LOCATING PARKS WITH A MULTIOBJECTIVE OPTIMIZATION METHOD

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Pomona College

THE PROBLEM

BOGOTÁ, COLOMBIA

- Large city

BOGOTÁ, COLOMBIA

- Large city
- Sports and recreation master plan

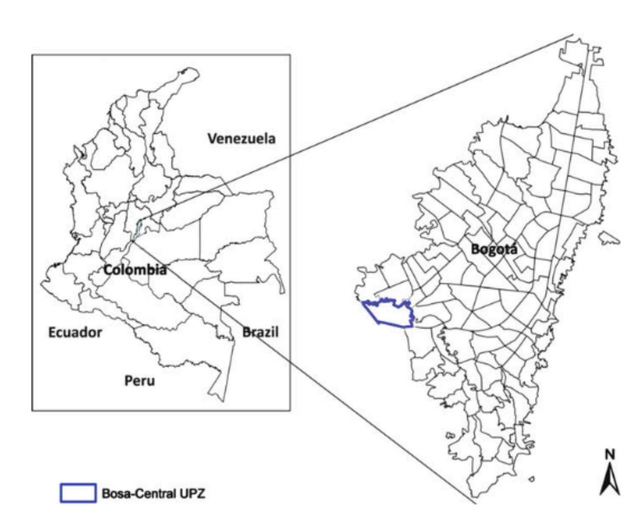
BOGOTÁ, COLOMBIA

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

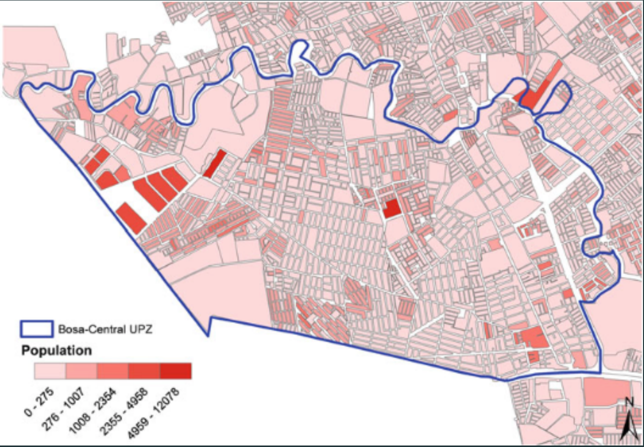
BOGOTÁ, COLOMBIA

- 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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- Mid-20th century development
- Limited resources

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- Competing activities

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- Optimal

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- Linear model

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

LINEAR PROGRAM

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

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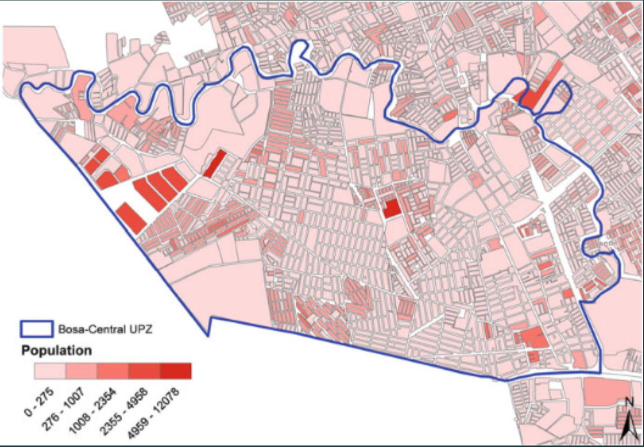
& x_1 \geq 0, x_2 \geq 0, \ldots, x_n \geq 0
\end{aligned}
$$

THE MODEL

BOGOTÁ, COLOMBIA



SIMPLIFYING ASSUMPTIONS

- $m \times n$ grid

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- One block = one square

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- 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

- Maximize geographical coverage

  f_1
- Maximize people serviced

OBJECTIVE FUNCTIONS

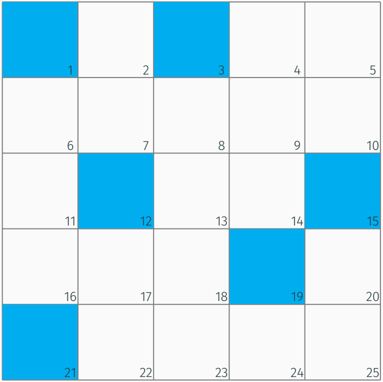
- Maximize geographical coverage

  f_1

- Maximize people serviced

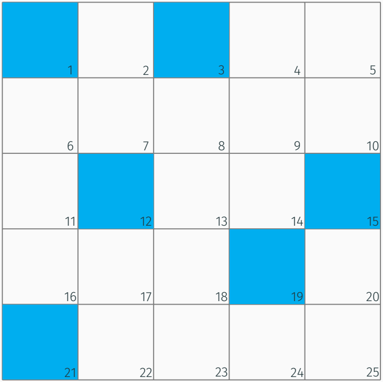
  f_3

EXAMPLE

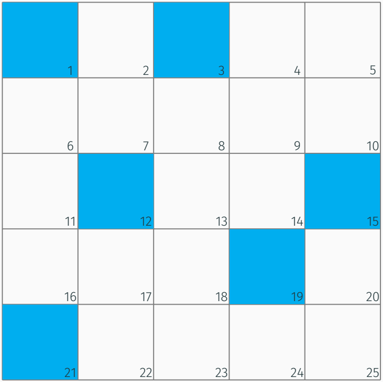


This is our 5×5 grid city

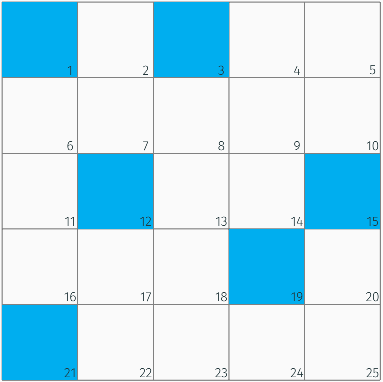
EXAMPLE



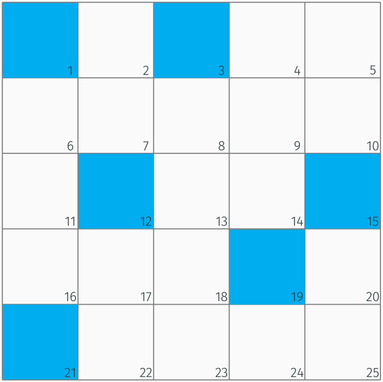
- Candidate parcels



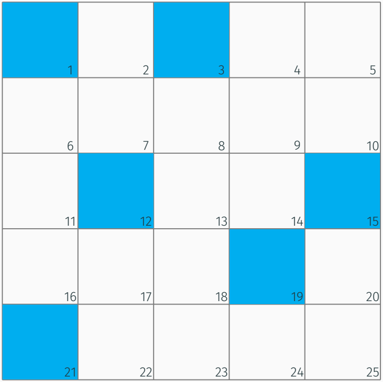
- Candidate parcels: $\mathcal{I} = \{1, 3, 12, 15, 19, 21\}$



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

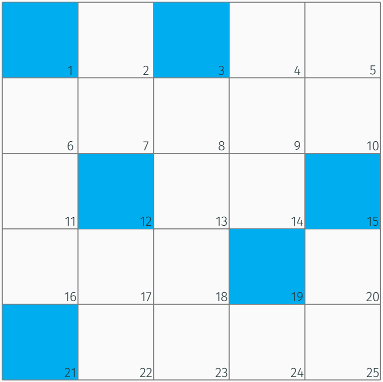


- Candidate parcels: $\mathcal{I} = \{1, 3, 12, 15, 19, 21\}$; $y_{19} = 1$



Which candidate parcel will maximize geographical coverage?

EXAMPLE



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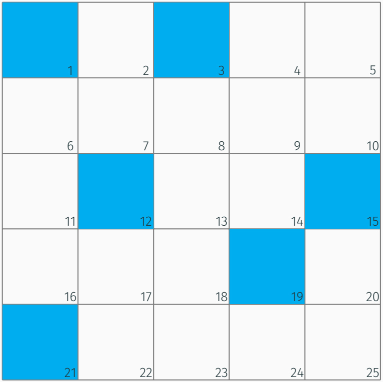
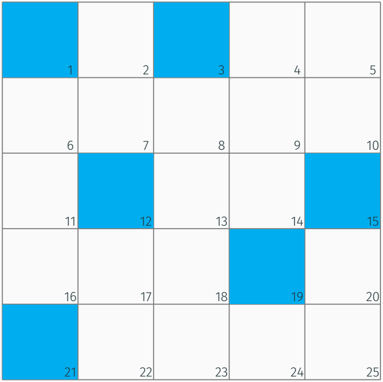
Candidate 12

EXAMPLE

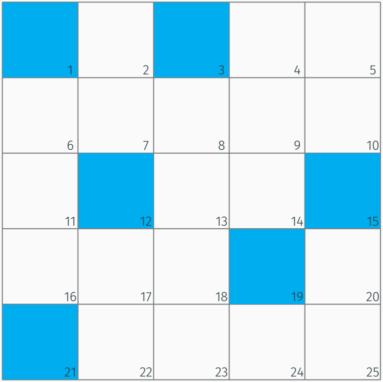


- $\mathcal{J} = \{2, 4, 6, 7, \ldots, 23, 24, 25\}$



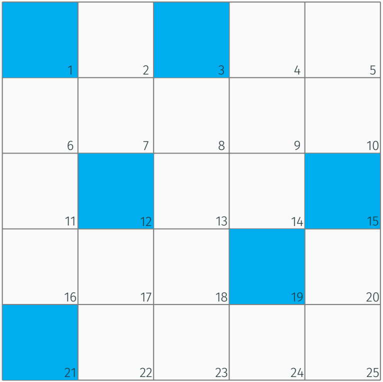
- $\mathcal{I} = \{2, 4, 6, 7, \ldots, 23, 24, 25\}$, the set of all blocks that would benefit from the construction of a new park

EXAMPLE



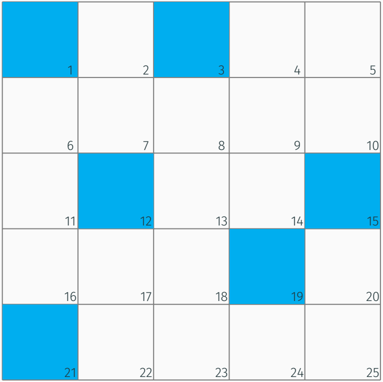
- $\mathcal{J} = \{2, 4, 6, 7, \ldots, 23, 24, 25\}$
- $z_j, \quad j \in \mathcal{J}$, 1 if block j is serviced by a selected parcel, 0 otherwise

EXAMPLE



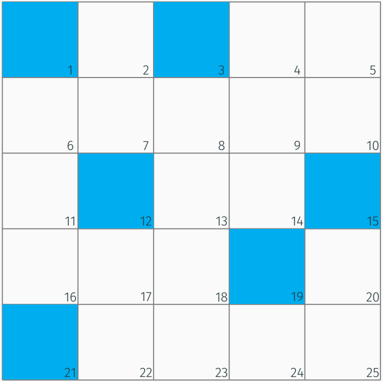
- $\mathcal{I} = \{2, 4, 6, 7, \ldots, 23, 24, 25\}$
- $z_2 = z_6 = z_7 = 1, \quad z_4 = z_8 = z_9 = \cdots = z_{24} = z_{25} = 0$

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

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

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

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
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Which candidate parcel will maximize the number of beneficiaries?

1	200 2	3	200 4	30 5
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$p_i, \quad i \in \mathcal{I}$

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Which candidate parcel will maximize the number of beneficiaries and the geographic coverage?

THE SOLUTION STRATEGY

- Maximize geographic coverage

- Maximize geographic coverage
- Maximize number of beneficiaries

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

MULTIOBJECTIVE

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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}
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z_j \in \{0,1\}, & \ j\in\mathcal{J} \\
y_i \in \{0,1\}, & \ i\in\mathcal{I}
\end{aligned}$$

f_1^*

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

f_3^*

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

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

f_3^*

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\max\ f_1 &= \sum_{j\in\mathcal{J}} z_j \\
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p_{max} &\ge \sum_{i\in\mathcal{I}} y_i \\
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p_{max} &\ge \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}$$

$$f_3^* = 810 \text{ people}$$

COMPROMISE THRESHOLD

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

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- α_k maximum acceptable deterioration for objective k

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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
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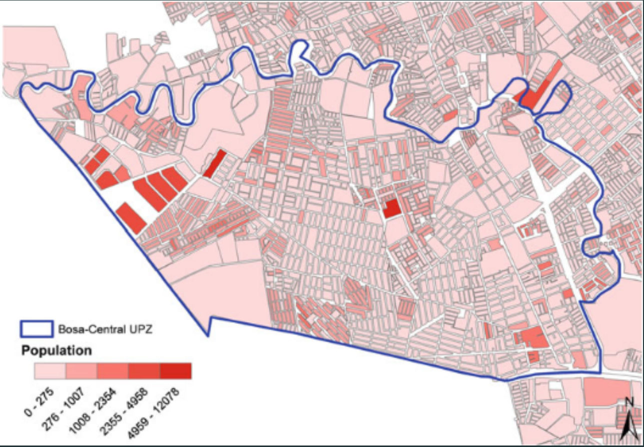
[Graphic of larger example will go here]

[table of solutions for previous example will go here]

BOGOTÁ, COLOMBIA



OBJECTIVE FUNCTIONS

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

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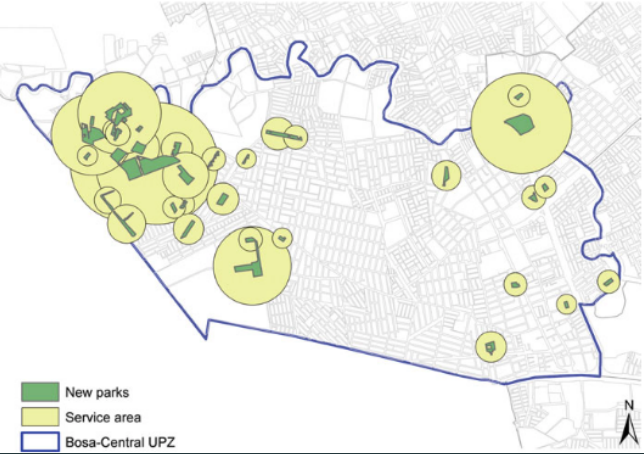
$$\min\ f_6 = \sum_{i \in \mathcal{I}} (c_i^l + c_i^b) y_i$$

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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- Difficult process!

THE END

Questions?