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

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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:

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

$$\sum_{i=1}^{N} P_i X_{ij} \leq S z_j \quad \forall j \quad (3)$$

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

$$z_j \leq \lambda_j Y_j \quad \forall j \quad (5)$$

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

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

X_{ij}, k_{lj}, $Y_j \in \{0,1\}$ and Z_j is a real variable.

$$\min \sum_{j=1}^{M} w_j Y_j \qquad (1)$$

This is the “objective function”

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

where $j=\{1,...,M\}$

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

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

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

- 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
- X_i represents census tract i where i = 1,…,N and N is the total number of census tracts in the city. Also, j = 1,….,M PODs.

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

- 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

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

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

$$z_j \leq \lambda_j Y_j \quad \forall j \qquad (5)$$

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

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

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

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

Table 1. Example census tract, centroid coordinate, and population data			
Census tract No.	Y	X	Population
101101	41.4821	–81.7496	2,213
101102	41.4862	–81.7568	4,457
101200	41.4871	–81.7411	2,995
101300	41.4803	–81.7618	1,901
101400	41.4704	–81.7638	2,264
101500	41.4728	–81.7558	2,929
101600	41.4719	–81.7514	2,712
101700	41.4746	–81.7480	2,856
101800	41.4767	–81.7391	3,324
101900	41.4780	–81.7330	1,877
102101	41.4607	–81.7638	3,365
102102	41.4506	–81.7639	2,617

Table 2. Example of POD site, POD coordinate and maximum capacity data			
POD site school name	**Y**	**X**	**Max. capacity**
School A	41.4619056	–81.75154	599
School B	41.4771028	–81.60976	532
School C	41.4619167	–81.59113	455
School D	41.53895	–81.62628	369
School E	41.4335	–81.83083	624
School F	41.4693056	–81.7259	594
School G	41.5532694	–81.57473	1,622
School H	41.4514361	–81.7041	679
School I	41.5178944	–81.63332	943
School J	41.4916611	–81.65166	1,300
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.			

Table 3. Example of recreational center coordinate data		
Recreational center	**Y**	**X**
Rec Center 1	41.50815	–81.5959
Rec Center 2	41.496783	–81.67044
Rec Center 3	41.469983	–81.72559
Rec Center 4	41.526797	–81.61596
Rec Center 5	41.479492	–81.75351

The Solution

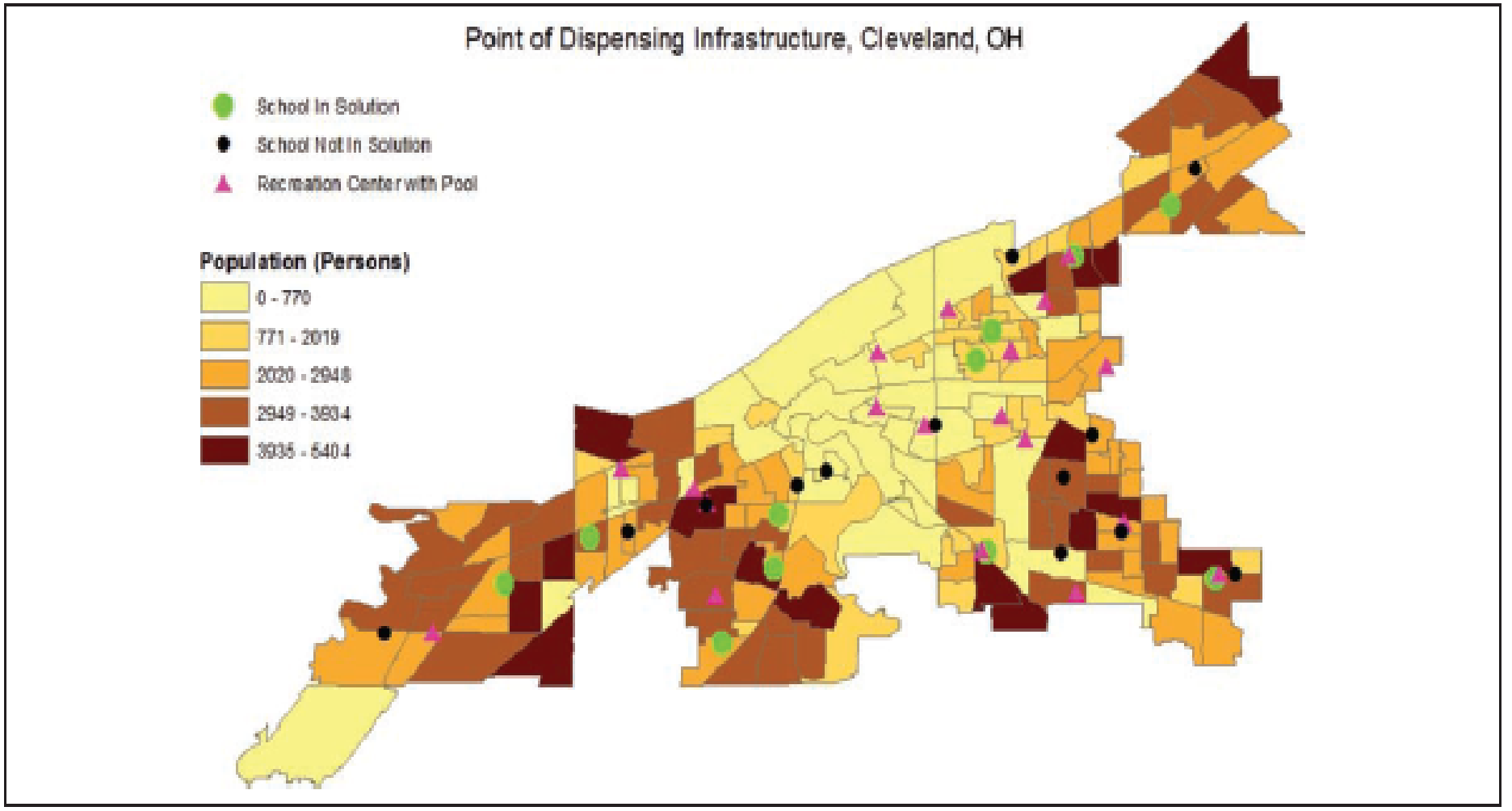

Figure 4. Solution for Cleveland's point-of-dispensing center infrastructure.

Table 5. Example of schools assigned as PODs: optimal staffing, census tracts assigned, numbers of people served, and closest swimming pool

School name	Optimal no. of staff assigned	Census tracts assigned	Total number of people visiting	Closest Rec. center
School G	154	111,300	539	Rec Center 5
		111,600	2,019	
		111,700	2,650	
		111,901	599	
		111,902	1,245	
		112,600	1,543	
		116,100	1,231	
		116,200	1,591	
		116,300	2,452	
		116,500	3,910	
		116,600	4,209	
		116,700	2,390	
		117,102	1,835	
		117,202	2,314	
		117,400	2,086	
		117,700	5,242	
		117,800	2,493	
		118,100	2,151	
		118,400	2,668	
		118,602	2,531	
		118,700	2,081	
		118,800	2,587	
		119,100	2,604	
			52,970	
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	

Table 5. Example of schools assigned as PODs: optimal staffing, census tracts assigned, numbers of people served, and closest swimming pool (continued)

School name	Optimal no. of staff assigned	Census tracts assigned	Total number of people visiting	Closest Rec. center
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	
		111,402	964	
		112,300	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	
		126,100	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

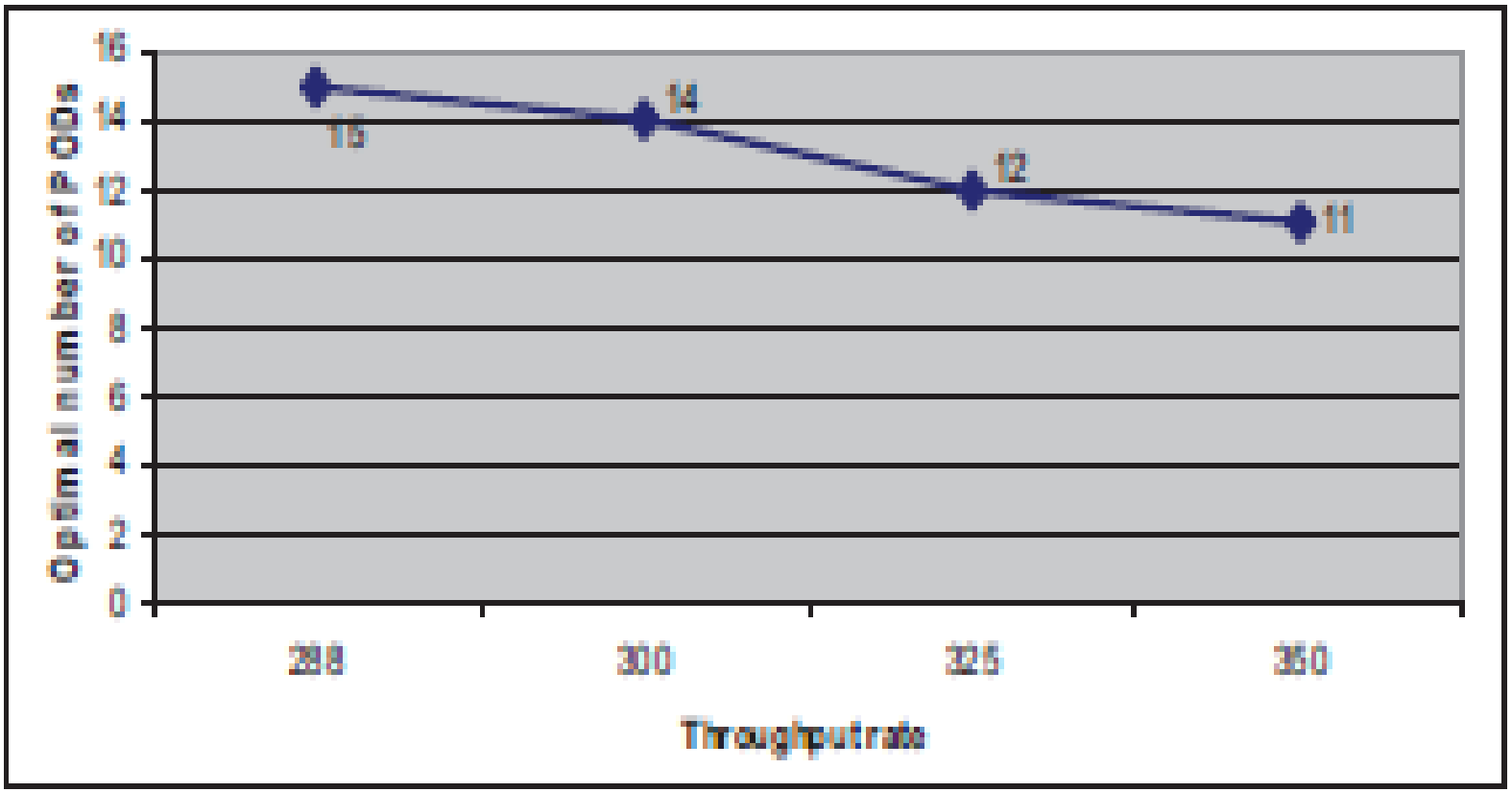

Figure 1. The optimal number of PODs needed for different throughput rates.

Sensitivity Analysis II

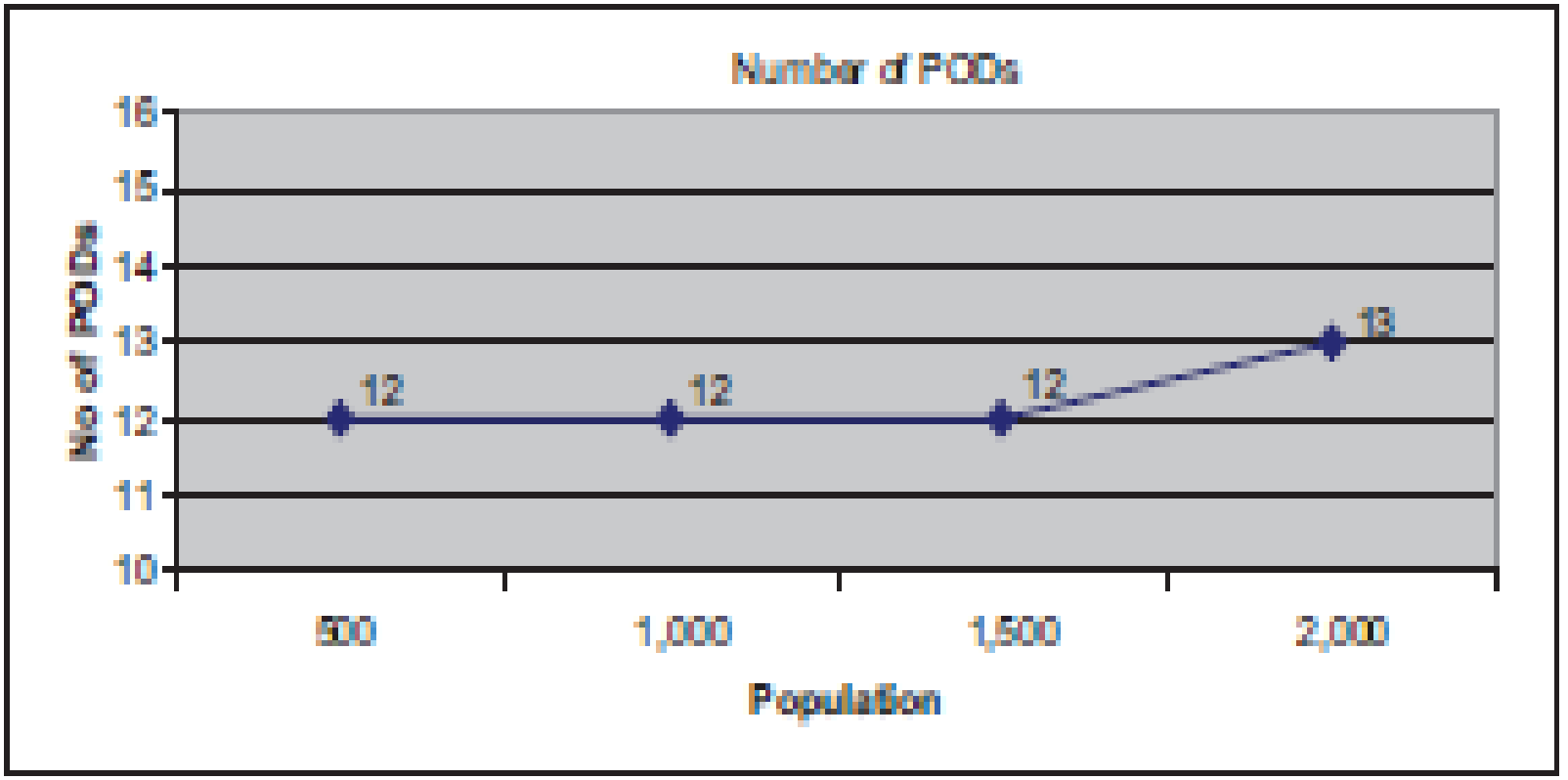

Figure 3. The impact of additional population on the number of PODs needed.

Table 4. Factor scoring judgment values						
School Name	Max. capacity*	Open space availability	Parking	Accessibility	Communication	Total weight (w_j)
School A	3†	4	1	4	5	17
School B	3	5	5	5	3	21
School C	4	1	3	3	3	14
School D	5	1	1	1	3	11
School E	2	1	1	2	5	11
School F	3	1	5	2	5	16
School G	1	1	1	1	3	7
School H	2	1	5	2	3	13
School I	1	1	2	1	3	8
School J	1	2	1	1	3	8
School K	1	3	1	1	4	10
School L	1	1	4	4	3	13
School M	5	5	1	1	5	17
School N	1	2	1	1	4	9
School O	1	4	1	3	3	12
School P	1	4	3	2	5	15
School Q	5	2	3	4	5	19
School R	2	1	3	3	2	11
School S	2	4	4	4	3	17
School T	4	1	1	1	3	10
School U	1	1	4	2	3	11
School V	2	1	3	3	4	13
School W	1	1	1	3	3	9
School X	5	3	3	1	3	15

*Maximum capacity of a facility is determined by the number of students at that school.
†Scores 1-5, 5 undesirable and 1 very desirable.