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A Multi-Objective Approach to the Competitive Facility Location Problem

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Abstract

In this paper, a new modeling approach is introduced for a competitive facility location problem in which multiple competitors aim to maximize their market shares. The problem is called the Competitive Maximal Covering Location Problem (CMCLP) based on the classical Maximal Covering Location Problem. Typically, the CMCLP is modeled as a Stackelberg game in which the first player and then the other one locate a fixed number of facilities. On the other hand, the present work considers multiple competitors, and the objective is on discovering a set of the competitors’ decision tuples that are not dominated by any other decision tuples in the solution space. Thereby, the proposed modeling approach aims to help competing firms understand tradeoffs when they engage in negotiations. A mathematical formulation for the CMCLP with two competitors is presented. A multi-objective genetic algorithm is used to solve the problems with multiple competitors. Computational experiments demonstrate that the genetic algorithm is able to approximate the true Pareto front.

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1 Introduction

Facility location problems are among the classical Operations Research problems with a broad range of application areas. One of the most widely studied facility location problems is the Maximal Covering Location Problem (MCLP) where a decision maker seeks to cover as much customer demand as possible by opening multiple facilities, selected from a set of candidate points. Customer demands are concentrated at a set of discrete points. A customer point is covered if there exists at least one facility within a critical distance from the customer point. The MCLP has been extensively studied in the

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The competitive version of the problem, where two competitors try to maximize their demand coverages in the same target market, is applicable when a firm determines facility locations in a competitive market. Regarding the nature of competition, the competitive MCLP can be modeled in two fashions: simultaneous or sequential (Kress & Pesch, 2012). In simultaneous models, the competitors are unaware of one another’s decisions or repeatedly reoptimize their decisions according to the other competitor’s decisions. Sequential models, which are more prevalent in the literature, are based on a Stackelberg game in which a competitor (i.e., leader) first locates its facilities, and then the second one (i.e., follower) locates its facilities optimally based on the leader’s decision. This problem is usually formulated as an integer bi-level optimization problem and NP-hard. Several heuristics (Alekseeva & Kochetov, 2013; Davydov et al., 2014(a); Davydov et al., 2014(b)) and exact approaches (Alekseeva et al., 2015; Robredo & Pessa, 2013) are proposed to solve the sequential competitive MCLP.

In this paper, we take a different approach to the competitive MCLP and propose a genetic algorithm based on the NSGA-II (Deb et al., 2002) to generate multiple Pareto-optimal solutions rather than only Nash or Stackelberg-Nash equilibria. We transform the problem into a multi-objective problem where multiple competitors try to maximize their total demand coverages. In this scenario, the objectives of the competitors are conflicting due to the dependencies among their decisions. The aim of the proposed approach is to find a set of decision vector tuples such that no other decision vector tuple in the solution space dominate them.

We should note that the MCLP has been formulated and studied previously as a multi-objective problem. An extensive list of multi-objective approaches to the MCLP is given in (Farahani et al., 2010). All of the current multi-objective approaches to the problem consider a single decision maker that tries to optimize various types of objectives simultaneously, such as maximizing the total demand coverage and minimizing the maximum distance between uncovered customer points and their nearest facilities (Karasakal & Silav, 2016). In addition to a novel interpretation of the problem, we also consider more than two competitors and present a mathematical model to verify the non-dominance of the decision vector tuples found by the proposed multi-objective genetic algorithm.

2 Problem Description

There are m competitors, denoted by set K, targeting the demands of n customer points distributed over a region. The candidate facility locations and customer points are represented by sets I and J of discrete points, respectively. Each customer point has a deterministic demand of \( w_j \). Each competitor \( k \) aims to maximize its total demand coverage \( z_k \) by opening \( z_k \) number of facilities selected from set I. Customers are indifferent among the competitors. The only factor that determines the decision of a customer is the distance to the facilities. It is assumed that customers can only access facilities located within a threshold distance of \( \lambda \). All demand of a customer point is covered by the closest accessible facility. However, the demand of a customer point is equally shared by the facilities that are located in the same closest distance to the customer point.

Let \( X_k = \{x_{k1}, x_{k2}, \ldots, x_{kn}\} \) be the decision vector of competitor \( k \) such that \( x_{ki} = 1 \) if competitor \( k \) locates a facility at point \( i \), and \( x_{ki} = 0 \) otherwise. Multiple competitors are allowed to locate their facilities at the same point. Let \( z_{kj} \) be a binary variable such that \( z_{kj} = 1 \) if customer point \( j \) is covered by the facility of
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