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Discrete Optimization

The disruptive anti-covering location problem

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ABSTRACT

Dispersion is a desirable element inherent in many location problems. For example, dispersive strategies are used in the location of franchise stores, bank branches, defensive missile silo placement, halfway homes, and correctional facilities, or where there is need to be dispersed as much as possible in order to minimize impacts. Two classic models that capture the essence of dispersion between facilities involve: (1) locating exactly p-facilities while maximizing the smallest distance of separation between any two of them, and (2) maximizing the number of facilities that are being located subject to the condition that each facility is no closer than r-distance to its closest neighboring facility. The latter of these two problems is called the anti-covering problem, the subject of this paper. Virtually all past research has involved an attempt to solve for the "best or maximal packing" solution to a given anti-covering problem. This paper deals with what one may call the worst case solution of an anti-covering problem. That is, what is the smallest number of needed facilities and their placement such that their placement thwarts or prevents any further facility placement without violating the r-separation requirement? We call this the disruptive anti-covering location problem. It is disruptive in the sense that such a solution would efficiently prevent an optimal packing from occurring. We present an integer linear program model for this new location problem, provide example problems which indicate that very disruptive configurations exist, and discuss the generation of a range of stable levels to this problem.

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1. Introduction

The anti-covering (or r-separation) location problem (ACLP) involves maximizing the number of selected sites, such that no two selected sites are within a specified distance or time standard of each other. This problem can be defined on a bounded continuous region or a discrete set of sites (Carrizosa & Tóth, 2015). When defined on a bounded continuous domain it is generally assumed that all facilities must be located within the region and be at least r-distance from the boundary and at least r-distance from each other. Although both problem domains are of interest, this paper is concerned with the ACLP defined upon a discrete set of sites. The solution to the ACLP is sometimes referred to as a packed arrangement. There may be many configurations to a problem instance in which all located facilities are at least the prescribed r-distance apart from each other. Those arrangements which involve the maximum number of located facilities are optimal ACLP solutions. Those solutions that use fewer than the maximum possible number of located facilities fall into two classes: (1) at least one unused site exists where it is possible to locate an additional facility while still maintaining all r-separation constraints; and, (2) all remaining unused sites are too close to an existing facility or boundary so that no further facilities can be added to the solution without violating the r-separation constraints. This paper deals with this second class of solution.

A logical question to ask is: what is the smallest number of facilities that can be deployed and placed such that no remaining sites can be used without violating one or more r-separation constraints? The basic idea is to find the smallest configuration that blocks to the greatest extent possible a maximal packing. We call this the Disruptive Anti-Covering Location Problem (DACLP). The objective of this paper is to develop a model to identify facility patterns that prohibit maximally packed configurations from being possible. This model can be useful in a number of possible applications. For example, the anti-cover location problem has been used by Grubesic and Murray (2008) to test possible policies on sex offender residential location. They used the ACLP to identify how many sex offenders could take up residence in a city when each offender had to live at least a given distance apart from all other sex offenders as well as from all public places where children are likely to be present (*e.g.* parks, day care facilities, and schools). A solution to the ACLP has been used to assess the impact of this proposed public policy for a given separation standard,

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but only under the assumption that a maximal packing will be possible and achievable. But, it is entirely possible that as sex offenders sequentially choose residential locations in some ad-hoc fashion, while ensuring that they keep away from other offenders and public spaces where children are present, the resulting pattern will be less than what could be maximally packed. In fact, some "choice" residential locations may effectively thwart a maximal packing and considerably reduce possible numbers of who could be accommodated in such a residential placement policy. Another example involves the use of the ACLP to test the impact of possible privatization of liquor sales associated with potential store placement under separation standards (Grubesic et al., 2012). Such an application helps to define the largest number of stores that could be placed. However, this approach ignores the fact that this situation may involve competitors, and each market entrant would most likely choose one or more location(s) which might preempt rivals from being able to locate in a close, packed-in arrangement when there are imposed separation requirements.

Therefore, attention should be directed towards what configurations disrupt maximal packing the most? The importance of this problem is both theoretical and practical. From either perspective, optimal solutions to the DACLP define a lower bound on the number of facilities that can be placed without violating the *r*-separation constraints as well as pre-empt any additional facilities from being feasibly added. This is an important consideration, particularly in problems where a lower-bound arrangement might occur, like in habitat nest/den site modeling, feasible residence locations for sex-offenders, franchise store location choice, or any other application for which the ACLP has been used or proposed. The main objective of this paper is to present a model for the DACLP, discuss possible solution techniques, and present several example solutions. The next two sections provide a brief background of the ACLP and a description of past approaches in formulating the ACLP as a binary integer programming problem. This is followed by a formulation for the disruptive anti-covering location problem. We also develop a model which can be used to identify "stable" configurations for different levels of potential facility deployment. Computational examples for both models are presented along with a discussion on potential avenues for modeling disruption within this new construct.

2. Background

Dispersion has been an objective of considerable interest in the field of location science. General forms of this problem have also been described for broader cutting and packing type problems (Wang, Huang, Zhang, & Xu, 2002; Wäscher, Haußner, & Schumann, 2007). Disbursing resources such that they are equitably distributed has also been a problem of recent interest (see Batta, Lejeune, & Prasad, 2014; Prokopyev, Konk, & Martinez-Torres, 2009). There are four basic forms of dispersion modeling used in location science. The first involves the dispersal of facilities from population centers (see Church & Cohon, 1976; Church & Garfinkel, 1978). A second form of dispersion involves the dispersal of facilities from each other (see Moon and Chaudhry (1984), and extended work by Erkut (1990) and Current and Storbeck (1994)). A third form of dispersion, which is a hybrid of the first two forms, involves keeping facilities away from each other as well as away from centers of population (Berman & Huang, 2008). Lei and Church (2013) have shown that these previous modeling forms may be represented in a unified model, and Lei and Church (2015) presents an efficient formulation and exact algorithm solution strategy. The fourth form is based upon a standard of minimum separation. Moon and Chaudhry (1984) were the first to focus on the use of a minimum separation standard. They proposed to locate as many facilities as possible while keeping them at least *r*-distance apart from each other. They called this the anti-covering location problem and is the principal subject of this paper. It has also been referred to as the *r*-separation problem (Erkut, ReVelle, & Ülküsal, 1996) and the packing problem (Stephenson, 2005; Wang et al., 2002).

In addition to the examples given above in analyzing policies associated with sex-offender residence locations and liquor store outlets, Downs, Gates, and Murray (2008) used the anti-cover problem to analyze the carrying capacity of a population of Sandhill cranes, Williams (2008) employed a separation distance in the selection of biological reserve sites, Church (2013) has used it in estimating the size and extent of core habitat, and Murray and Church (1996) describe a form of anti-covering for a forest harvest selection problem. Problems that use a similar model structure as the ACLP have been defined for dashboard layout (Castillo, Kampas, & Pinter, 2008), placing cutting patterns on fabric (Wong & Leung, 2009), map label placement (Ribeiro & Lorena, 2008a), DNA sequencing (Joseph, Meidanis, & Tiwari, 1992), and the location of undesirable facilities (Berman & Huang, 2008; Murray & Church, 1999). A number of techniques have been used to solve the anti-cover problem and related problems including: greedy (Chaudhry, McCormick, & Moon, 1986), bee colony optimization (Dimitrijević, Teodorović, Simićc, & Šelmicć, 2012), Lagrangian relaxation (Murray & Church, 1997b), genetic algorithms (Chaudhry, 2006; Wei & Murray, 2014), column generation (Ribeiro & Lorena, 2008b), and greedy randomized adaptive search (Cravo, Ribeiro, & Lorena, 2008). Many other similar heuristic approaches have been developed for problems related to the ACLP such as: the container loading problem (Pisinger, 2002), two and three dimensional bin-packing problems (Bischoff, 2006; Lodi, Martello, & Vigo, 1999; 2002), packing cylinders into a rectangular container (Birgin, Martínez, & Ronconi, 2005), packing of unequal sized circles within a larger circle (Wang et al., 2002), and genetic algorithms for the two-dimensional strip packing problem using rectangular pieces (Bortfeldt, 2006).

Most of the applications of the anti-covering problem entail the use of an integer-linear programming model. Prospective sites are identified in advance as "discrete" locations, representing centers of raster cells (Church, 2013), commercial parcels (Murray & Kim, 2008; Grubesic et al., 2012), or nodes of a network. Murray and Church (1997a) have shown that the discrete anti-cover problem is an equivalent problem to the vertex packing problem on a network or the maximal independent set problem on a graph, and therefore is NP hard. There can be possible uncertainty in potential site positions, and Wei and Murray (2012) have analyzed the impacts of site uncertainty within the context of the anti-cover problem.

Optimal solutions to the anti-covering problem represent the largest number of facilities that can be simultaneously located while keeping each of them at least a minimum distance, *r*, from each other. Unfortunately, there can be circumstances in which a maximum packing is disrupted; that is, not optimally packed. They may be disrupted by earlier residential choices, already established crane nests and territories, or by poor site choices in already located franchisee establishments. Whether maximal packing arrangements are disrupted by accident, happenstance or by intent, such disruption and the potential impact of disruption should be of interest when using this type of model. In the next section we describe the two basic ways in which the anti-covering problem has been formulated as an integer programming problem. Following this we present a brief discussion on packing solutions and a model which seeks to maximally disrupt potential solutions to the anti-covering problem.

3. Formulating the anti-covering location problem (ACLP)

The disruptive anti-cover location problem is, in essence, a derivative of the anti-cover location problem (ACLP) as any solution to the disruptive case, by definition, must meet the conditions of anti-cover: that is, all facilities are located at least *r*-distance apart from each other. In this section we provide details in formulating the anti-cover location problem and in the next section we show how an anti-cover

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