An Approach for Spatial Optimization on Positioning Surveillance Cameras

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Motivation

- Importance and relevance of crime monitoring, surveillance, and prevention
- CCTV as a popular tool
- Surveillance systems deployment and associated costs
- Recognize the spatial nature of crime incidence
- Maximize coverage ⟷ Minimize costs
- Spatial optimization approach

Previous work

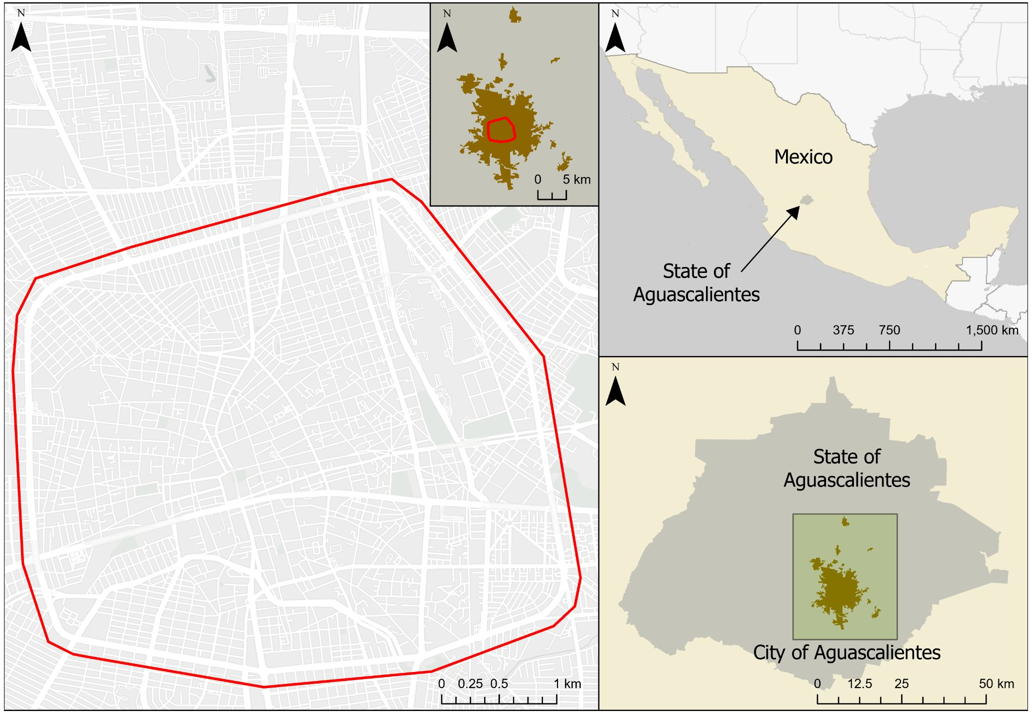
- Art Gallery problem (Klee and Chvátal, 1973)
- Location Set-Covering Problem (Church and Meadows, 1979)
- Maximal Covering Location Problem (Hogan and ReVelle, 2012)
- Backup Coverage Model (Hogan and ReVelle, 2012)
- Spatially explicit (Meta-)Heuristic and genetic algorithms?
- Greedy algorithms?

Our proposal

Propose the Criminal Visibility Index (CVI) to rank the suitability of any possible camera location. The CVI is used to identify the top *n* locations that, based on their spatial configuration and criminal incidence, would require surveillance cameras.

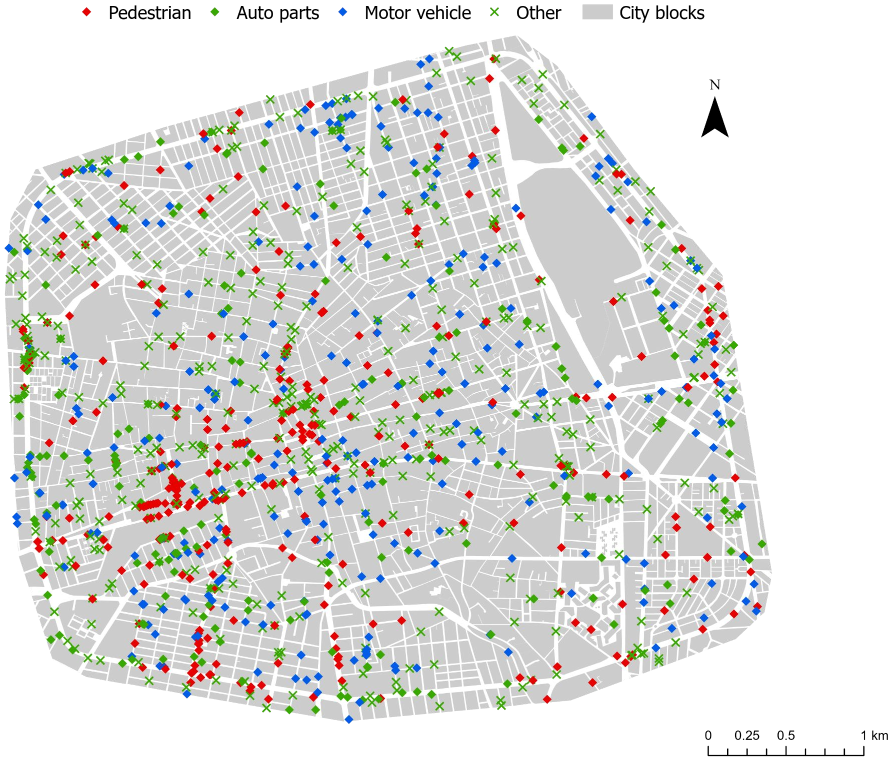
Use a greedy algorithm to find a near optimal solution as a benchmark against which future improvements should be tested.

Study Area and Data



- Area inside the First Ring of the City of Aguascalientes, in the State of Aguascalientes, Mexico.
- City blocks and road network from the National Institute of Statistics and Geography

Study Area and Data



- Geo-referenced criminal incidence records from the state’s General Attorney’s office for thefts that occurred in 2018
- Little over 1,300 data points

The Criminal Visibility Index CVI

CVI is a measure to estimate the ability to detect criminal theft events given a set of cameras positioned in the region of interest.

We assume a roughly even distribution of events throughout the years and consider the potential cameras to be represented by the set **p**:

$$\mathbf{p} = \{p_i | p_i = (x_i, y_i), \text{for } i \in \{0, 1, \ldots, n\}\}$$

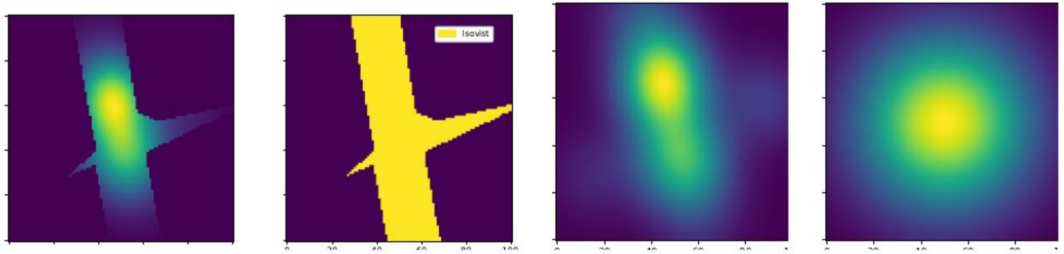
where (x_i, y_i) are the coordinates of each camera.

The Criminal Detection Sensitivity Map

It depends on the following three spatial variables:

1. The closeness to the camera position described by a Gaussian kernel (*K*)
2. The crime density as a result of applying a Gaussian kernel to the raster image of geo-referenced crimes (*D*).
3. The visible range of each camera described by its isovist, which is a binary map (*V*).`

$$R = V \circ D \circ K$$



The Global Criminal Detection Sensitivity Map

$$R(p_i)[m,n] = \begin{cases} 0 \text{ if } \sqrt{(m-x_i)^2+(n-y_i)^2} > r \\ V_i(x_i,y_i)\cdot D_i(x_i,y_i)\cdot K_i(x_i-m-r, y_i-n-r) \text{ otherwise} \end{cases}$$

where m, n are all the possible coordinates, and r is the desired or technical visibility distance constraint parameter for a given camera.

The Criminal Visibility Index I for surveillance cameras is then:

$$I(\mathbf{p}) = \sum_{x\in M}\sum_{y\in N} \max_i R(p_i)[x,y]$$

Cost function

$$\mathbf{p}^* = \arg\max_{\mathbf{p}} I(\mathbf{p})$$

$$\text{subject to: } \{(p_i, p_j) | \text{Distance}(p_i, p_j) \geq r, \forall (i, j) \in [0, \ldots, |\mathbf{p}| - 1]\}$$

$$\text{and}$$

$$|\mathbf{p}| = s\,,$$

where all the possible pairs (p_i, p_j) must have an Euclidean distance of at least a radius of *r*, and *s* is the number of sensors.

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A Greedy Algorithm

Require: $\mathbf{p}^{\text{sort}}$

Require: s $\triangleright$ Number of sensors

Ensure: $\mathbf{p}^*$ $\triangleright$ Solution

$\mathbf{p}^* \leftarrow \{p^{\text{sort}}_{\text{first}}\}$

$\mathbf{p}^{\text{candidate}} \leftarrow \{p_i^{\text{sort}} | \text{Distance}(p^{\text{sort}}_{\text{first}}, p_i^{\text{sort}}) > r, \forall i, (i \neq \text{first})\}$ $\triangleright$ Euclidean Distance

$\mathbf{p}^{\text{sort}} \leftarrow \mathbf{p}^{\text{candidate}}$

while $(\mathbf{p}^{\text{sort}} \neq \{\emptyset\})$ and $|\mathbf{p}^*| < s$ **do**

    $\mathbf{p}^* \leftarrow \{\mathbf{p}^* \cup \text{first}(\mathbf{p}^{\text{sort}})\}$

    $\mathbf{p}^{\text{candidate}} \leftarrow \{p_i^{\text{sort}} | \text{Distance}(p^{\text{sort}}_{\text{first}}, p_i^{\text{sort}}) > r, \forall i, (i \neq \text{first})\}$

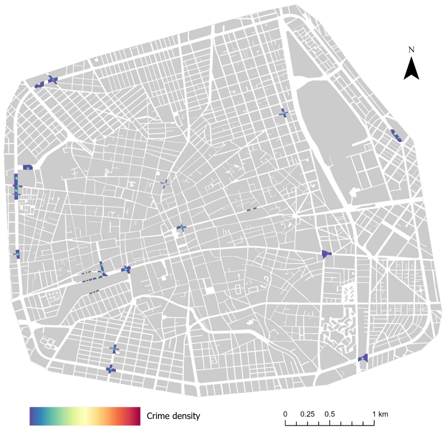
    $\mathbf{p}^{\text{sort}} \leftarrow \mathbf{p}^{\text{candidate}}$

end while

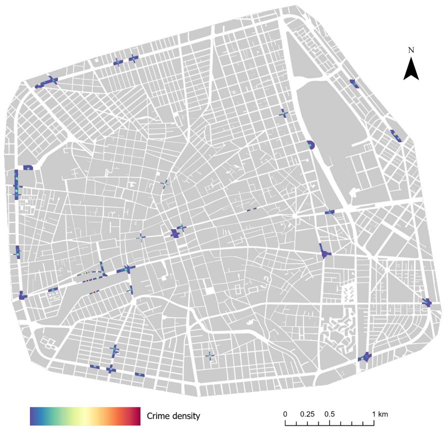
Results

We produce 1m resolution crime density maps using a radius $r = 50\text{m}$.

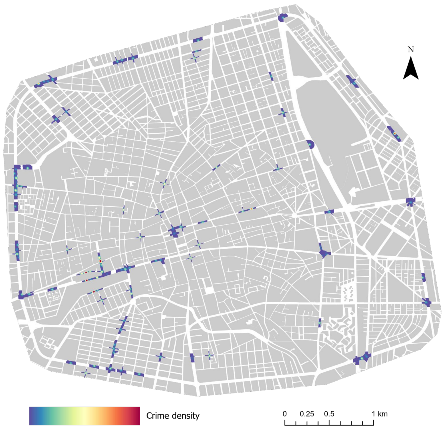
We obtain the optimal locations for 25, 50, 100, 250, 500, and 1000 cameras, respectively.



25 cameras

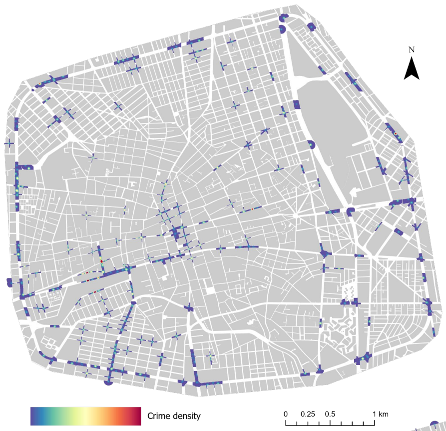


50 cameras

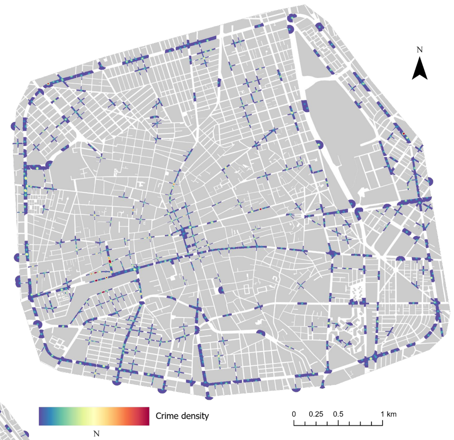


100 cameras

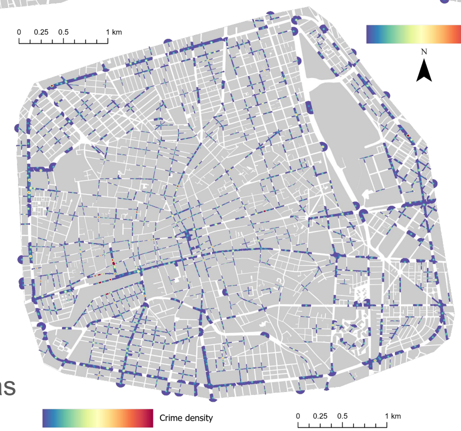
Results



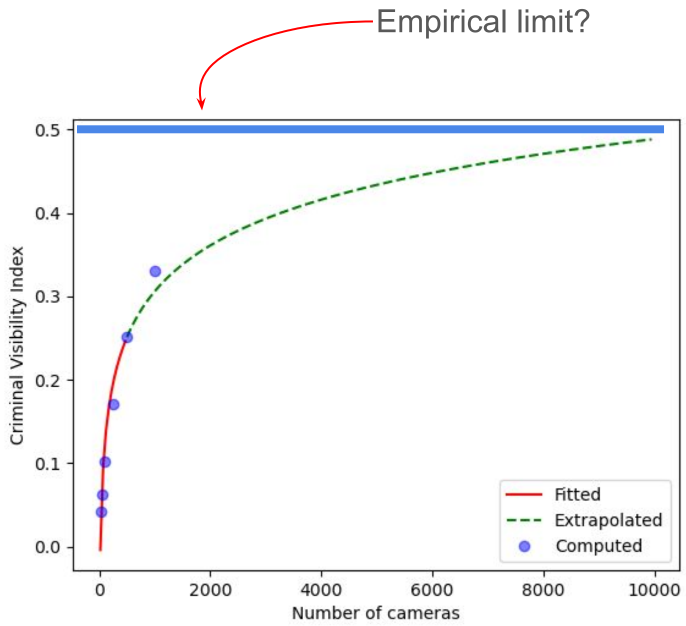
250 cameras



500 cameras



1000 cameras



Results

We've only scratched the surface with respect to evaluating the number of cameras to achieve maximum coverage.

But it seems unnecessary to fill the study area with cameras in order to achieve a good cost/benefit ratio.

Number of cameras	Index	Percent of total
25	0.04153	7%
50	0.06246	10%
100	0.10188	16%
250	0.17084	27%
500	0.25129	40%
1000	0.33097	53%

Future work

Parallelize parts of the algorithm

The greedy algorithm is the best solution, but it is expensive.

Need to look into reducing unnecessary overheads

Compare with other methods and spatial optimization strategies

Test with other cities and data sets (real-time ones)

Incorporate cadastral or urban data to account for

visibility obstacles.

Compare results with actual placed cameras

Thank you!

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