LOCATING PARKS WITH A MULTIOBJECTIVE OPTIMIZATION METHOD

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Pomona College

THE PROBLEM

BOGOTÁ, COLOMBIA

- Large city

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- Large city
- Sports and recreation master plan

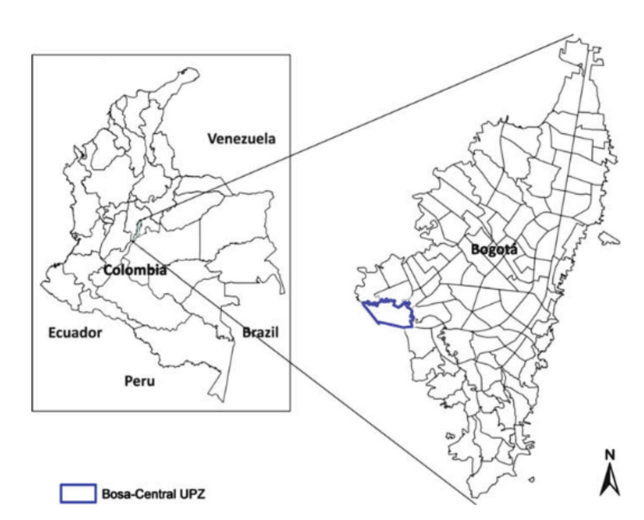
BOGOTÁ, COLOMBIA

- Large city
- Sports and recreation master plan
- Instituto Distrital de Recreación y Deporte

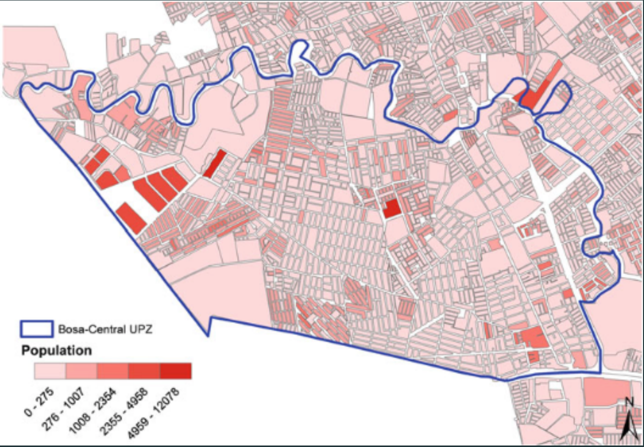
BOGOTÁ, COLOMBIA

- Large city
- Sports and recreation master plan
- Instituto Distrital de Recreación y Deporte
- A challenge

BOGOTÁ, COLOMBIA



BOGOTÁ, COLOMBIA



PARK SELECTION

- Candidate parcels

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- Number of beneficiaries

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- Geographic coverage

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- Candidate parcels
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- Geographic coverage
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- Positive and negative externalities provided by nearby facilities
- Construction and parcel acquisition cost
- Competing objectives
- Community Based Operations Research

THE GROUNDWORK

LINEAR PROGRAM

- Mid-20th century development

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- Limited resources

LINEAR PROGRAM

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- Limited resources
- Competing activities

LINEAR PROGRAM

- Mid-20th century development
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- Optimal

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- Limited resources
- Competing activities
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- Linear model

LINEAR PROGRAM

- Mid-20th century development
- Limited resources
- Competing activities
- Optimal
- Linear model
- Planning activities

$$
\begin{aligned}
\text{Maximize:} \quad & Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n, \\
\text{subject to:} \quad & a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n \leq b_1 \\
& a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n \leq b_2 \\
& \qquad\qquad\qquad \vdots \\
& a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n \leq b_m, \\
& x_1 \geq 0, x_2 \geq 0, \ldots, x_n \geq 0
\end{aligned}
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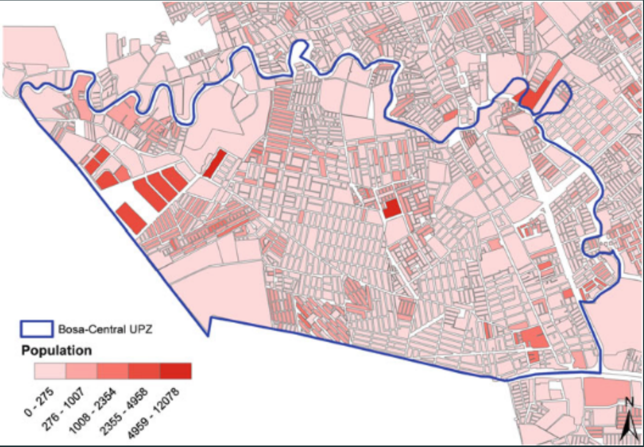
THE MODEL

BOGOTÁ, COLOMBIA



SIMPLIFYING ASSUMPTIONS

- $m \times n$ grid

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- One block = one square

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- $m \times n$ grid
- One block $=$ one square
- Every block same size

SIMPLIFYING ASSUMPTIONS

- $m \times n$ grid
- One block = one square
- Every block same size
- Service area of a block is all bordering blocks (excluding candidate parcels)

- Maximize geographical coverage

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  f_1

OBJECTIVE FUNCTIONS

- Maximize geographical coverage

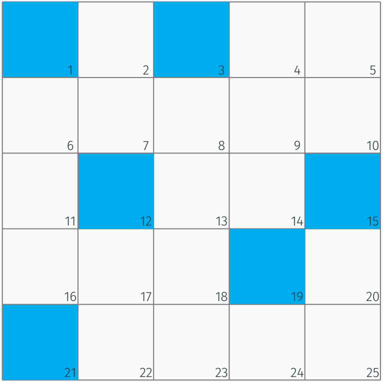
  f_1
- Maximize people serviced

OBJECTIVE FUNCTIONS

- Maximize geographical coverage

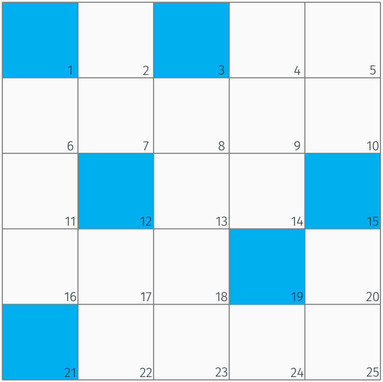
  f_1
- Maximize people serviced

  f_3



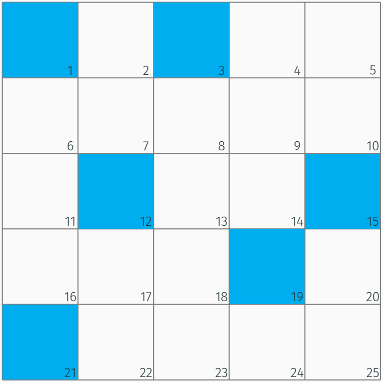
This is our 5×5 grid city

EXAMPLE



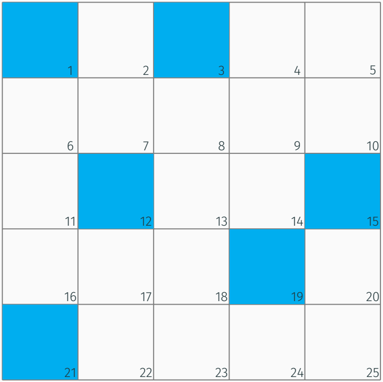
- Candidate parcels

EXAMPLE

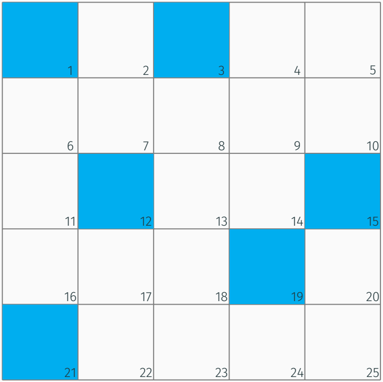


- Candidate parcels: $\mathcal{I} = \{1, 3, 12, 15, 19, 21\}$

EXAMPLE

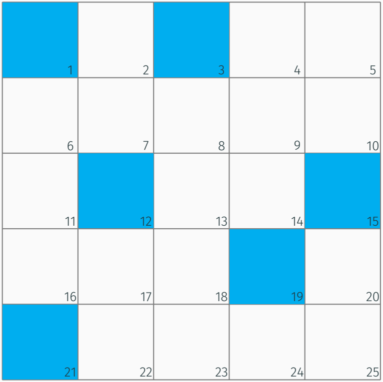


- Candidate parcels: $\mathcal{I} = \{1, 3, 12, 15, 19, 21\}$; $y_i,\ i \in \mathcal{I}$



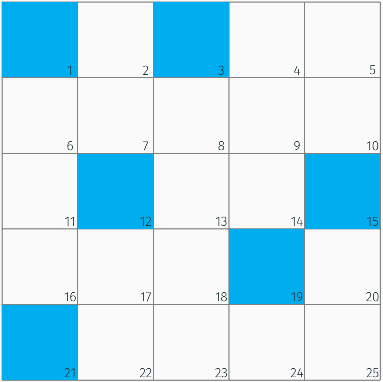
- Candidate parcels: $\mathcal{I} = \{1, 3, 12, 15, 19, 21\}$; $y_{19} = 1$

EXAMPLE



Which candidate parcel will maximize geographical coverage?

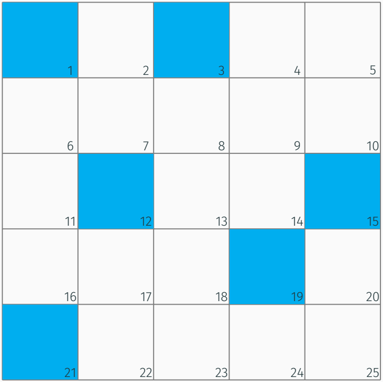
EXAMPLE



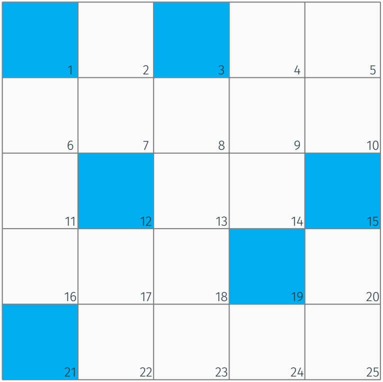
Which candidate parcel will maximize geographical coverage?

Candidate 12

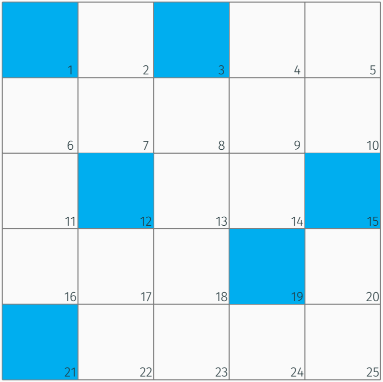
EXAMPLE



- $\mathcal{J} = \{2, 4, 6, 7, \ldots, 23, 24, 25\}$

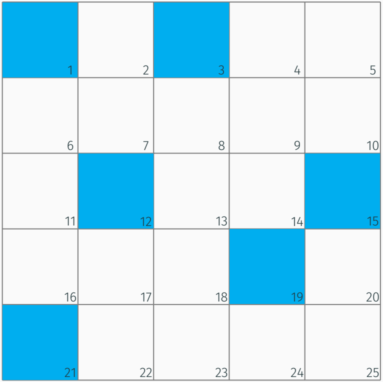


- $\mathcal{J} = \{2, 4, 6, 7, \ldots, 23, 24, 25\}$, the set of all blocks that would benefit from the construction of a new park



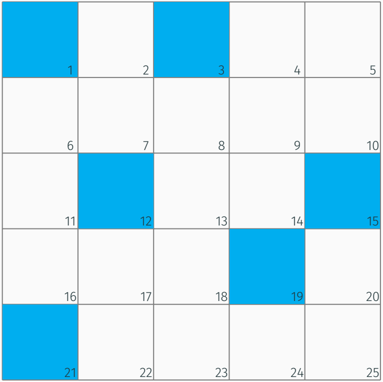
- $\mathcal{J} = \{2, 4, 6, 7, \dots, 23, 24, 25\}$
- $z_j, \quad j \in \mathcal{J}$, 1 if block j is serviced by a selected parcel, 0 otherwise

EXAMPLE



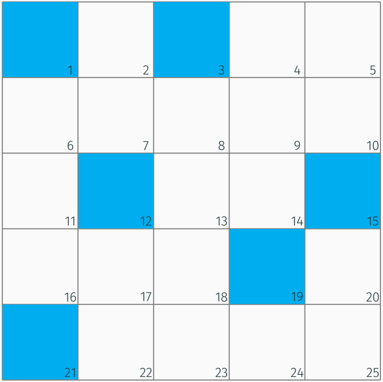
- $\mathcal{J} = \{2, 4, 6, 7, \ldots, 23, 24, 25\}$
- $z_2 = z_6 = z_7 = 1, \quad z_4 = z_8 = z_9 = \cdots = z_{24} = z_{25} = 0$

EXAMPLE



- $\mathcal{J} = \{2, 4, 6, 7, \ldots, 23, 24, 25\}$
- $z_j, \quad j \in \mathcal{J}$, takes on value 1 if block j is serviced by a selected parcel, 0 otherwise
- $\mathcal{W}_j, \quad j \in \mathcal{J}$, the set of candidate parcels that serve block j

EXAMPLE



- $\mathcal{J} = \{2, 4, 6, 7, \ldots, 23, 24, 25\}$
- $z_j, \quad j \in \mathcal{J}$
- $\mathcal{W}_7 = \{1, 3, 12\}$

LP TO MAXIMIZE GEOGRAPHICAL COVERAGE

$z_j = 1$ if block j is serviced by a selected parcel, 0 otherwise

$y_i = 1$ if candidate parcel i is selected to become a park, 0 otherwise

$$\begin{aligned}
\max \; f_1 = \sum_{j \in \mathcal{J}} z_j \\
\text{subject to } z_j \leq \sum_{i \in \mathcal{W}_j} y_i, \quad & j \in \mathcal{J} \\
\left|\mathcal{W}_j\right| z_j \geq \sum_{i \in \mathcal{W}_j} y_i, \quad & j \in \mathcal{J} \\
z_j \in \{0, 1\}, \quad & j \in \mathcal{J} \\
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\end{aligned}$$

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$$z_j \in \{0, 1\}, \quad j \in \mathcal{J}$$

$$y_i \in \{0, 1\}, \quad i \in \mathcal{I}$$

LP TO MAXIMIZE GEOGRAPHICAL COVERAGE

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$$\text{subject to } z_j \leq \sum_{i \in \mathcal{W}_j} y_i, \quad j \in \mathcal{J}$$

$$|\mathcal{W}_j| \, z_j \geq \sum_{i \in \mathcal{W}_j} y_i, \quad j \in \mathcal{J}$$

$$p_{max} \geq \sum_{i \in \mathcal{I}} y_i$$

$$z_j \in \{0, 1\}, \quad j \in \mathcal{J}$$

$$y_i \in \{0, 1\}, \quad i \in \mathcal{I}$$

SWITCHING THE OBJECTIVE

1	200 2	3	200 4	30 5
40 6	100 7	150 8	160 9	20 10
40 11	12	150 13	140 14	15
40 16	50 17	130 18	19	80 20
21	60 22	70 23	80 24	40 25

SWITCHING THE OBJECTIVE

1	200 2	3	200 4	30 5
40 6	100 7	150 8	160 9	20 10
40 11	12	150 13	140 14	15
40 16	50 17	130 18	19	80 20
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Which candidate parcel will maximize the number of beneficiaries?

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40 11	12	150 13	140 14	15
40 16	50 17	130 18	19	80 20
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Which candidate parcel will maximize the number of beneficiaries?

$p_i, \quad i \in \mathcal{I}$

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40 16	50 17	130 18	19	80 20
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Which candidate parcel will maximize the number of beneficiaries and the geographic coverage?

THE SOLUTION STRATEGY

- Maximize geographic coverage

MULTIOBJECTIVE

- Maximize geographic coverage
- Maximize number of beneficiaries

$$
\begin{aligned}
\max \ \mathsf{f}_1 &= \sum_{j \in \mathcal{J}} z_j \\
\max \ \mathsf{f}_3 &= \sum_{i \in \mathcal{I}} p_i y_i \\
\text{subject to } z_j &\leq \sum_{i \in \mathcal{W}_j} y_i, j \in \mathcal{J} \\
\left|\mathcal{W}_j\right| z_j &\geq \sum_{i \in \mathcal{W}_j} y_i, j \in \mathcal{J} \\
p_{max} &\geq \sum_{i \in \mathcal{I}} y_i \\
z_j &\in \{0, 1\}, j \in \mathcal{J} \\
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\end{aligned}
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\max f_1 = \sum_{j \in \mathcal{J}} z_j & \\
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\begin{aligned}
\max f_3 = \sum_{i \in \mathcal{I}} p_i y_i & \\
\text{subject to } z_j \leq \sum_{i \in \mathcal{W}_j} y_i, & \; j \in \mathcal{J} \\
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p_{max} \geq \sum_{i \in \mathcal{I}} y_i & \\
z_j \in \{0, 1\}, & \; j \in \mathcal{J} \\
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\end{aligned}
$$

$$\begin{aligned} \max\ f_1 = \sum_{j \in \mathcal{J}} z_j \\ \text{subject to } z_j \leq \sum_{i \in \mathcal{W}_j} y_i, j \in \mathcal{J} \\ \left|\mathcal{W}_j\right| z_j \geq \sum_{i \in \mathcal{W}_j} y_i, j \in \mathcal{J} \\ p_{max} \geq \sum_{i \in \mathcal{I}} y_i \\ z_j \in \{0, 1\}, j \in \mathcal{J} \\ y_i \in \{0, 1\}, i \in \mathcal{I} \end{aligned}$$

f_1^*

$$\begin{aligned} \max\ f_3 = \sum_{i \in \mathcal{I}} p_i y_i \\ \text{subject to } z_j \leq \sum_{i \in \mathcal{W}_j} y_i, j \in \mathcal{J} \\ \left|\mathcal{W}_j\right| z_j \geq \sum_{i \in \mathcal{W}_j} y_i, j \in \mathcal{J} \\ p_{max} \geq \sum_{i \in \mathcal{I}} y_i \\ z_j \in \{0, 1\}, j \in \mathcal{J} \\ y_i \in \{0, 1\}, i \in \mathcal{I} \end{aligned}$$

f_3^*

MULTIOBJECTIVE

$$
\begin{aligned}
\max f_1 &= \sum_{j \in \mathcal{J}} z_j \\
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\max f_3 &= \sum_{i \in \mathcal{I}} p_i y_i \\
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z_j &\in \{0, 1\}, j \in \mathcal{J} \\
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\end{aligned}
$$

$f_1^* = 8 \text{ blocks}$

f_3^*

$$\begin{aligned} \max\ f_1 = \sum_{j \in \mathcal{J}} z_j & \\ \text{subject to } z_j \leq \sum_{i \in \mathcal{W}_j} y_i, & \ j \in \mathcal{J} \\ \left|\mathcal{W}_j\right| z_j \geq \sum_{i \in \mathcal{W}_j} y_i, & \ j \in \mathcal{J} \\ p_{max} \geq \sum_{i \in \mathcal{I}} y_i & \\ z_j \in \{0,1\}, & \ j \in \mathcal{J} \\ y_i \in \{0,1\}, & \ i \in \mathcal{I} \end{aligned}$$

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$f_1^* = 8$ blocks, $f_3^* = 810$ people

COMPROMISE THRESHOLD

- compromise threshold: $(1 - \alpha_k)$

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- α_k maximum acceptable deterioration for objective k

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- $k = 1, 3$

COMPROMISE THRESHOLD

- compromise threshold: $(1 - \alpha_k)$
- α_k maximum acceptable deterioration for objective k
- $k = 1, 3$
- α_1 = 40% means objective function 1 must be at least 60% as optimal as the solution acquired in isolation

$$
\begin{aligned}
\max\ f_3 &= \sum_{i \in \mathcal{I}} p_i y_i \\
\text{subject to } z_j &\leq \sum_{i \in \mathcal{W}_j} y_i, j \in \mathcal{J} \\
\left|\mathcal{W}_j\right| z_j &\geq \sum_{i \in \mathcal{W}_j} y_i, j \in \mathcal{J} \\
p_{max} &\geq \sum_{i \in \mathcal{I}} y_i \\
\sum_{j \in \mathcal{J}} z_j &\geq (1 - \alpha_1) f_1^* \\
z_j &\in \{0, 1\}, j \in \mathcal{J} \\
y_i &\in \{0, 1\}, i \in \mathcal{I}
\end{aligned}
$$

SOLUTION

1	200 2	3	200 4	30 5
40 6	100 7	150 8	160 9	20 10
40 11	12	150 13	140 14	15
40 16	50 17	130 18	19	80 20
21	60 22	70 23	80 24	40 25

A DAUNTING EXAMPLE

50	55		40	60	85	65	120	105	95	85		65	45	
	50	45	60	110	120	95	110		100	65	75	40	45	30
80	75	55	70	105	130	115		105	115	80	50	65	50	
165		65		65	80	95	110	105		70	55	45		25
225	200	70	75	100		100	105	120	105	55		20	25	15
250	120		85	105	100	110	70	80	70	65	50	15	5	10
200	100	180	155	125	105	80		95	75	40	45	35		15
250			145		235	100	80	135	95	70		50	45	20
300		265	205	235	505	500	245	175	80	85	65	30		25
305	255	275	215	225	400	405	410	500	305		45	50	40	30

A DAUNTING EXAMPLE

50	55		40	60	85	65	120	105	95	85		65	45	
	50	45	60	110	120	95	110		100	65	75	40	45	30
80	75	55	70	105	130	115		105	115	80	50	65	50	
165		65		65	80	95	110	105		70	55	45		25
225	200	70	75	100		100	105	120	105	55		20	25	15
250	120		85	105	100	110	70	80	70	65	50	15	5	10
200	100	180	155	125	105	80		95	75	40	45	35		15
250			145		235	100	80	135	95	70		50	45	20
300		265	205	235	505	500	245	175	80	85	65	30		25
305	255	275	215	225	400	405	410	500	305		45	50	40	30

Maximum number of blocks = 40

A DAUNTING EXAMPLE

50	55		40	60	85	65	120	105	95	85		65	45	
	50	45	60	110	120	95	110		100	65	75	40	45	30
80	75	55	70	105	130	115		105	115	80	50	65	50	
165		65		65	80	95	110	105		70	55	45		25
225	200	70	75	100		100	105	120	105	55		20	25	15
250	120		85	105	100	110	70	80	70	65	50	15	5	10
200	100	180	155	125	105	80		95	75	40	45	35		15
250			145		235	100	80	135	95	70		50	45	20
300		265	205	235	505	500	245	175	80	85	65	30		25
305	255	275	215	225	400	405	410	500	305		45	50	40	30

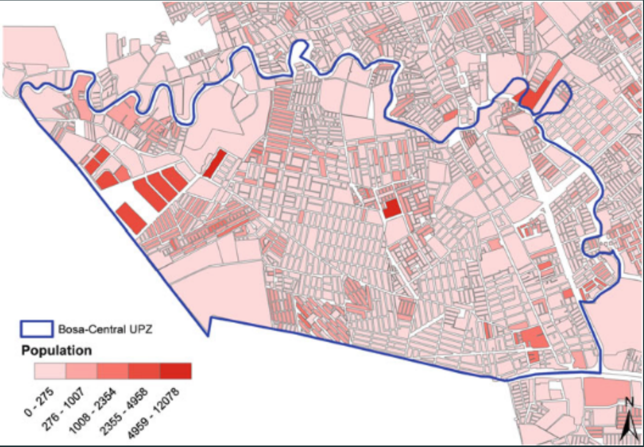
Maximum number of blocks $= 40$

Maximum number of beneficiaries $= 6690$

SOME SOLUTIONS

$(1-\alpha_1)$	Allowable deterioration	# beneficiaries (% of max)	# blocks served (% of max)
0.9	0.1	5855 (87.5)	37 (92.5)
0.85	0.15	6035 (90.2)	35 (87.5)
0.8	0.2	6345 (94.8)	33 (82.5)
0.75	0.25	6395 (95.6)	30 (75.0)
0.7	0.3	6575 (98.2)	28 (70.0)
0.65	0.35	6575 (98.2)	28 (70.0)
0.6	0.4	6640 (99.3)	25 (62.5)
0.55	0.45	6690 (100)	22 (55.0)

BOGOTÁ, COLOMBIA



OBJECTIVE FUNCTIONS

$$\max \mathsf{f}_1 = \sum_{\mathsf{j} \in \mathcal{J}} \mathsf{z}_\mathsf{j}$$

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$$\max \mathsf{f}_2 = \sum_{i \in \mathcal{I}} \left(\sum_{\{k \in \mathcal{E}_{\mathcal{P}} : d_{ik} \leq r^e\}} \left(1 - \frac{d_{ik}}{r^e}\right) y_i - \sum_{\{k \in \mathcal{E}_{\mathcal{N}} : d_{ik} \leq r^e\}} \left(1 - \frac{d_{ik}}{r^e}\right) y_i \right)$$

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$$\max\ f_3 = \sum_{i \in \mathcal{I}} p_i y_i$$

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OBJECTIVE FUNCTIONS

$$\max\ f_1 = \sum_{j \in \mathcal{J}} z_j$$

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$$\max\ f_3 = \sum_{i \in \mathcal{I}} p_i y_i$$

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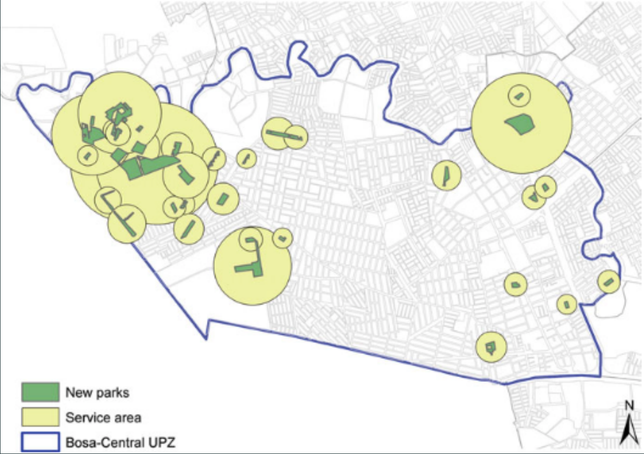
$$\max\ f_5 = \sum_{i \in \mathcal{I}} e_i y_i$$

$$\min\ f_6 = \sum_{i \in \mathcal{I}} (c_i^l + c_i^b) y_i$$

BOGOTÁ, COLOMBIA



THE CONCLUSION

KEY POINTS

- Park location case study

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- Community Based Operations Research

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- Linear program

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- Multiobjective problem

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- Community Based Operations Research
- Linear program
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- Worked through an example
- Solutions
- Difficult process!

THE END

Questions?