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Location and reorganization problems: The Calabrian health care system case

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ABSTRACT

In the last few years, the Italian healthcare system has been coping with radical changes, aimed at guaranteeing more efficiency while containing costs. Starting from the actual service network organization, we discuss the problem faced by the Italian authorities of reorganizing the healthcare service network and we propose some optimization models to support the decision-making process. In the first part of the work, we compare the existing health care service network of the northern area of Calabria (Italy) with the configurations determined by solving well-known facility location models. In the second part, taking into account the healthcare reorganization plans imposed by local governments, we consider the problem of reorganizing the public health care service network of the northern area of Calabria. Indeed, we propose two ad-hoc optimization models that consider national and regional guidelines and constraints. The behavior of the proposed models, in terms of solution quality, is evaluated on the basis of an extensive computational study on real data.

1. Introduction

Facility location decisions play a crucial role at a strategic level, for both private and public sectors, as they have a strong impact on operational performances. In particular, in the public sector, the localization of services can deeply affect the accessibility of users and, hence, the quality of the service, this is the case of hospitals, schools and emergency services.

The Facility Location Problem (FLP) literature is quite extensive and several formulations have been proposed, taking into account different objective functions, features of the facilities, characteristics of the demand and its interaction with facilities.

Some interesting reviews of models and methods for addressing FLP are proposed in Francis and White (1974), Drezner and Hamacher (2002), Klose and Drexl (2004), Nickel and Puerto (2005), ReVelle and Eiselt (2005), Church and Murray (2009), Farahani and Hekmatfar (2009), Eiselt and Marianov (2011). An accurate identification of the parameters that can be used to classify FLP is presented in Klose and Drexl (2004).

The three classes of facility location models mainly used in a public context are the *median*, *covering* and *center* models.

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In the *median models* the objective is to find the optimal location of exactly p facilities (p-median problems), so that the (weighted) sum of the distances between customers and their assigned facilities is minimized. The first formulation of the p-median problem is described in Hakimi (1964), another seminal paper on the subject is ReVelle and Swaim (1970).

Covering models are constructed by introducing the so called *coverage radius* and by considering a facility covering a demand point, if their distance does not exceed the predefined coverage radius. More in detail, there are two different formulations of covering models: the *Set Covering Location Problem* (see Toregas, Swain, ReVelle, & Bergmann, 1971; Toregas & ReVelle, 1973; ReVelle, Toregas, & Falkson, 1976) where the objective is to minimize the number of facilities to cover the entire demand in a given area and the *Maximum Covering Location Problem* (see Church & ReVelle, 1974; White & Case, 1974), where the objective is to maximize the covered demand under a limited number of facilities.

These models have various real world applications in the public sector, we cite for example the cases of locating emergency services (see Jia, nez, & Dessouky, 2007), bus stops (see Gleason, 1975), health clinics (see Eaton, Church, Bennet, & Namon, 1981). Another interesting application is related to the hierarchical health services case, where the objective is to localize structures that can supply different types of services and that are related in a hierarchical manner (Lee & Lee, 2010; Moore & ReVelle, 1982; Teixeira & Antunes, 2008). A good

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review of hierarchical facility models is also presented in Şahin and Süral (2007).

In the *center models*, in a worst case setting, the objective is to minimize the maximum distance between demands and their allocated facilities. This class of problems involves locating one or more facilities in such a way that every demand receives its service from the closest facility and the maximum distance between each demand node and its facility is as small as possible. In fact, center location problems are usually used in locating emergency services, where the quickest response time represents the most important objective. The center models were first introduced by Hakimi in Hakimi (1964, 1965), where the location of a single facility in a network is considered.

Some works related to facility location in healthcare applied to a real case are presented in Chu and Chu (2000), de Aguiar Vallim Fo and Mota (2012), Mehrez, Sinuany-Stern, Arad-Geva, and Binyamin (1996)

In some practical applications, starting from an existing facility network, a reorganization, involving some changes to the set of facilities that are currently active in the area of interest, is required. The changes can be related to the number or the position of facilities, to their capacities and/or types of supplied services. In the literature, the reorganization follows on variations of some of the parameters that influence the current location, like demand, costs, market structure, degree of competition. Indeed, given to the variability of such parameters, the current scenario could be inefficient and requires a reorganization of the system. The most variable parameter discussed in the literature is the demand. The reorganization can take place either before (ex-ante) the changes occur, on the basis of forecasting the future, or after the changes have happened (ex-post).

The ex-ante reorganization models can also be distinguished in deterministic multi-period models, where the decisions are made in different time periods of a given planning horizon, on the basis of the known value of parameters over time, and stochastic models, where decisions are made once on the basis of an uncertain knowledge of the future value of input parameters. Some important contributions related to multi-period models can be found in Warsazawski (1973), Wesolowsky and Truscott (1975), Roodman and Schwarz (1977), Roy and Erlenkotter (1982), Galvão and del R. Santibañez Gonzalez (1992), Melo, Nickel, and Gama (2006), Dias, Captivo, and Clìmaco (2007), Albareda-Sambola, Fernandez, Hinojosa, and Puerto (2009), Wilhelm, Han, and Lee (2013), while some interesting and recent stochastic models are presented in Berman and Drezner (2008), Sonmez and Lim (2012).

The rationale of ex-post reorganization models is to change the actual facility layout, according to some new defined rules, by modifying either objective function or constraints or both. In Wang, Batta, Badhury, and Rump (2003) reorganization models are formulated in order to meet the new demand distribution. In ReVelle, Murray, and Serra (2007) the authors consider the case where the reduction in the number of existing facilities is necessary for economic contingencies. In particular, they consider two cases where firms need to reduce their facilities, one related to firms operating in a competitive market and the other relative to a market without competition. In the first case, firms aim at maximizing the retained demand (or minimizing demand loss to competitors) when the facilities are reduced by a specified number. In the second case, the firms need to close some facilities to reduce costs, with the objective of minimizing the uncovered population.

In this paper, we address localization and reorganization problems arising in the Italian health care system. In particular, attention is focused on the specific situation of a region in the South of Italy (i.e. Calabria). We first describe the current localization of public hospitals in Calabria; successively, through the definition of appropriate performance indexes, we compare the actual configuration with an ideal localization, obtained by applying some classical facility location models to real data.

The second part of the work is focused on reorganization and is dedicated to developing some optimization models, supporting the reorganization of the regional public hospitality network, due to new governmental guidelines. In particular, we consider two different situations. In the first scenario, the aim is to minimize the number of public hospitals to be opened, considering the local authorities constraints, without taking explicitly into account the demands. The obtained configuration is then utilized as input for a covering model, in order to evaluate the quality of service of the solution in terms of a satisfied demand. In the second scenario, the aim is to satisfy the demand in the new hospital configuration, by reallocating part of the demand to the retained facilities, whose capacity can be expanded within definite limits.

The rest of the paper is organized as follows: Section 2 presents some classical localization models that are applied to the scenarios under study; while in Section 3 we formulate two new optimization models to address the reorganization issues faced by local authorities in designing the current health care regional network; Section 4 compares, in a computational study, the actual health care facilities network with the configuration obtained from the application of the described models on a set of real data; the paper ends with Section 5, where we draw some conclusions.

2. Facility location models

In this section, we describe some classical facility location models that we will further apply to the case under study.

The following parameters and variables are necessary to formulate the considered mathematical programming models.

- Parameters
  - $N = 1, \dots, n$ the set of possible hospital locations;
  - $R = 1, \dots, r$ the set of possible hospital departments. It is worth noting that each hospital can contain only a sub-set of departments;
  - $M = 1, \dots, m$ the set of demand centers, i.e. the potential departments users;
  - l_j^k the capacity in terms of number of beds of department k, $k = 1, \dots, r$ in hospital j, $j = 1, \dots, n$;
  - d_i^k the demand from center i, $i = 1, \dots, m$ to department k $k = 1, \dots, r$.
- Variables
  - y_j a binary variable equal to 1 if hospital j is opened, 0 otherwise;
  - x_{ij}^k the fraction of demand from center i served by department k of hospital j;
  - c_{ij} the connection cost expressed in terms of travel time between the center i and the hospital location j;
  - t_{ij} the distance between the center i and the hospital location j.

The first formulation is a classical *p-median* problem (for more details, the reader is referred to ReVelle & Swaim (1970)). The aim is to locate p hospitals, while assigning the demand from the centers to departments, with the objective of minimizing the total network travel time.

The mathematical formulation of the p-Median Hospitals Location Problem (pMedian_HLP, for short)is reported in what follows.

$$\min \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{r} c_{ij} x_{ij}^k \tag{1}$$

$$\sum_{j=1}^{n} x_{ij}^k = 1 \quad \forall i = 1, \dots, m, \quad k = 1, \dots, r \tag{2}$$