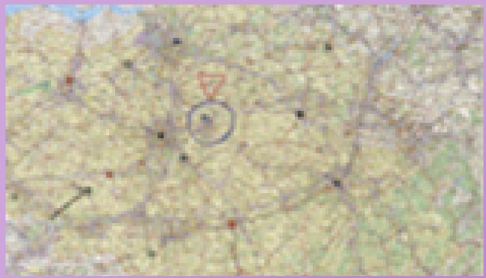
- There is a “Police Geography”
- Service is influenced by Geography
- What is the best Police Geography?
  - Save money
  - Equitably distribute limited police resources throughout the city
  - Reduce response time
  - Create a fair division of risk among police officers
- How can we:
  - Obtain the mathematically optimal solution
  - Present alternatives to decision makers



Literature Review

- Determining Deployment Plans
  - Historically “By Hand”
  - H&H Method
  - Pin Maps
  - Heuristic solutions sometimes near optimal
- GIS for combinatorial optimization problems
  - GIS is not capable of solving these problems optimally
  - Other software is, but has no graphic interface
- Optimal Location Models
  - Locate facilities in such a way as to optimize an objective
  - Many models exist, but few if have been employed in policing





Maximal Cover for Police Patrols

- Minimizing distance to past crimes is not acceptable
  - Encourages location only to high crime areas
  - Leaves low crime areas vulnerable
- Service Response Time is crucial to Police Departments
  - It is a primary quantitative measure of police service
  - First question asked about a call to the police… "How quickly did they arrive?"
- Max Cover can answer many questions for police administrators
  - Can our current police geography be redesigned and improved?
  - Is there an arrangement that is more equitable in terms of resources and service provision?
  - When demand and resources changes in an emergency how should we rearrange our patrols or service?

The Police Patrol Area Covering Model (PPAC)

- Objective Function
  - Maximize the coverage of calls for service
- Constraints
  - (1) Covering constraint
  - (2) P patrol areas must be determined by user
  - (3) and (4) Integer Constraints
- Additional notation
  - I = the set of crime locations
  - J = potential patrol area command centers
  - S = the service distance (desired response time)
  - d_{ij} = the shortest distance from i to j
  - y_i = 1 if an incident location at i is covered by at least one located police patrol area, and 0 otherwise
  - $N_i = \{j \text{ in } J \mid d_{ij} \leq S\}$
  - a_i = weight or priority of crime incidents at incident location i
  - P = the number of police patrol areas to be located

$$\text{Maximize Z} = \sum_{i \in I} a_i y_i$$

Subject To :

$$\sum_{j \in N_i} x_j \geq y_i \quad \text{for all } i \in I \qquad (1)$$

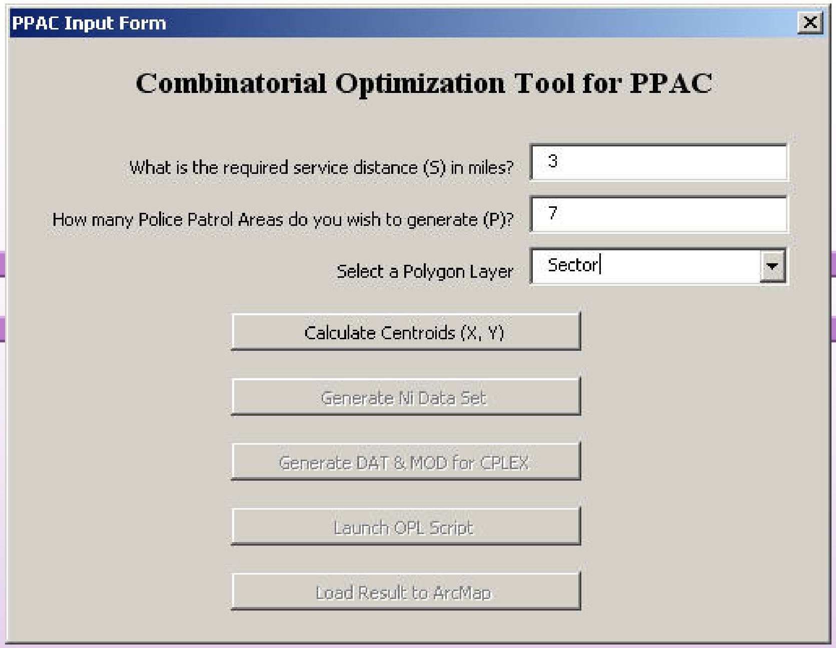
$$\sum_{j \in J} x_j = P \qquad (2)$$

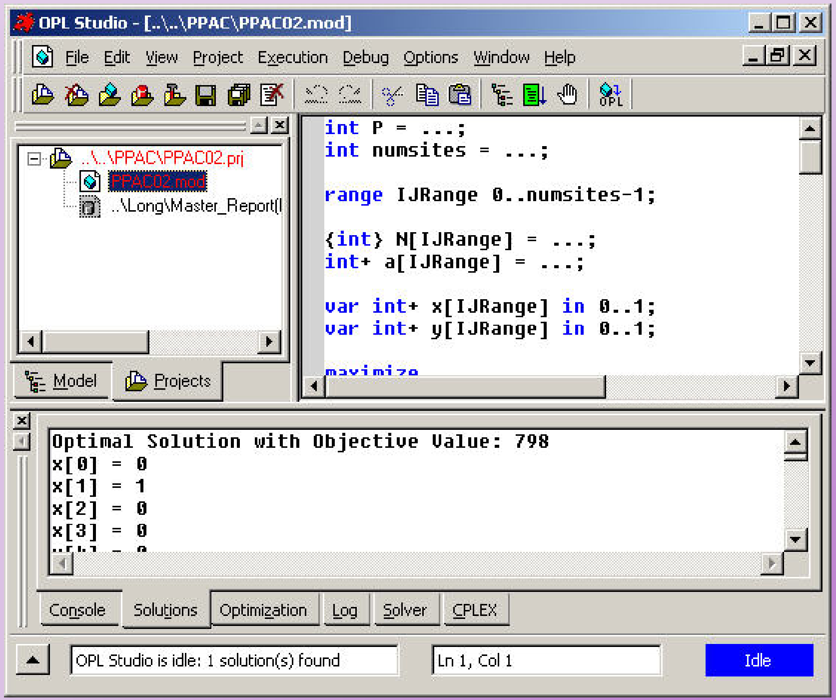
$$x_j = (0,1) \quad \text{for all } j \in J \qquad (3)$$

$$y_i = (0,1) \quad \text{for all } i \in I \qquad (4)$$

Solution Procedure Flow

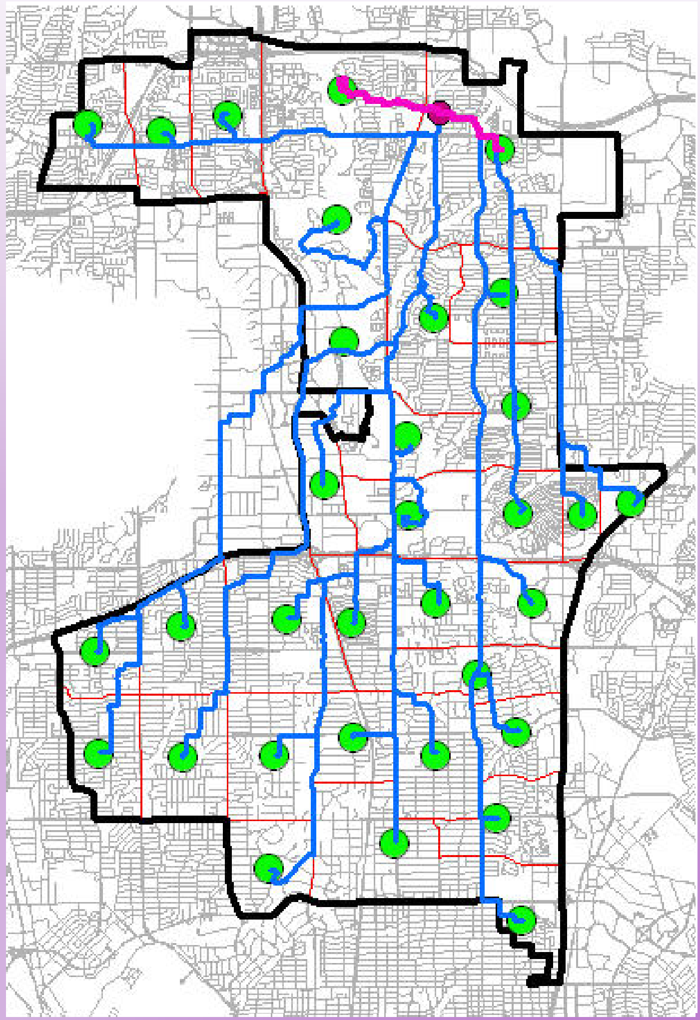
- Collect input data from the user in ArcMap
- Generate Centroids on Polygon Input Layer
- Generate the sets of covering locations
- Export information to Linear Programming Solver Software
- Output results back to GIS for display





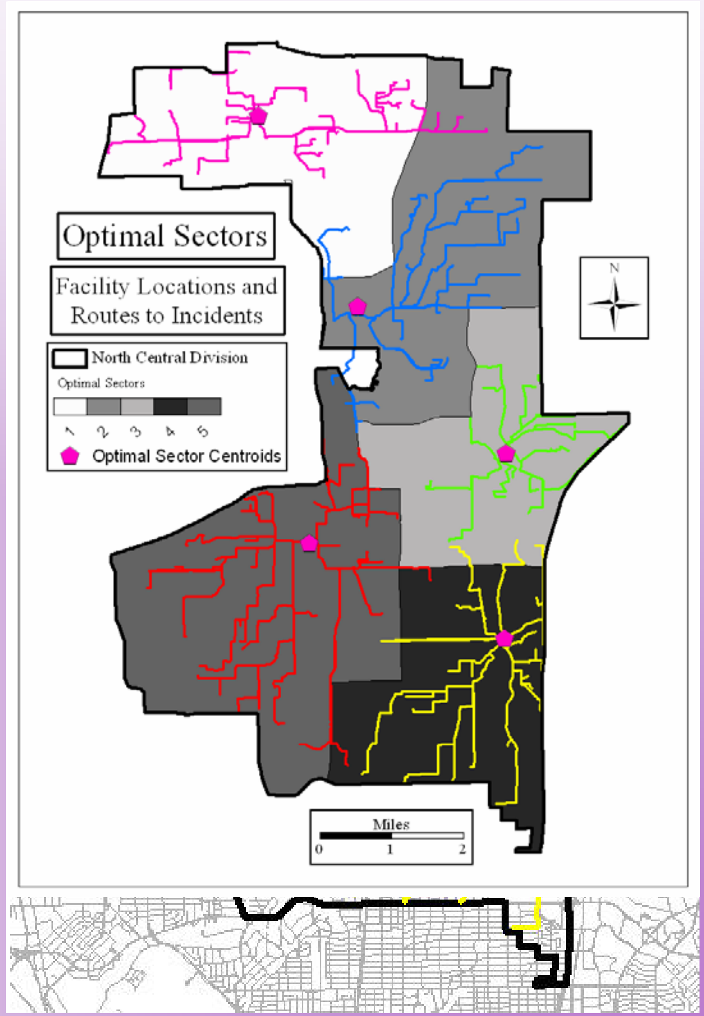
Generating Inputs from GIS

- North Central Division
  - 5 Sectors
  - 33 Beats
- Find the optimal sector boundaries
  - Serve crime or incident locations
  - 267 calls for service on 07/20/2002
  - Generate 5 best sector command locations
    - Beat Centroids
  - Generate OD Matrix of Network Distances
  - Select those potential command center sites within the service distance of each incident location to generate sets N_i



Generating Results

- Export Data to CPLEX
  - Number of origins and destinations
  - Sets N_i
  - a_i values (Call priority values)
- Import Solution back to ArcGIS
  - Locate / display command center sites
  - Determine closest facility for all incidents
  - Generate quantitative comparisons:
    - » Total Miles Traveled
      - Old Solution - 617 Miles Total Miles
      - New Solution - 447 Miles Total Miles
      - 27.6% Decrease in Total Miles Traveled
    - » Worst Case Distance
      - Old Solution – 5.23 Miles
      - New Solution – 4.40 Miles
      - 15.9% Decrease



Additional Results – All Divisions

Division	Existing Total Miles	Optimal Total Miles	% Decrease in Total Distance	Existing % of calls covered within *S*	Optimal % of calls covered within *S*
NorthWest	625.0	534.2	14.5%	71.1%	83.2%
NorthCentral	616.7	446.7	27.6%	45.7%	73.0%
NorthEast	811.0	760.4	6.2%	66.7%	78.3%
Central	252.3	230.0	8.8%	72.6%	83.4%
SouthWest	841.3	727.2	13.6%	59.1%	78.7%
SouthEast	1252.6	959.4	23.4%	50.3%	76.8%
Total Area	4398.9	3657.9	18.9%	60.9%	78.9%

Results over extended time periods

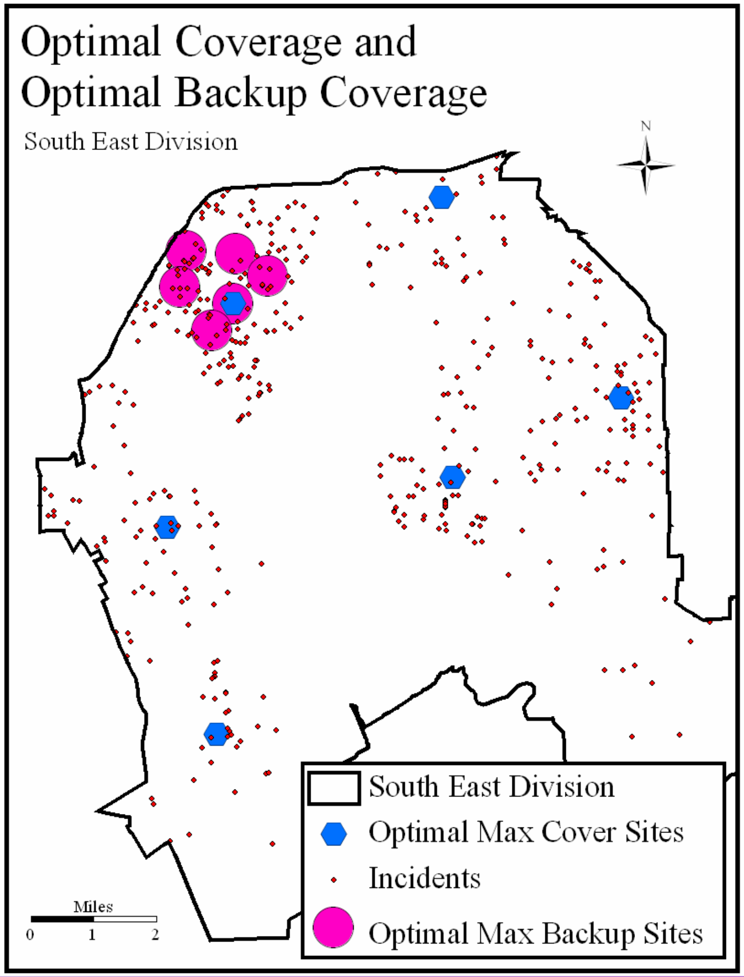
- What is the research time period?
  - One day might be appropriate for a particular recurring event
    - Football game TX-OU
    - Pro Championship
  - One week might be appropriate for a festival
    - TX State Fair
  - Month
  - Seasonal differences
  - Whole year

Time Period	Number of Calls	Objective Function Value
1 Year	87,603	192,930
Winter	20,212	44,234
Spring	22,692	49,505
Summer	22,494	50,026
Fall	22,205	49,165
January	6,790	15,125
July	7,220	16,246
Week (August)	1,796	4,052
Week (December)	1,881	4,206

Backup Coverage

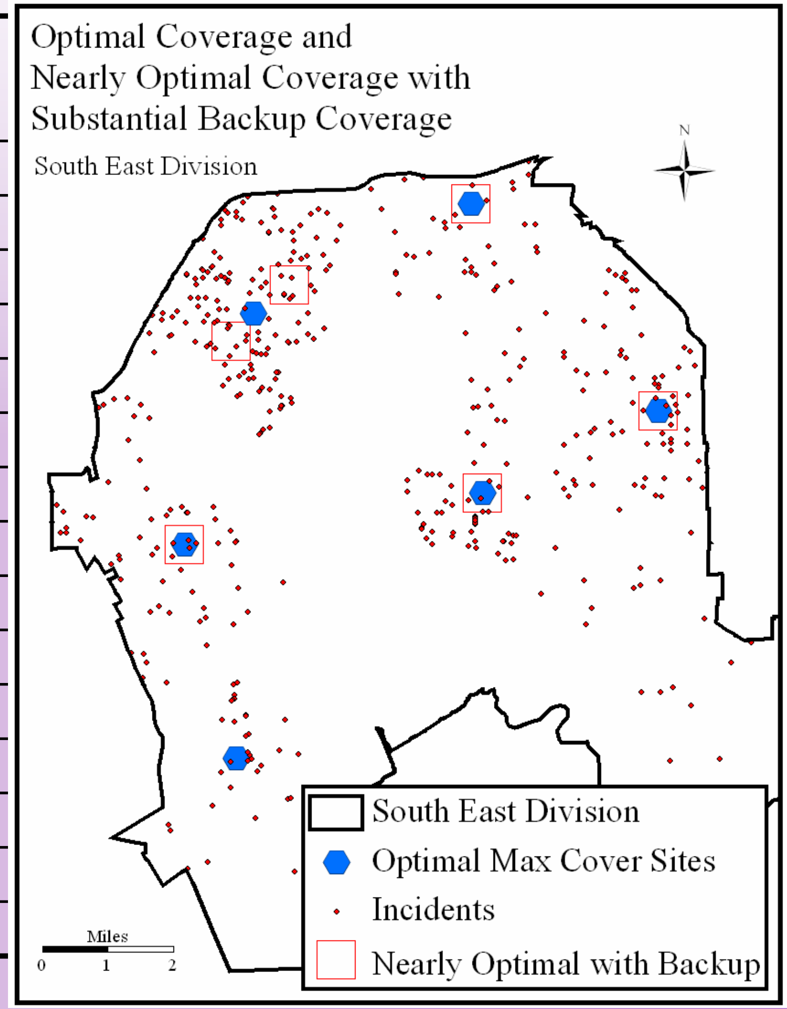
$$y_i = (0, P) \quad \text{for all } i \in I \qquad (5)$$

- Some incidents require backup
  - We want to cover as many as possible, but can we also overlap coverage?
- When backup is maximized
  - A few, high priority crimes are covered many times
  - Many low priority crimes are not covered
- Backup coverage by itself is not a good objective



Backup v. Traditional Coverage Tradeoff

Solution #	Maximal Backup Objective	Maximal Covering Objective	Total Incidents Covered	Cov1	Cov2
1	2279	495	170	9	10
2	2268	500	172	10	11
3	2210	743	244	83	16
4	2154	748	246	85	17
5	2085	774	253	92	18
6	2037	930	296	140	18
7	2007	932	297	143	24
Snip	Snip	Snip	Snip	Snip	Snip
18	1632	1141	368	248	68
19	1601	1215	388	255	133
20	1592	1219	390	261	129
21	1541	1245	400	297	103
22	1532	1249	402	303	99
23	1307	1296	415	412	3
24	1298	1298	416	416	0



Improvements and Further Research

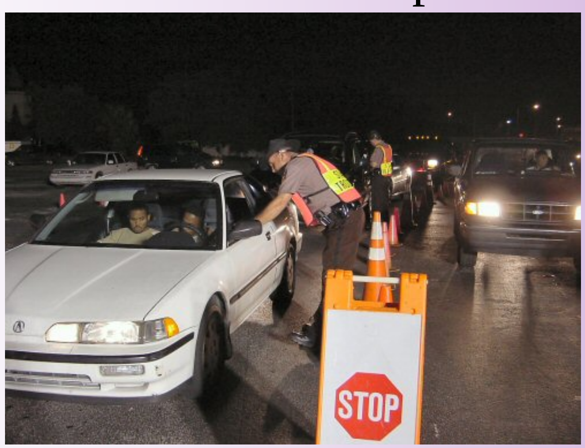
- Data Issues
  - a_i values
    - » The current priority codes are 1 through 5
    - » Is a call with priority 1 five times more important than a call with priority 5?
  - Refine the set of potential facility locations
  - What are the limits on the number of incidents and locations for solution?
- Formulation Issues
  - Maximum crime incident values per patrol area (for equity of risk, workload capacity)

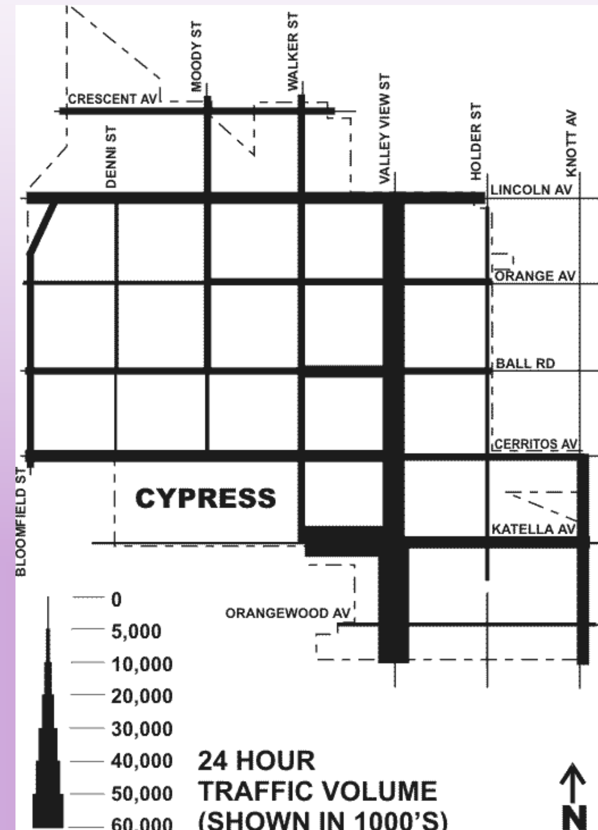
$$\sum_{i \in N_j} a_i x_j \leq M_j \quad \text{for all } j \in J$$

- Additional Models for Different Deployment Objectives
  - P-median for tactical response
  - Dispersion for safety
  - Flow-covering for interdiction

Flow Covering Models - Interdiction

- Military “Bridge bombing” models
  - Which locations on enemy supply or transport lines should be destroyed
  - Maximally disrupt the flow of material or personnel
- Policing context
  - Optimally deploy officers for interdiction
  - e.g. drunk driving or immigration checkpoints
  - Locate in such a way that the greatest flow can be captured by the deployments
- Capture as much flow as possible





P-Median Models – Tactical Response

- If there are a known set of targets or potential targets
- Minimize Demand Weighted Distance
  - Concentrate resources on high demand areas

$$\text{Minimize } Z = \sum_{i=1}^{n} \sum_{j=1}^{n} a_i d_{ij} x_{ij}$$

Subject To :

$$\sum_{j=1}^{n} x_{ij} = 1 \quad \text{for all } i$$

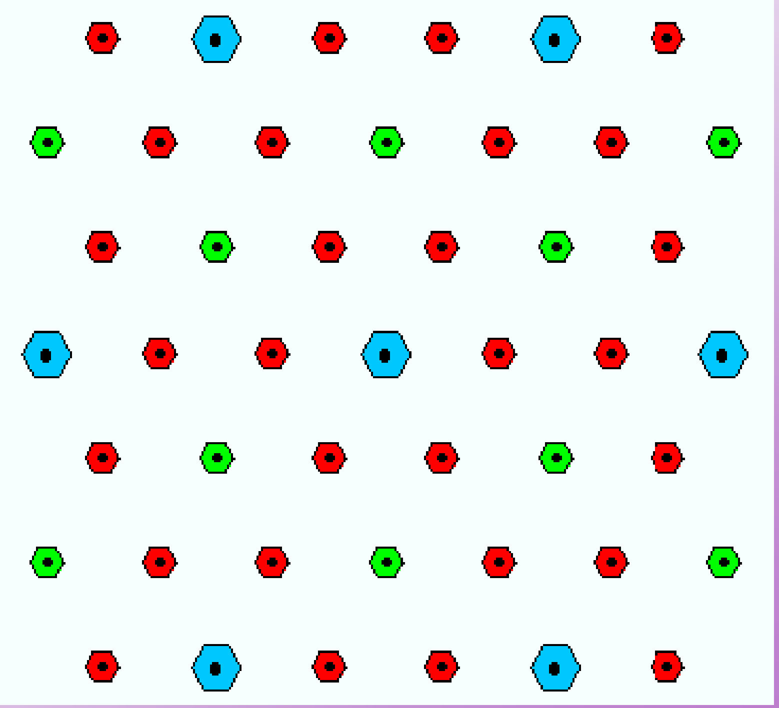
$$\sum_{j=1}^{n} x_{jj} = P$$

$$x_{ij} \le x_{jj} \quad \text{for all } i \text{ and } j$$

$$x_{ij} = (0,1) \quad \text{for all } i \text{ and } j$$

Maximal Dispersion – Asset Protection

- Maximize the distance between assets
  - Preserve asset safety in the event of attack
  - Protecting people or facilities that are targets for terror
- P-defense problem
  - Maximize the sum of the minimum distances between assets
  - Concerned with overall system safety
  - Multiple types of assets to protect (Curtin 2002; Curtin and Church 2006)



Conclusions

- Provide Alternatives
- Provide Objective quantitative measures of deployment performance
- Provide a functional tool for generating both through the integration of GISystems, GIScience, and combinatorial optimization solution procedures