Fast reaction police units in Medellín: A budget-constrained maximal homicide covering location approach

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Fast reaction police units in Medellín: A budget-constrained maximal homicide covering location approach[1]

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Abstract. We propose a maximal covering location problem with a budget constraint to determine the optimal location of facilities that provide fast police assistance to homicide hot spots, to mitigate criminal activity in Medellín (Colombia). We use the Google Maps Application Programming Interface (API) to estimate the average traveling times between police units and criminal spots, and impose a budget constraint taking into account the project's costs. Our procedure identifies how the optimal locations for fast reaction police units have a diminishing marginal coverage pattern when subject to loosened budget constraints.

JEL classification: C44, H4.
Keywords: Homicide, Maximal Coverage Location Problem, Police Station.

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Comandos de Atención Inmediata en Medellín: Un problema de ubicación con máxima cobertura de potenciales puntos criminales[5]

Abstract. Este documento considera un problema de localización de cobertura máxima con restricciones de presupuesto para determinar la ubicación óptima de instalaciones policiales que brinden atención rápida a potenciales puntos criminales, para así mitigar la actividad delictiva en Medellín (Colombia). Se utiliza la Interfaz de programación de Google Maps (API) para estimar los tiempos promedio de viaje entre las unidades policiales y los puntos criminales, y se imponen restricciones presupuestarias teniendo en cuenta los costos del proyecto. El procedimiento identifica cómo la cobertura asociada a las ubicaciones óptimas de los comandos de policía de atención inmediata tiene un aumento marginalmente decreciente en la medida que se reducen las limitaciones presupuestarias.

Clasificación JEL: C44, H4.
Palabras Clave: Homicidio, Problema de localización de cobertura máxima, Estación de Policía.

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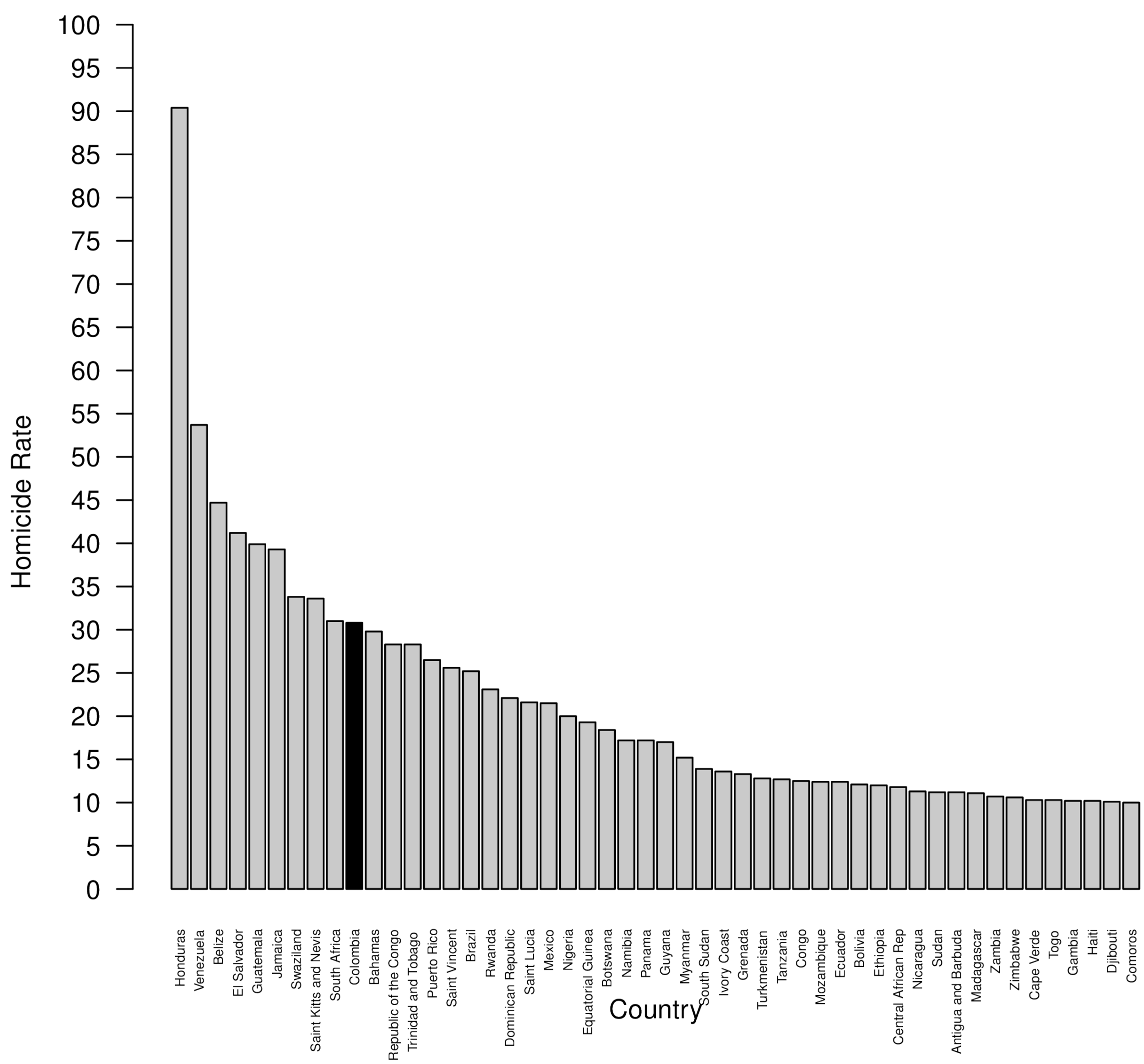
1 Introduction

Empirical research has found that criminal activity clusters geographically Freeman et al. (1996); Andresen (2006); Cozens (2008); Wang et al. (2013), and that police forces have local effects (Di Tella and Schargrodsky, 2004). This evidence suggests that the efficient spatial allocation of law enforcement units is of main relevance to reducing criminal activity (Ackerman and Murray, 2004). Thus, in this paper we propose a methodology to identify the optimal locations of fast reaction police units as a good strategy to mitigate crime in Medellín. This city is located in Colombia, the country which took 10th place among the countries with the highest homicide rates in the world. In particular, Colombia had 30.8 homicides per 100,000 inhabitants in 2012 (see Figure 1).

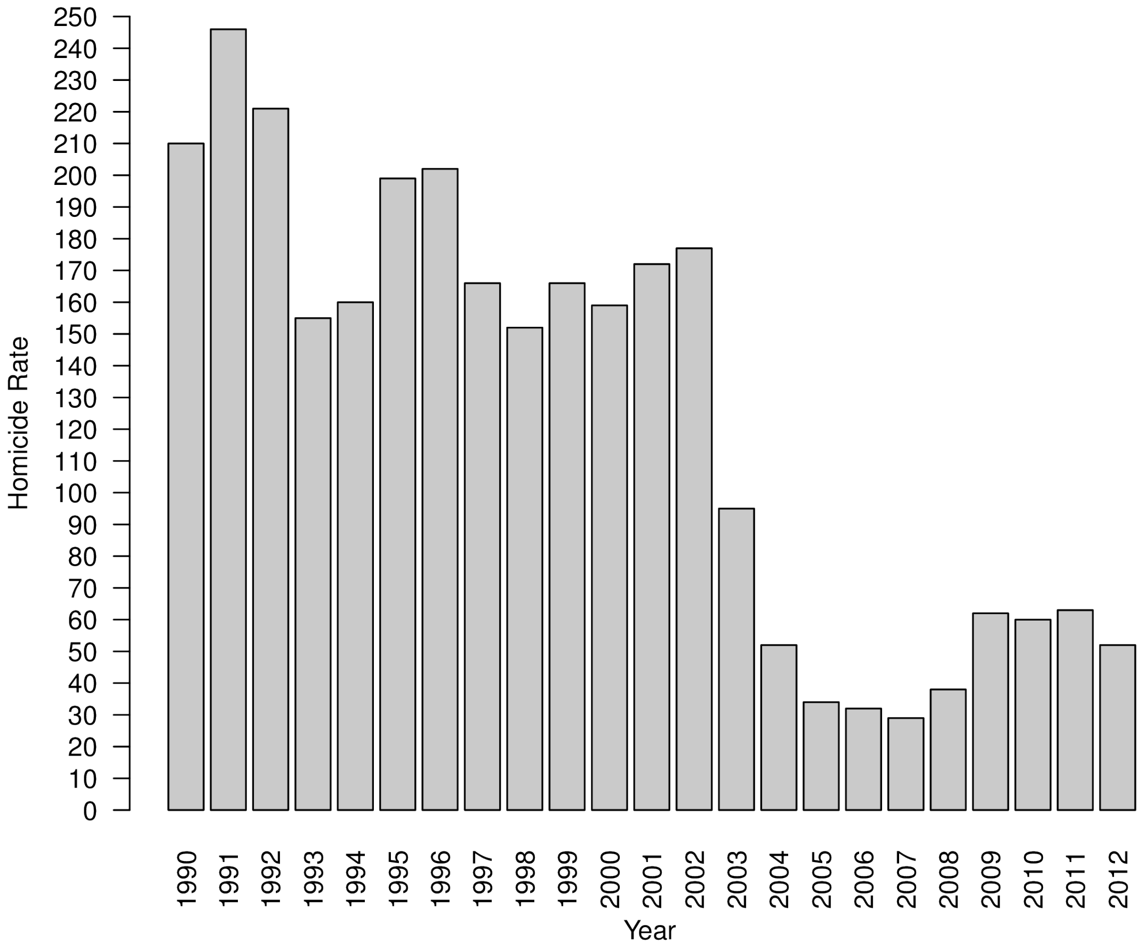
Figure 1: Homicide Rates: Top 50 countries worldwide, 2012



We can see in Figure 2 the dynamics of the homicide rate in Medellín between 1990 and 2012: as we observe in this figure, the homicide rate in this city reached a peak of 246 in 1991, and although there is a downward trend that implied a minimum of 29 in 2007, there are two disturbing facts: first, the minimum figure is very high compared to homicide rates in developed countries, which on average are lower than 5 homicides per 100,000 inhabitants. Second, there is a slight positive slope in recent years, which meant an average rate equal to 55 homicides. These facts, and the strong negative effects of violence on society (Soares, 2006), are the main motivation for proposing formal techniques to mitigate this social problem in this city.

As is well known, extended periods of violence entail large costs to society, such as losses in the quality and length of life, enormous amounts of fiscal and private spending on unproductive activities, destruction of physical and human capital, and decreased investment and innovation. Soares (2006) suggests that when considering some intangibles, the average cost of violence for Latin America may be as high as 14 percent of GDP. This figure is particularly important in cities exposed to long periods of conflict and high crime rates, such as Medellín.

Figure 2: Homicide Rate: Medellín, 1990–2012



The explanation of criminal acts has been a matter of priority due to their huge negative effects on society. Becker (1968) pioneered an economic explanation for understanding crime as a part of optimal microeconomic decisions, giving theoretical support to this social problem, and unleashing empirical studies that have sought to deepen the analysis of this issue.

Crime literature has determined that the socioeconomic conditions of individuals have an important influence on decisions to commit crimes (Becker, 1968; Bourguignon, 2001; Ackerman and Murray, 2004). As a consequence, societies characterized by higher levels of poverty, exclusion, income inequality, among other things, tend to exhibit high crime rates. Unfortunately, these variables change gradually, so interventions in these fields may only become visible in the long run.

Given the slow pace of socioeconomic interventions to reduce violence, different interventions are necessary to relieve the problem in the short term. Becker (1968)'s seminal paper establishes that criminal activity offers economic rewards, but also moral and social costs. So, high capture probabilities or strong punishments imply less criminal activity due to the effects of deterrence and incapacity (Levitt, 1998; Lee and McCrary, 2009). Specifically, empirical evidence suggests that police force presence has a positive and significant effect on crime reduction (Craig, 1987; Di Tella and Schargrodsky, 2004; Chalfin and McCrary, 2013), and small units are particularly effective (Wheaton, 2006).

Therefore, in this paper we propose a procedure to determine the optimal location of fast reaction police units in Medellín. In this procedure, we solve a sequence of integer programs to maximize the coverage of homicide locations, such that a budget constraint due to the project's costs is introduced. The final objective of our proposal is to reduce criminal activity. There are two novel features that make our methodology interesting for this application. First, we define our maximal covering location problem with a budget constraint that takes into account limited financial resources, which restricts governmental intervention, based on an estimation of the market price per square meter and equipment costs. Second, we use as input the average traveling times between the police units and locations of the homicides. In particular, we use the Google Maps Application Programming Interface (API) to calculate these times: thus, we avoid using distance measures that are not realistic due to not taking into account the road infrastructure and traffic conditions.

This paper is organized as follows. We introduce the budget-constrained maximal homicide covering location problem in Section 2. Section 3 describes the construction of the input required to implement our procedure, and shows the results of the use of this model to locate fast response police units in Medellín. Concluding remarks are given in Section 4.

2 Methodology

Ackerman and Murray (2004) found that the optimal location of police units is a good strategy for mitigating criminal activity. Thus we propose building fast reaction police units located at the points obtained by the solutions of a sequence of optimization problems, to reduce crime in Medellín. Fast reaction police units are the smallest jurisdiction of a police agency, "strategically" located on the urban perimeters of the main Colombian cities, and are responsible for guiding and strengthening urban surveillance, and protecting citizens' rights and freedom. The main principle of these units is timely arrival to places where citizens require them, which should be shorter than three minutes, so their optimal location is of main concern. Unfortunately, most of the "strategic" location of these police units are based on police officers' intuition, without any scientific principle to guide their "optimal" decisions. To overcome this lack of formal procedures to define the optimal locations, we introduce the budget-constrained maximal homicide covering location problem as an alternative for selecting the optimal locations of fast response units in Medellín.

Maximal Covering Location Problems (MCLP) aim to search for the optimal location of facilities such that the coverage of the demand served by these facilities is maximized. In the case of emergency response facilities, especially those associated with police units, researchers often use records, such as crime locations, to identify spots that represent potential claims along space to solve the MCLP (Curtin et al., 2010; Gu et al., 2010; Keskin et al., 2012; Ying and Mu, 2012; Guo and Qi, 2014).

The MCLP has developed greatly since the seminal paper of Church and Revelle (1974), including a wide range of applications, extensions to tackle uncertainty in travel times and other parameters, alternative definitions of coverage, the development of exact and heuristic solution procedures, among others. For a detailed review of covering problems in facility location, the reader is referred to Farahani et al. (2012).

Let $\mathcal{H}$ be the set of reported homicides, and $\mathcal{F}$ the set of potential locations for fast reaction police units. Building a fast reaction police unit has differing costs depending on its location; the parameter c_i $(i \in \mathcal{F})$ represents this fact. Likewise, the parameter b represents the budget available for construction of fast reaction police units. Moreover, we define binary parameter a_{ij}, that equal 1 if the travel time between the possible location $i \in \mathcal{F}$ and the location of homicide $j \in \mathcal{H}$ is smaller than three minutes, and 0 otherwise. Finally, we define two decision variables: the binary variable y_i takes the value of 1 iff site i is selected to locate a fast reaction police unit and 0 otherwise; likewise, the binary variable x_j takes the value of 1 iff homicide $j \in \mathcal{H}$ is covered and 0 otherwise (i.e., it has at least one fast reaction police unit located within the three-minute threshold). The budget-constrained maximal homicide covering location problem is represented as an integer program as follows:

$$\max \quad z = \sum_{j \in \mathcal{H}} x_j \tag{2.1}$$

subject to

$$\sum_{i \in \mathcal{F}: a_{ij}=1} y_i \geq x_j, \qquad \forall j \in \mathcal{H} \tag{2.2}$$

$$\sum_{i \in \mathcal{F}} c_i y_i \leq b, \tag{2.3}$$

$$y_i \in \{0,1\}, \qquad \forall i \in \mathcal{F} \tag{2.4}$$

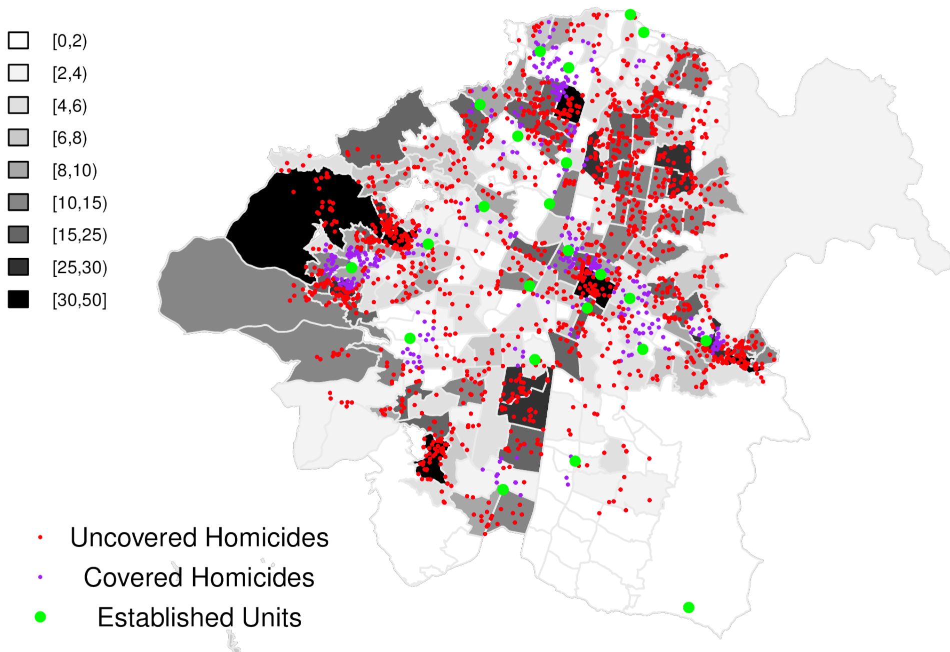
$$x_j \in \{0,1\}, \qquad \forall j \in \mathcal{H} \tag{2.5}$$

The objective function (2.1) to be maximized counts the number of covered homicide locations. The constraints (2.2) state that to be covered, a homicide location must have at least one fast response police unit within the three-minute threshold. The budget constraint is given in Equation (2.3). Lastly, the constraints (2.4) and (2.5) state the nature of the decision variables.

3 Case study

In order to find appropriate locations for fast response police units, we use model (2.1)–(2.5) in an iterative fashion. Beginning with a small budget of only US\$100K, we iteratively increase the value of b in steps of US\$100K until reaching full coverage. This procedure resembles the

Figure 3: Established Fast Reaction Police Units: Homicides in Medellín, 2011-2012



ϵ-constraint approach used in multi-objective facility location problems to explore the trade-offs between objectives (Villegas et al., 2006). Using this approach it is possible to find several interesting solutions of the problem. In this section, we discuss how we build the data required to apply the proposed model to Medellín's case and the results obtained after applying this procedure.

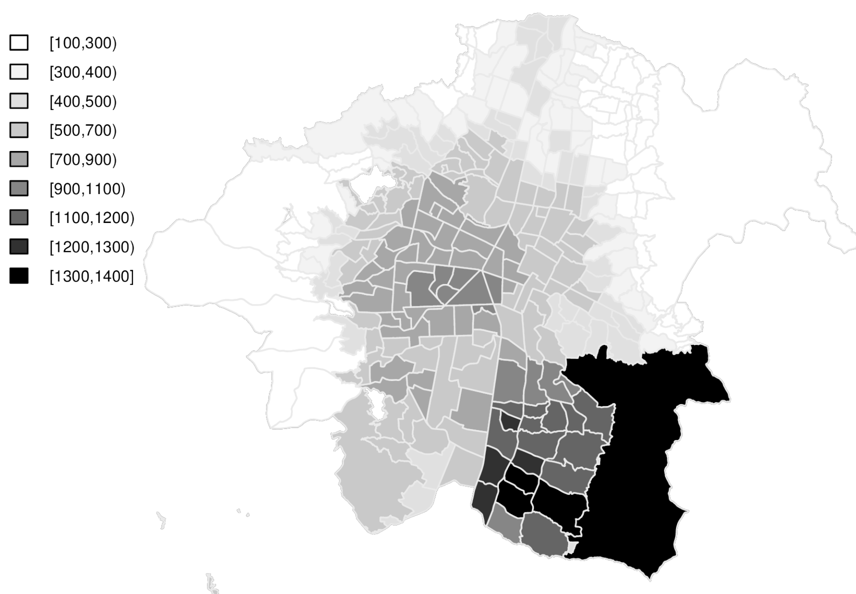
3.1 Inputs

We used the Google Maps Application Programming Interface (API) to build a matrix of average traveling times between georeferenced homicide points (which were provided by SI-JIN, the Police criminal investigation agency) and determined the locations for fast reaction police units in the city. Besides, in our model, we consider the sites of unattended homicides as candidate locations for new fast response police units (i.e., $\mathcal{F}$).

This travel time matrix takes into account traffic conditions and the road infrastructure, so it has advantages over unrealistic distance matrices based on the Euclidean distance or similar procedures. By construction, this matrix has zeros on its main diagonal, and is asymmetric. We transform this matrix to a binary matrix A whose element a_{ij} is equal to 1 if the traveling time is less than three minutes, and 0 otherwise. We can observe in Figure 3 the effect of using the Google Maps API to build our distance measure, rather than a Euclidean distance: the covered homicides are not located inside a ball whose center is a police unit.

In total, there were 2,426 homicides to be covered by 23 established urban units, 1,914 of which correspond to unattended homicides in 2011 and 2012 since the traveling time exceeds the three-minute time limit. This implies an unattended rate equal to 79%. We show in Figure 3 the spatial configuration of the current situation: the gray tonality of each neighborhood indicates the number of homicides. We use homicides because this variable is much less affected by statistical censoring due to unreported cases than are other criminal activities.

Figure 4: Average market price per square meter: Medellín, 2011 (US$/ m^2)



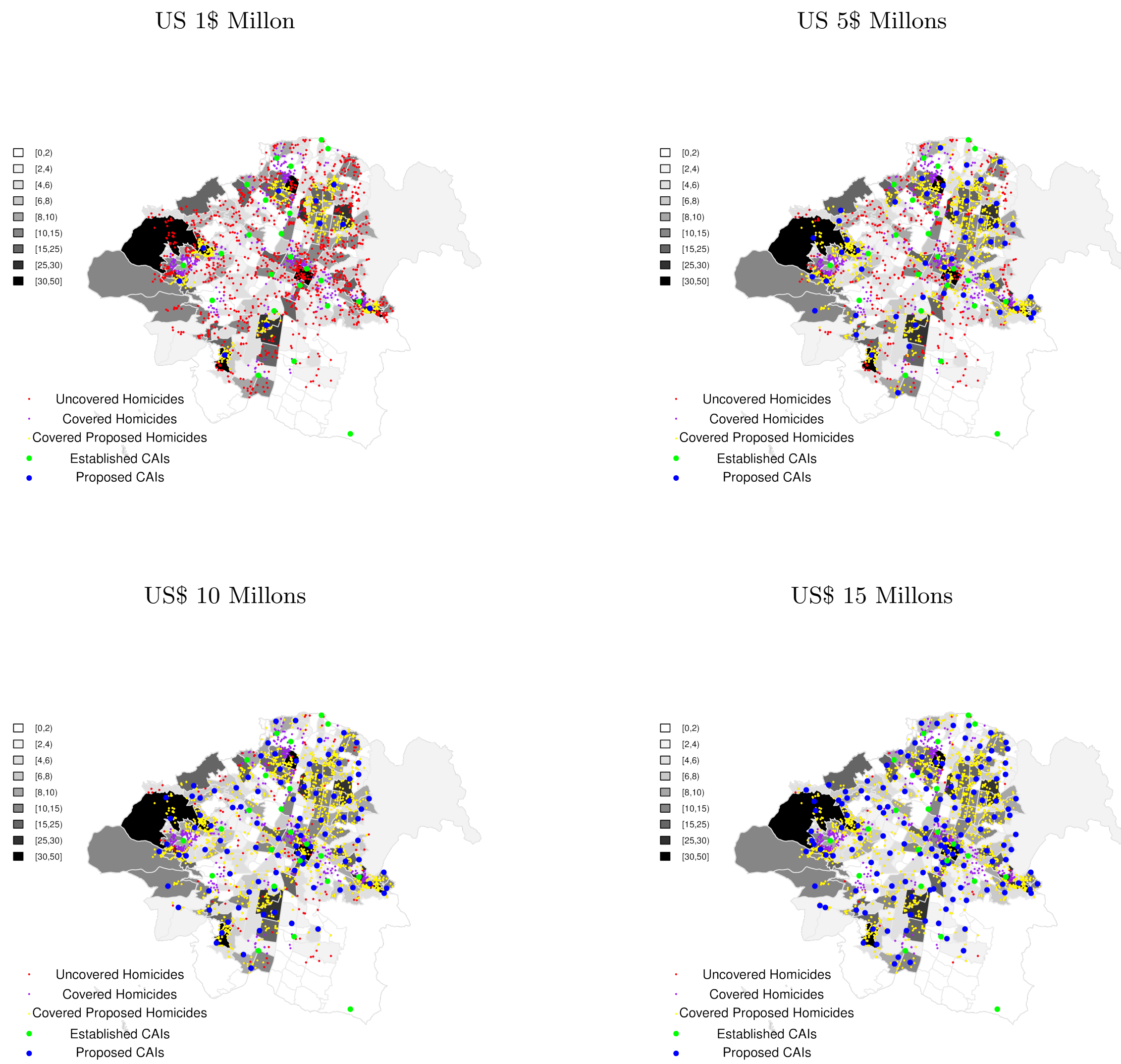
To collect the required data for the budget constraint (2.3), we took the project's costs into account. Specifically, the equipment costs of a fast reaction police unit were equal to US$ 60K in 2011. Additionally, a facility of 100 square meters is required. To calculate its market cost, we estimate the average market price of housing facilities, taking the information about rent and self-assessed rent for this concept using the 2011 Life Quality Survey in Medellín, which has a statistically representative sample size of 13,333 households. We found that 60% of the inhabitants own their housing facilities, who overestimate on average 11.7% their rent compared to market rents; so we correct our estimates using this factor. Once we have the average housing facilities' rents, we use data from the main house rental agencies in the city to estimate the average size of housing facilities, thus we obtain the average rent per square meter. Finally, we calculate the average market price per square meter of the facilities using their relationship with the rent per square meter in Colombia (Jaramillo and Cuervo, 2014).

We georeferenced each house facility in the Life Quality Survey, then we use Kriging to predict the average market prices per square meter in the urban area of Medellín. In particular, we exhibit the average market price of the neighborhoods' centroids in Figure 4. We observe in this figure that the highest prices are located in the southeastern region, these prices are equal to US$/m^2 1,350 on average, whereas the lowest prices are located in the northeastern and central west regions: these are equal to US$/m^2 200 on average.

3.2 Results

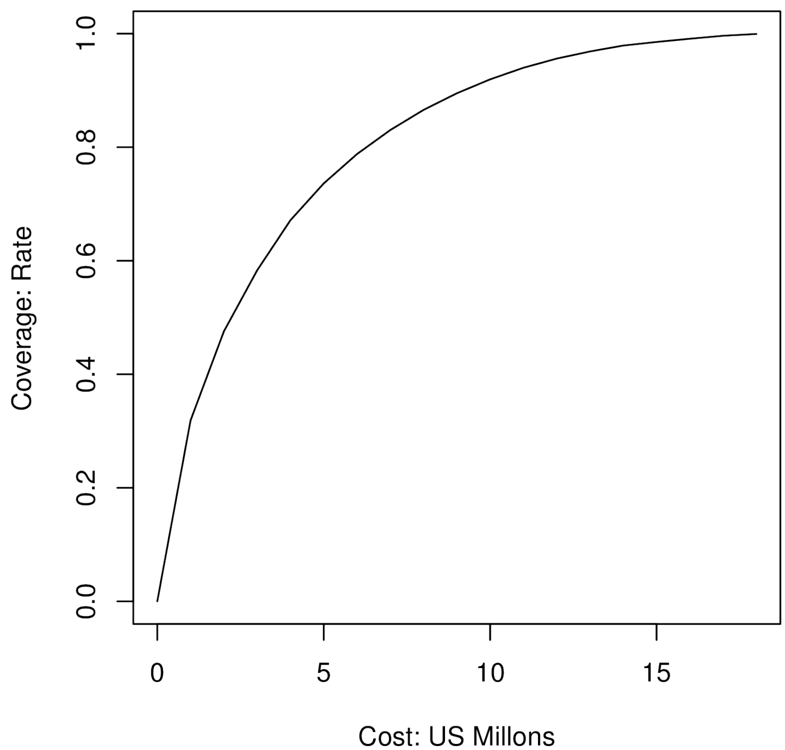
In Figure 5 we can observe the optimal locations of new fast reaction police units in Medellín (Colombia) for different values of b. We have in the top left-hand panel the optimal location associated with a budget of US$ 1M: this budget allows the government to construct 10 new units, that generate a 32% coverage rate of unattended homicides in time requirements. In the top right-hand panel is the optimal location with a US$ 5M budget, which allows the government to construct 50 new fast reaction police units with a coverage rate equal to 74%. A budget of US$ 10M permits achieving a coverage rate of 92% with 96 new facilities (see the bottom left-hand panel in Figure 5). Finally, we show the optimal locations of the police units using a budget of US$ 15M in the bottom right-hand panel in Figure 5; this framework allows building 142 new facilities, achieving a coverage rate of 99%.

Figure 5: Optimal location: fast reaction police units, Medellín (Colombia)



In Figure 6 can be seen the relationship between the coverage rate of unattended homicides and the costs of building new police units. As we can see, there are decreasing marginal returns. For instance, if the government decides to change the situation from investing US$ 1M to US$ 2M, the coverage rate increases from 32% to 48%, which is a 16% increase, whereas increasing the investment from US$ 2M to US$ 3M implies an increase of 10%. This pattern continues, as we can observe in this figure. A coverage rate equal to 100% is achieved with a budget of approximately US$ 17.9M.

Figure 6: Coverage vs Costs: Optimal location



4 Conclusions

The empirical literature shows that the optimal location of small police units is a good strategy for fighting crime. Unfortunately, the actual location of these police units in Medellín has been based on police officers' intuition, without any scientific framework to support their decisions. Although common sense and empirical experience are priceless assets, techniques based on scientific principles would improve their effectiveness in reducing crime in this city.

The solution of our maximal homicide covering location problem, which is based on traveling times and project costs, indicates that a budget of US$ 100K permits building just one fast reaction police unit. The location of this new unit allows police officers to arrive in a shorter time than three minutes to 4% of the homicide spots that are currently not attended by police units.

To the extent that government allocates larger budgets, our maximal homicide covering location problem obtains larger homicide coverage rates. However, there are decreasing marginal returns. For instance, if a desirable goal is to achieve a coverage rate equal to 50%, the government should invest approximately US$ 2M.

In addition, we observe from our application that although downtown is one of the places with the highest homicide rates in the city (the black central polygon in our optimal location maps), only budgets higher than US$ 2.5M allow the location of police units in this area. This is due to three factors: first, some homicides in this area are already covered by the established police units. Second, downtown is a very commercially active area: as a consequence, facility costs are very high, and so the budget constraint guides the search for optimal solutions outside this area. Third, the low speeds in the downtown area make it very difficult to achieve a high coverage. These factors suggest that fast reaction police units are not the best way to tackle downtown crime activity.

We must recognize two important aspects of our approach. First, any model is a logical reference for making decisions, so our main purpose is to indicate optimal reference spots such that any new fast reaction police unit should be nearby. This warning is because optimal locations are conditional on space availability. Second, and the most important, crime, particularly homicide, is a dynamic activity, so homicide hot spots change through time and space. Therefore, fast reaction police units can help to mitigate crime activity in the short term due to their deterrence and incapacity effects, but long term solutions are required. The latter would be based on improving the social and economic conditions of Medellín's inhabitants.

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