Spatial Partitioning of Police Districts: a Multi-Criteria Model

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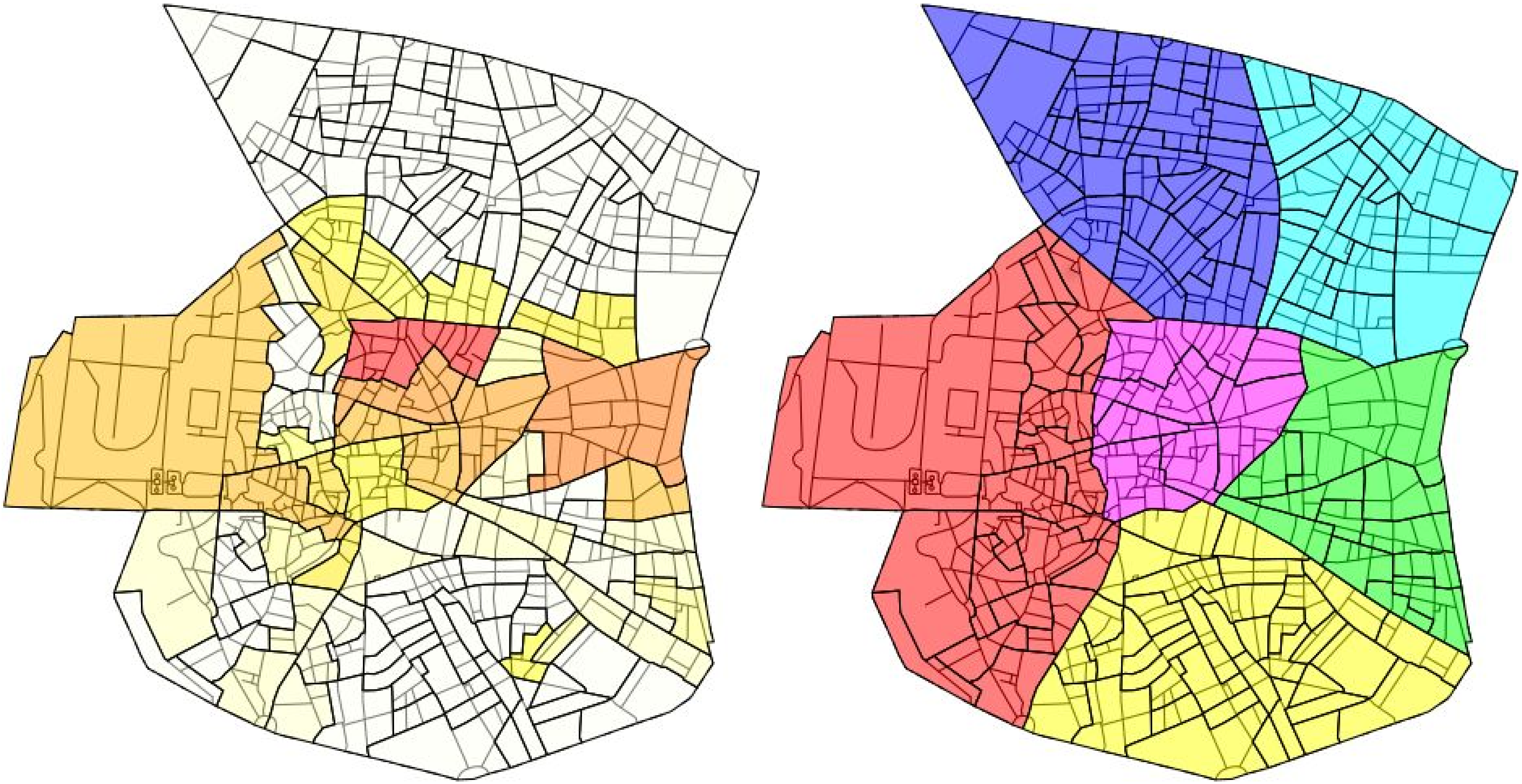
Introduction

Background and motivation

What is this talk about



Rationale

- Objectives of **Police Departments**:
  1. Improving the effectiveness of patrolling operations.
  2. Increasing the efficiency in the use of scarce resources.

- **Possible Solution:**

  Implementing a **Predictive Patrolling Policy**

Context

- In Spain, the security of towns is responsibility of the Spanish National Police Corps (SNPC)
- A strong crisis has reduced the number of police officers and resources available to the SNPC
- The distribution of patrols is done by the inspectors.
  - They locate the agents according to neighborhood borders defined more than 50 years ago.

Districting Problem

- Grouping elementary units (or atoms) of a given territory into larger districts (or clusters), according to relevant attribut
- Applied to:
  - Definition of electoral areas
  - Sales and service districting
  - Social facilities districting
  - Emergency service districting
  - …

The Police Districting Problem (PDP)

- Variation of Districting Problem.
- Specifically tailored to the needs of police agencies.
- Generally considers the following attributes:
  - Number of emergency calls
  - Response time to the calls
  - A measure of the workload

PDP Related Work

- Mitchell (1972) proposes a clustering heuristic for the redesign of patrol beats in Anaheim, California.
  - He considers the total expected weighted distance to incidents, as well as a workload measure defined as the sum of the expected service time and the expected travel time.
- Bodily (1978) adopts a utility theory model that incorporates the preferences of three interest groups, namely, the citizens, the administrators, and the service personnel.

PDP Related Work

- Benveniste (1985) is the first author to include **workload equalization** in the optimization process.

- The model by D'Amico et al. (2002) calculates sectors' workload by calling an external software, PCAM, that defines the optimal number of agents in a particular shift.

- Zhang and Brown (2013) propose a heuristic algorithm for the generation of districting, evaluated

Predictive Patrolling

- “**Predictive policing** refers to any policing strategy or tactic that develops and uses information and advanced analysis to inform forward-thinking crime prevention”, Dr. John Morgan, NIJ Symposyum
- **Predictive Policing + Police Districting Problem = Predictive Patrolling**
  - Focus resources where needed.
  - Adapts to the idiosyncrasies of a specific shift.
  - Change of paradigm: **from detention to prevention**

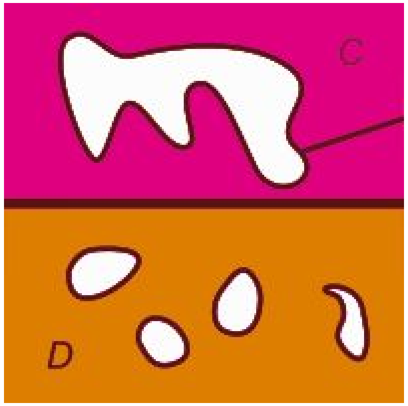
Problem Formulation

A Multi-Criteria Police Districting Problem

- **Goal** of the model:
  - To **partition** into patrol sectors the territory under the jurisdiction of a district, in the best possible way.
  - Find a balance between **efficiency** and **workload distribution**.
  - Patrol sectors must be **connected** and **convex**.

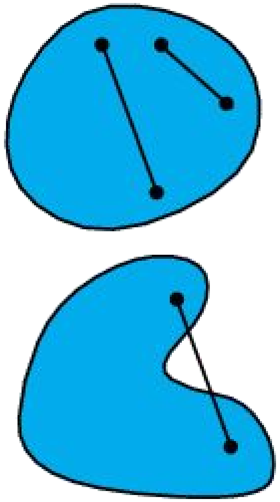
Connectivity and Convexity

Connected Space



Disconnected Space

Convex Space



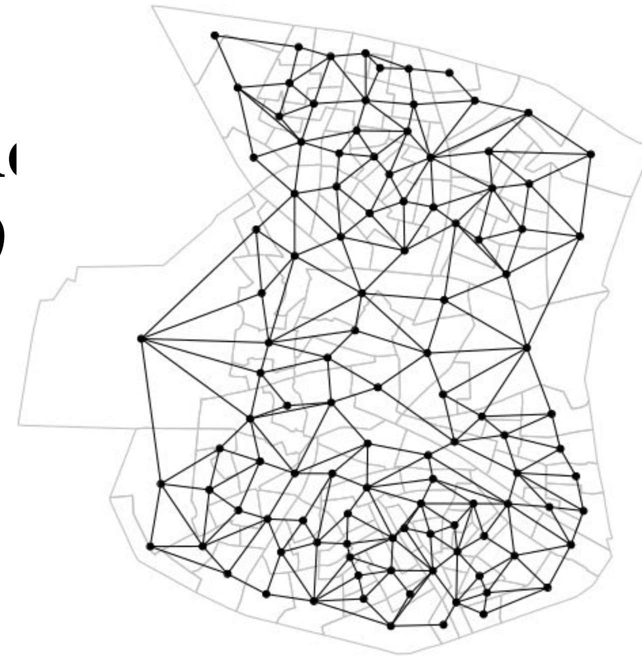
Concave Space

Characteristics of a «good» territory partition

- Compact areas
  - Better control of the territory
  - Faster response of agents
- Homogeneity in terms of workload
  - More efficient distribution of work
  - Equality increases satisfaction of agents
- Mutual support
  - Desirable in case of need or emergency

Input Data

- Graph ***G(N,E)***
- ***N*** set of nodes, indexed by ***i*** an
- ***E*** set of edges, indexed by ***(i,j)***
- $\boldsymbol{r_i}$, crime risk at node ***i***
- $\boldsymbol{a_i}$, area to be patrolled at node
- $\boldsymbol{l_{ij}}$, length of edge ***(i,j)***



- ***p***, number of patrolling sectors
- **w**, decision-maker preference weights
- $\boldsymbol{\lambda}$, balance coefficient

Sector Attributes - 1

- Area
  - a^s – This attribute identifies the size of the territory that an agent should patrol.
- Support Received
  - b^s – Two sectors support each other if the distance between their geometric medians is less than or equal to a defined constant, K.
- Crime Risk
  - c^s – The demand is defined as the total risk of the sector, i.e., the sum of the risk associated to the cells belonging to the sector.
- Diameter
  - d^s – The diameter of a sector is defined as the maximum distance between any pair of cells belonging to it.

Attributes - 2

- Used to define criteria
- Decision-maker can specify preference among the criteria by using weights, **w**

Patrol sector's workload:

$$W^s = w_a a^s + w_b b^s + w_c c^s + w_d d^s$$

Objective Function

$$obj(P) = \lambda \cdot \max\{W^s\} + (1-\lambda).\sum_{s \in P} \frac{W^s}{p}$$

$0 \leq \lambda \leq 1$, the model gives a range from optimization ($\lambda = 0$) to balance ($\lambda = 1$).

$$obj(P) = \lambda \cdot \max\{W^s\} + (1-\lambda).\sum_{s \in P} \frac{W^s}{p}$$

Problem Formulation

$$\min obj(P)$$

$$s.t. \quad \varnothing \notin P$$

$$\bigcup_{s \in P} s = N$$

$$r \cap s = \varnothing \quad \forall s,r \in P \mid s \neq r$$

$$|P| = p$$

$$Conn(s) = 1 \quad \forall s \in P$$

$$Conv(s) = 1 \quad \forall s \in P$$

Solving the MC-PDP

- Heuristic approach:
  Multi-start Tabu Search algorithm initialized by a randomized Greedy algorithm.
  - Starts with a reasonably good solution generated randomly.
  - Iteratively improves the solution by perturbing the partition to find better configurations.
- Methodology capable of generating in just one minute patrolling configurations that are more efficient than those currently adopted by the SNPC.

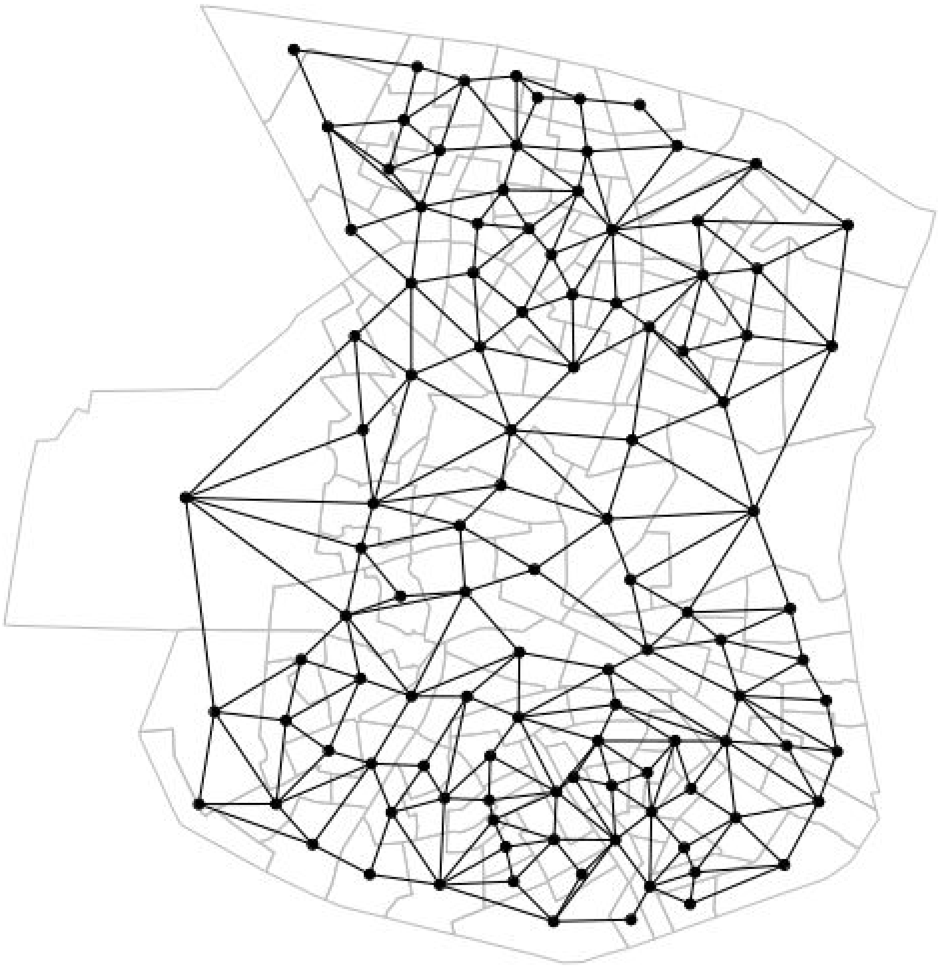
Madrid : Central District

Case Study

- Madrid Central District population is approximately 150,000 people, 26.87% of which are immigrants. Very heterogeneous.
- High transient population that commute to this district for reasons of work, sightseeing or leisure.
- 30% of all the crimes in Spain happen here.

Dataset

- 111 nodes corresponding to census districts
- 276 edges
- a_i : total length of roads
- l_{ij} : great-circle distance of census districts' centers



Preference Weights and Balance Coefficient

Parameters provided by service coordinator:

w = (0.45, 0.05, 0.45, 0.05)

$\boldsymbol{\lambda}$ = 0.1

$\boldsymbol{r_i}$: **theft** committed in three shifts

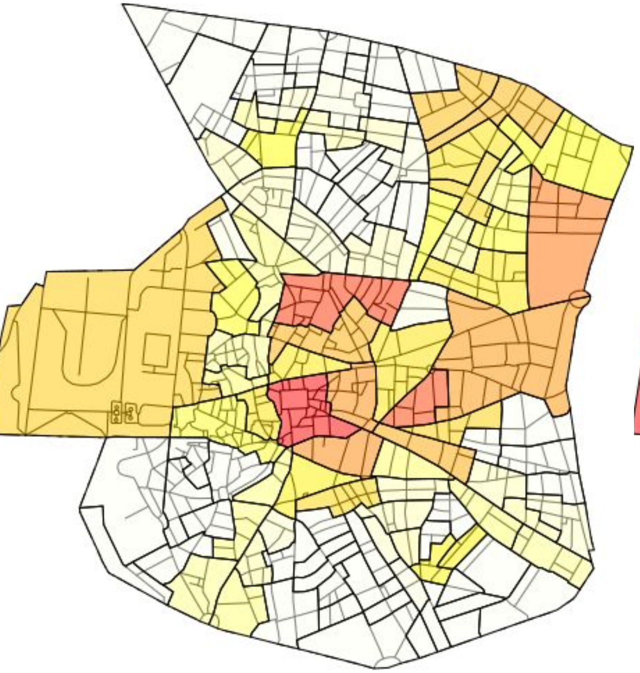
- Saturday 10/13/12, night shift
- Sunday 10/13/12, morning shift
- Monday 10/14/12, afternoon shift

Experiments

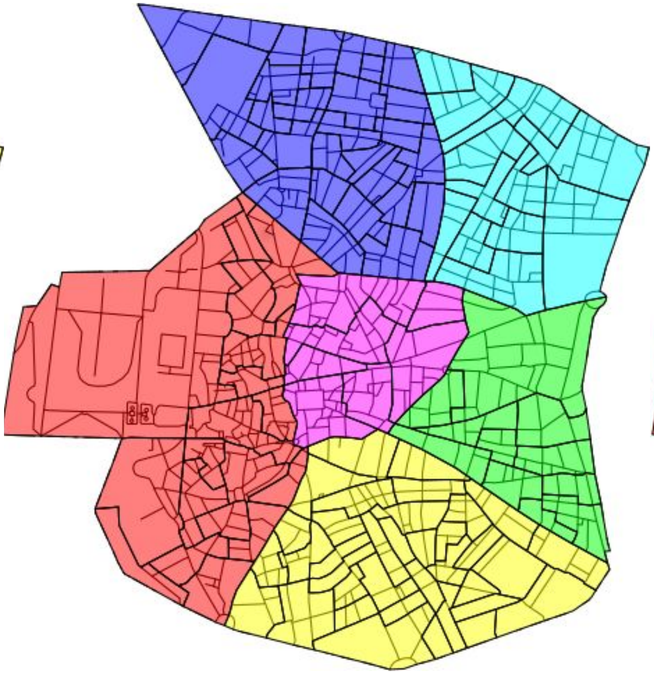
- We have run each configuration 50 times and computed the 95% confidence intervals
- Computational time: 60 seconds
- We compared the solutions found by our approach to the configuration currently adopted by the SNPC.

Saturday Night Shift

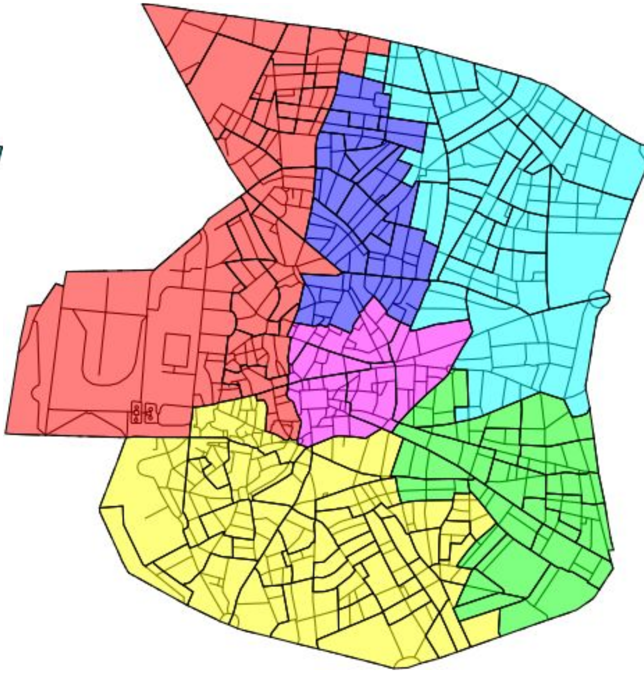
Crime Level



SNPC Solution

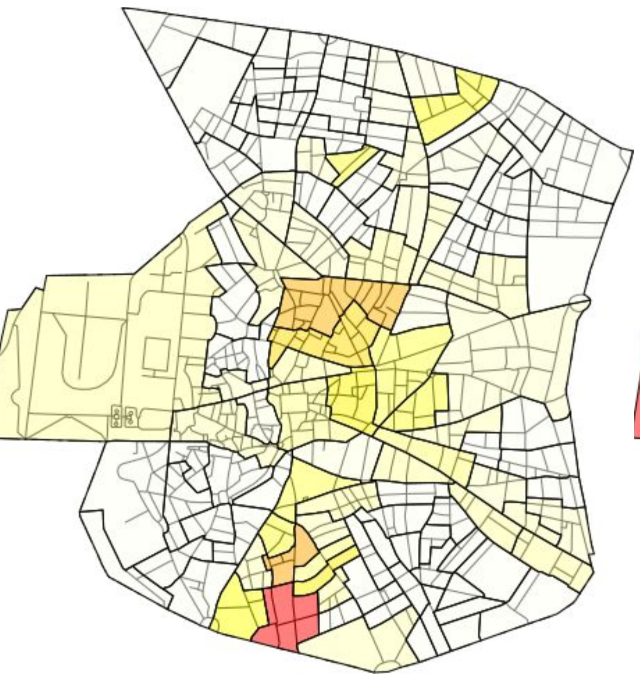


Model's Solution

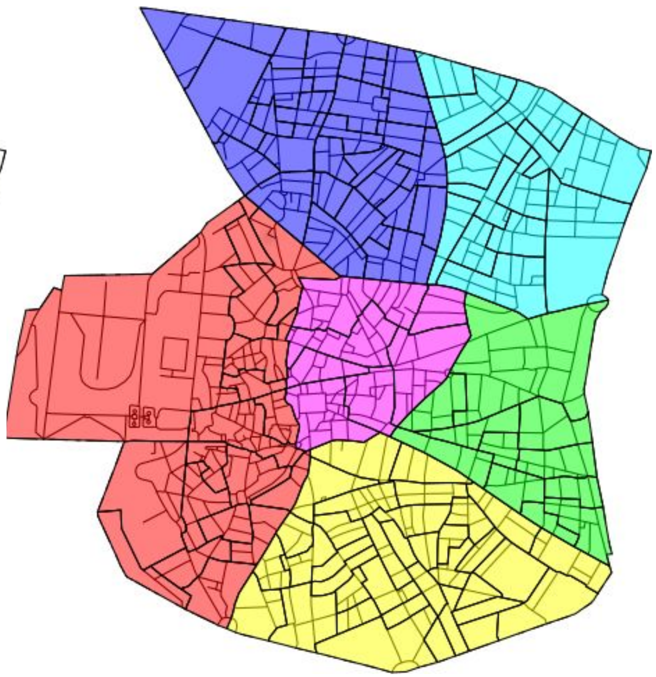


Sunday Morning Shift

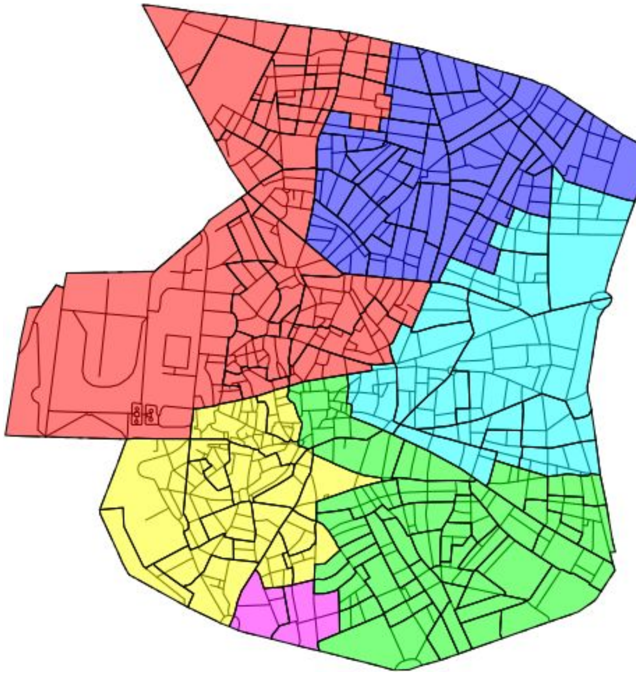
Crime Level



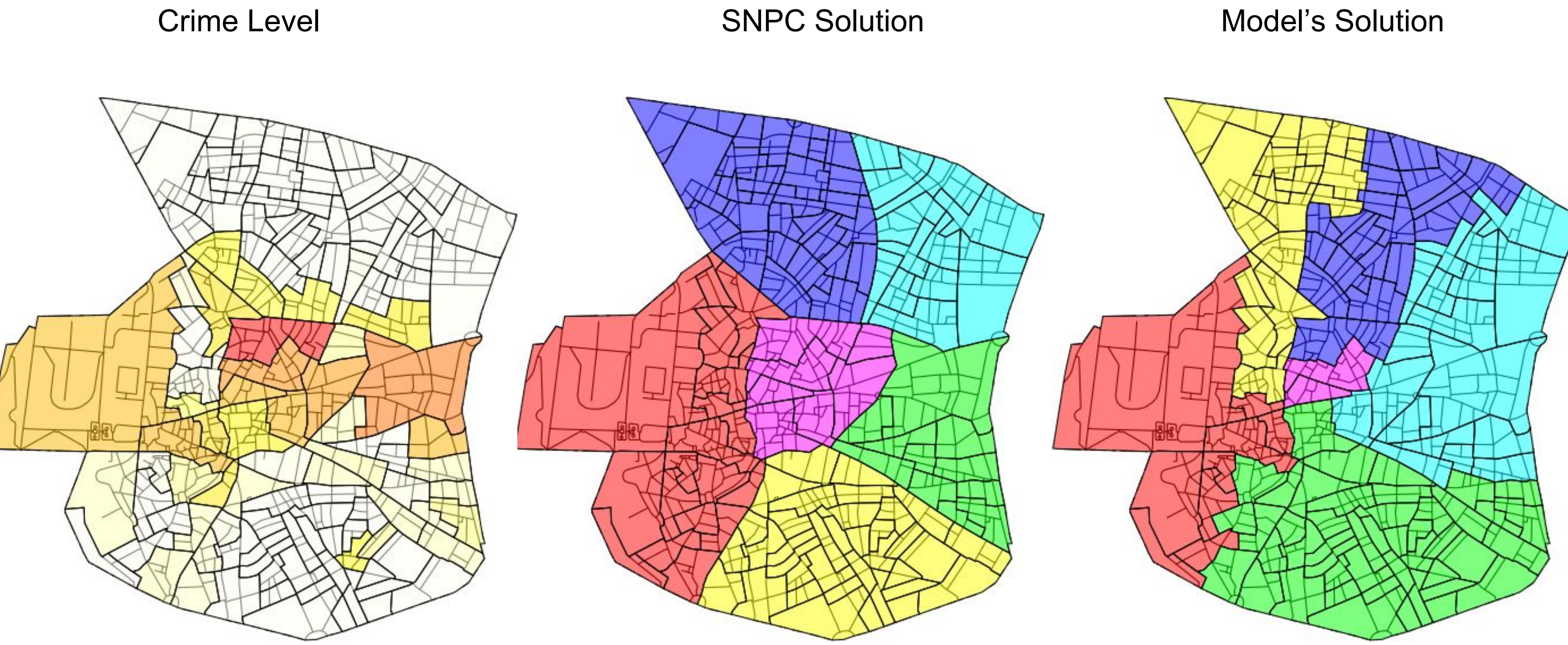
SNPC Solution



Model's Solution



Monday Afternoon Shift



RESULTS

Shift	# of Patrol Sectors	SNPC Solution	MCPDP Solution	Improvement
Saturday Night	2	0.56	**0.49**	12.5%
Saturday Night	6	0.20	**0.19**	5%
Sunday Morning	2	0.56	**0.49**	12.5%
Sunday Morning	6	0.21	**0.19**	9.52%
Monday Afternoon	2	0.55	**0.49**	10.91%
Monday Afternoon	6	0.21	**0.18**	9.52%

Conclusions

Conclusions

- Empirical tests show that **the algorithm generates** rapidly **patrolling configurations that are more efficient than those devised by professionals**, in the case study considered.

Future Research Topics

- **Effectiveness of other heuristic and metaheuristic** algorithms, such as ant colonies and genetic algorithms.
- Design of **optimal algorithms**, possibly based on decomposition (e.g., column generation)
- Other problems:
  - Objective evaluation of the agents.
  - Determination of the optimal number of agents required in a shift.

THANK YOU!!!

Bibliography

M. Camacho-Collados, F. Liberatore, J.M. Angulo, "A multi-criteria police districting problem for the efficient and effective design of patrol sectors," European *Journal of Operations Research*, 246(2): 674-684, 2015.

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