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Innovative Applications of O.R.

A multi-criteria Police Districting Problem for the efficient and effective design of patrol sector

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ABSTRACT

The Police Districting Problem (PDP) concerns the efficient and effective design of patrol sectors in terms of performance attributes such as workload, response time, etc. A balanced definition of the patrol sector is desirable as it results in crime reduction and in better service. In this paper, a multi-criteria Police Districting Problem defined in collaboration with the Spanish National Police Corps is presented. This is the first model for the PDP that considers the attributes of area, risk, compactness, and mutual support. The decision-maker can specify his/her preferences on the attributes, on workload balance, and efficiency. The model is solved by means of a heuristic algorithm that is empirically tested on a case study of the Central District of Madrid. The solutions identified by the model are compared to patrol sector configurations currently in use and their quality is evaluated by public safety service coordinators. The model and the algorithm produce designs that significantly improve on the current ones.

1. Introduction

For most of the 20th century, police districts have been drawn by police officers on a road map with a marker, just by following the major streets in the area, without making too much of an effort to accomplish geographic or workload balance (Bruce, 2009). Since the seminal paper by Mitchell (1972), a number of mathematical optimization models have been proposed and the Police Districting Problem (PDP) was born. The PDP aims at partitioning the territory under the jurisdiction of a Police Department in the best possible way, with respect to several time, cost, performance, and topological attributes. Only after recent advances in Geographic Information Systems (GIS) and computer technology, which have allowed reasonable computational times and ease of representation and manipulation, have automatic methodologies for the definition of police districts gained popularity among practitioners (Wang, 2012). However, studies integrating GIS and sophisticated mathematical modeling for police districting remain a rarity (Bruce, 2009), and the "map-and-marker method" is still one of the most widely used redistricting procedures. Nevertheless, the importance of a balanced definition of the police districts is unquestioned and the implementation of tools for aiding in making the decisions about the allocation of police resources has proven to be extremely beneficial, as shown by the substantial academic literature on this topic in the last decades (D'Amico, Wang, Batta, & Rump, 2002). In fact, all the works report a dramatic improvement in workload distribution compared to hand-made districts which, in turn, results in enhanced performance and efficiency.

In Spain, the security of towns is the responsibility of the Spanish National Police Corps (SNPC), usually sharing territory with other local security forces. The SNPC is an armed Institute of a civil nature, dependent on the Ministry of Home Affairs. Among its duties are: keeping and restoring order and public safety and preventing the commission of criminal acts. The SNPC is one of the country's most valued institutions and is located at the global forefront of the fight against crime, with the aim of constant innovation. The socio-economic context in recent years in Spain has been that of a serious crisis, which has reduced the resources and the number of police officers available to the SNPC. In order to continue providing the same level of security, the SNPC is taking cutting-edge steps to increase its competitiveness. Under the current system, the distribution of patrols is the responsibility of the inspectors who, under normal conditions, locate the agents according to the neighborhood borders defined more than 50 years ago. To improve the effectiveness of patrolling operations and increase the efficiency in the use of scarce resources, the SNPC has started to develop a Decision Support System (DSS) comprising tools and models to assist in various public security

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tasks (Camacho-Collados & Liberatore, 2015). One of the main objectives of the system is the implementation of a predictive patrolling policy to increase the presence of agents in the areas where they are most needed, to reduce the probability of the occurrence of crime. To this end, the authors have developed, in collaboration with professionals from the SNPC, an optimization model for the definition of patrolling sector configurations, tailored to suit the requirements of the SNPC. As the model is to be included in the DSS and, therefore, should be sufficiently interactive, the authors implemented a heuristic algorithm that provides good solutions quickly. By combining the proposed algorithm with a crime risk forecasting model (Perry, McInnis, Price, Smith, & Hollywood, 2013; Short, Bertozzi, & Brantingham, 2010), a predictive patrolling system is obtained. For the SNPC, the implementation of a predictive patrolling system also represents a paradigm shift, from detention to prevention, resulting in reductions in the costs of detention and in an improvement in the actual, subjective, and social level of safety.

The contributions of this article are the following. An extensive literature review on the PDP is presented. This review includes the identification of the main aspects revised in related reports and a categorized description of methodological approaches. In summary, a broad range of references is classified to identify lacks in the literature. The main contribution of this paper lies in the optimization model for the PDP designed in collaboration with the SNPC. The model is multi-criteria in nature as it includes in the optimization process four different attributes. Also, the model allows the decision maker to define her preference between global optimality and workload balance among the patrol districts. The model is solved by means of a fast local search algorithm, to comply with the strict time requirements given by its inclusion as a tool in a DSS. The model and the algorithm are tested on a case study on the Central District of Madrid. We show empirically that the optimization methodology proposed generates solutions that outperform the current patrolling configurations adopted by the SNPC. Finally, concluding remarks and research guidelines are given.

The rest of the paper is organized as follows. In Section 2 we briefly introduce the generic districting problem and we review more in detail the literature on the PDP. In Section 3 we present the proposed multi-criteria PDP model and the algorithm devised to solve it. Next, we test the algorithm on a case study of the Central District of Madrid and compare the quality of the solutions with the patrolling configurations currently used in the district. We conclude with some insights and guidelines for future research.

2. Literature review

This section presents the problem of defining the districts, and contextualizes it in the framework of police resource allocation. A conceptual classification of previous research according to the attributes considered and methodologies adopted is presented, and then some insights will be provided.

2.1. The districting problem

District design can be seen as the problem of grouping elementary units (or atoms) of a given territory into larger districts (or clusters), according to relevant attributes (or criteria). Depending on the problem faced, the attributes considered might belong to different contexts, including economic, demographic, geographic, etc. In the last decades, the districting problem has been applied to a broad number of fields, including:

- Electric power districting (Bergey, Ragsdale, & Hoskote, 2003a; 2003b).
- Emergency service districting (Iannoni, Morabito, & Saydam, 2009; Larson, 1974).
- Internet networking (Park, Lee, Park, & Lee, 2000).
- Health information systems (Braa & Hedberg, 2002).
- Police patrol districting.
- Political districting for the definition of electoral areas (Bozcaya, Erkut, & Laporte, 2003; Cirincione, Darling, & O'Rourke, 2000; Mehrotra, Johnson, & Nemhauser, 1998).
- Public transportation network districting (Tavares-Pereira, Rui Figueira, Mousseaus, & Roy, 2007; 2009).
- Sales and service districting (Blais, Lapierre, & Laporte, 2003; Galvão, Novaes, Souza de Cursi, & Souza, 2006).
- School districting (Caro, Shirabe, Guignard, & Weintraub, 2004; Schoepfle & Church, 1991).
- Social facilities districting (Minciardi & Zoppoli, 1981).
- Solid waste disposal districting (Hanafi & Freville, 1999).
- Winter service districting (Muyldermans, 2003; Muyldermans, Cattrysse, Oudheusden, & Lotan, 2002).

A unified territorial design model that allows the formulation and solution of districting problems in a variety of applications is the subject of Kalcsics and Schröeder (2005). The authors also review the existing literature in territorial design, highlighting application fields, criteria, and solution methodologies for solving these types of problems.

2.2. The Police Districting Problem

In the United States, police departments partition the territory under their jurisdiction according to a hierarchical structure: command districts (or precincts), patrol sectors (or beats), and reporting districts (or r-districts). Each command district hosts a headquarters where the commanding officer supervises the operations. A command district is subdivided into patrol sectors, each having at least one car assigned to patrol the area and attend to the calls originating from it. Finally, r-districts constitute the atomic element in the hierarchy: the smallest geographical unit for which statistics are kept. As reported in Sarac, Batta, Bhadury, and Rump (1999), r-districts can coincide with census block groups. In Europe, the territorial organizational structure of police departments depends on the country or the region considered. Nevertheless, a hierarchal structure similar to the one adopted in the United States is predominant.

The PDP concerns the optimal grouping of r-districts into externally "homogeneous" patrol sectors. In fact, the car assigned to the patrol sector should attend to all the incidents taking place in the area. Normally, if the car is busy responding to a call when another incident happens, a car from a neighboring area has to attend to it. As Mayer (2009) points out, this generally leads to a domino effect, where cars are pulled from their area to another, leaving the patrol sector unattended and, therefore, more susceptible to criminal incidents. In the light of this scenario, a balanced workload among the districts and the enforcement of a maximal response time become of primary importance.

The first paper on the PDP is presented by Mitchell (1972), which proposes a clustering heuristic for the redesign of patrol beats in Anaheim, California. The author 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. A simple local search algorithm swaps patrol beats from one sector to another to improve the value of the utility function. Benveniste (1985) was the first author to include workload equalization in the optimization process, solving a non-linear stochastic model by means of an approximation algorithm. D'Amico et al. (2002) solve a police districting problem subject to constraints of contiguity, compactness, convexity, and equal size. The novelty of the model lies in the incorporation of