Preparedness for Epidemic Disease or Bioterrorism: Minimum Cost Planning for the Location and Staffing of Urban Point-of-Dispensing Centers

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(forthcoming in Journal of Emergency Management)
Point of Dispensing Centers (PODS)

• Mass medication dispensing facilities for providing pills, tablets, capsules, or vaccinations (prophylaxis) to protect the general population from biological threats

• Not shelters, trauma centers, emergency rooms, or urgent care centers for providing medical treatment

• Facilities to which individuals in an exposed population are directed to go in the event of epidemic disease or bioterrorist attack
POD Infrastructure Planning

• CDC and Homeland Security have tasked urban health authorities with planning for POD infrastructure

• Regulations require plans including
  – Locations of PODs needed to provide prophylaxis to the entire population within 48 hours;
  – POD locations near swimming pools
  – size of population served by each such POD
  – staffing requirements for each POD
The Problem

• How should cities select from among the multitudes of potential facilities in any given city?
• No specific method for selecting locations has been prescribed
• Specifically how to select the relatively small subset of feasible facilities that
  – (a) meets all applicable standards and
  – (b) avoids wasted resources and keeps costs to a minimum
The Right Number, Size and Location

• Too few PODs (or too small)
  – reduces capacity to process people in an orderly and expeditious manner
  – federal standards will not be met
  – enough people will not receive medication and vaccination in the required time period

• Too many PODs
  – more security, coordination, organization, communication, delivery vehicles, drivers, and core staff members such as nurses
  – excessively costly to preplan, organize, and operate
What Must Be Considered?

- Size and location relative to the assigned population
- Accessibility to major roads and transportation
- Facility capacity to handle large numbers of people under cover and out of the weather
- Heat and air conditioning to maintain controlled room temperature
- Refrigeration for vaccines
- Adequate bathrooms, water, and electricity
- Loading area for receipt of supplies
- Adequate parking for staff and populace
- Handicapped access
Possible Facilities to Consider

• Public schools
• Universities
• Community colleges
• Community recreation centers
• Armories
• Government buildings
• Some cities have literally hundreds of alternative feasible locations
A Mixed Integer Programming Approach

- Paper formulates and demonstrates the use of an integer programming technique that can help solve this problem
- Minimizes the number of PODS while meeting all of the federal guidelines and regulations
- Determines the optimal staffing requirement in terms of the number of nurses at each POD
- Demonstrated using real data from Cleveland
- Assumes the set of alternatives are all city schools
- Can be readily adapted to a wide range of urban areas
A Word on Integer Programming

• Integer programming takes various linear inequalities relating to some situation and finds the "best" or “optimal” value obtainable under those conditions

• A specific form of linear programming in which some variables assume real-numbered values while others assume only non-negative integer values

• Widely used in location analysis, scheduling, staffing, shipping (e.g. FedEx and UPS)
\[ \min \sum_{j=1}^{M} w_j Y_j \quad (1) \]

Subject to:

\[ \sum_{j=1}^{M} X_{ij} = 1 \quad \forall i \quad (2) \]

\[ \sum_{i=1}^{N} P_i X_{ij} \leq Sz_j \quad \forall j \quad (3) \]

\[ \sum_{j=1}^{M} d_{ij} X_{ij} \leq C_1 \quad \forall i \quad (4) \]

\[ z_j \leq \lambda_j Y_j \quad \forall j \quad (5) \]

\[ h_{lj} Y_j \leq C_2 + k_{lj} 100 \quad \forall j, \forall l \quad (6) \]

\[ \sum_{l=1}^{L} k_{lj} \leq L - 1 \quad \forall j \quad (7) \]

\( X_{ij}, k_{lj}, Y_j \in \{0,1\} \) and \( Z_j \) is a real variable.
This is the “objective function”

\[
\min \sum_{j=1}^{M} w_j Y_j
\]

(1)

\[ Y_j : \begin{cases} 
1, & \text{if } POD_j \text{ is selected,} \\
0, & \text{otherwise.}
\end{cases} \]

where \( j = \{1, \ldots, M\} \)

\[ w_j : \text{a set of subjective weights that reflect the attractiveness of } POD_j, \ j = \{1, \ldots, M\}. \]

The objective function says to minimize a weighted function of the number of PODS

The linear program minimizes the value of the objective function subject to the condition that the constraints are all satisfied
This, and all the remaining equations stipulate “constraints”

This particular constraints stipulates that each census tract in the city must be assigned to one and only one POD

$\sum_{j=1}^{M} X_{ij} = 1 \quad \forall i$  \hspace{1cm} (2)

$X_i$ represents census tract $i$ where $i = 1, \ldots, N$ and $N$ is the total number of census tracts in the city. Also, $j = 1, \ldots, M$ PODs.
• This makes sure that there is enough serving capacity at every POD
• The total number of people from the census tracts being assigned to POD $j$ cannot exceed the total number of people who can be served by the total number of staff at that POD during a 48 hour period

$$\sum_{i=1}^{N} P_i X_{ij} \leq S z_j \quad \forall j$$
Ensures that any person in any census tract travels a maximum of \( C_1 \) miles to get to the POD to which he/she is being assigned
This constraint limits the number of staff members assigned to a particular POD (due to capacity limitations) and also makes sure that if a possible location is not selected as a POD (that is, =0) then there will not be any staff assigned to that location.

\[ z_j \leq \lambda_j Y_j \quad \forall j \] (5)
These final two constraints together ensure that there is at least one recreational center within $C_2$ miles proximity to every POD selected.
### The Data

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<th>Census tract No.</th>
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<th>Population</th>
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Three of the schools listed here are high schools and the rest are elementary schools. School names are not provided because they contain no additional information of value for this article.
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The Solution

Figure 4. Solution for Cleveland's point-of-dispensing center infrastructure.
<table>
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<tr>
<th>School name</th>
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<th>Census tracts assigned</th>
<th>Total number of people visiting</th>
<th>Closest Rec. center</th>
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| School I    | 89                           | 104,200               | 771                           | Rec Center 6        |
|             |                              | 107,200               | 373                           |                      |
|             |                              | 107,300               | 40                            |                      |
|             |                              | 107,500               | 184                           |                      |
|             |                              | 107,800               | 2,027                         |                      |
|             |                              | 108,900               | 786                           |                      |
|             |                              | 110,400               | 199                           |                      |
|             |                              | 110,500               | 1,190                         |                      |
|             |                              | 110,600               | 537                           |                      |
|             |                              | 110,800               | 2,104                         |                      |
|             |                              | 111,200               | 1,064                         |                      |
|             |                              | 111,800               | 1,388                         |                      |
|             |                              | 112,700               | 661                           |                      |
|             |                              | 112,800               | 1,216                         |                      |
|             |                              | 113,400               | 1,050                         |                      |
|             |                              | 113,700               | 168                           |                      |
|             |                              | 113,800               | 1190                          |                      |
|             |                              | 114,100               | 850                           |                      |
|             |                              | 114,400               | 234                           |                      |
|             |                              | 114,600               | 2,057                         |                      |
|             |                              | 114,700               | 1,101                         |                      |
|             |                              | 114,900               | 3,499                         |                      |
|             |                              | 118,900               | 1,709                         |                      |
|             |                              | 119,702               | 3,315                         |                      |
|             |                              | 120,200               | 3,420                         |                      |
|             |                              |                      | 31,133                        |                      |

| School J    | 123                          | 102,600               | 1,756                         | Rec Center 7        |
|             |                              | 103,200               | 901                           |                      |
|             |                              | 103,400               | 3,418                         |                      |
|             |                              | 104,900               | 3,622                         |                      |
|             |                              | 108,100               | 24                            |                      |
|             |                              | 109,800               | 1,807                         |                      |
|             |                              | 111,401               | 1,955                         |                      |
|             |                              | 112,402               | 964                           |                      |
|             |                              | 112,600               | 741                           |                      |
|             |                              | 112,500               | 1,522                         |                      |
|             |                              | 112,900               | 607                           |                      |
|             |                              | 113,300               | 1,049                         |                      |
|             |                              | 114,200               | 452                           |                      |
|             |                              | 115,200               | 1,259                         |                      |
|             |                              | 115,900               | 3,975                         |                      |
|             |                              | 119,600               | 3,596                         |                      |
|             |                              | 120,100               | 1,015                         |                      |
|             |                              | 120,500               | 3,318                         |                      |
|             |                              | 121,100               | 3,051                         |                      |
|             |                              | 121,300               | 3,698                         |                      |
|             |                              | 127,500               | 4,049                         |                      |
|             |                              |                      | 42,779                        |                      |

| School K    | 130                          | 107,400               | 8                             | Rec Center 5        |
|             |                              | 108,700               | 485                           |                      |
|             |                              | 111,500               | 1,906                         |                      |
|             |                              | 112,200               | 1,954                         |                      |
|             |                              | 113,900               | 71                            |                      |
|             |                              | 114,500               | 657                           |                      |
|             |                              | 116,900               | 2,682                         |                      |
|             |                              | 117,101               | 3,349                         |                      |
|             |                              | 117,201               | 3,733                         |                      |
|             |                              | 117,300               | 3,578                         |                      |
|             |                              | 117,500               | 3,553                         |                      |
|             |                              | 117,600               | 3,355                         |                      |
|             |                              | 117,900               | 3,473                         |                      |
|             |                              | 118,200               | 3,045                         |                      |
|             |                              | 118,300               | 2,927                         |                      |
|             |                              | 118,500               | 1,716                         |                      |
|             |                              | 118,601               | 905                           |                      |
|             |                              | 119,401               | 2,574                         |                      |
|             |                              | 119,502               | 2,222                         |                      |
|             |                              | 120,100               | 2,940                         |                      |
|             |                              |                      | 45,133                        |                      |
Contribution

• Straightforward application of math programming that will probably not get cited a lot
  – Operations researchers not public health professionals or emergency responders
  – Public health professional or emergency responders not operations researchers

• But might help some cities conserve some of their limited resources: shows clearly how to do it

• Easily generalizable to other cities
Sensitivity Analysis I

Figure 1. The optimal number of PODs needed for different throughput rates.
Sensitivity Analysis II

Figure 3. The impact of additional population on the number of PODs needed.
Table 4. Factor scoring judgment values

<table>
<thead>
<tr>
<th>School Name</th>
<th>Max. capacity*</th>
<th>Open space availability</th>
<th>Parking</th>
<th>Accessibility</th>
<th>Communication</th>
<th>Total weight ((w_j))</th>
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<td>5</td>
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*Maximum capacity of a facility is determined by the number of students at that school.
†Scores 1-5, 5 undesirable and 1 very desirable.