Computers & Industrial Engineering 89 (2015) 177–185

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

The design of capacitated facility networks for long term care service

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ARTICLE INFO

Article history:
Available online 27 March 2015

Keywords:
Long term care services
Closest assignment rule
Branch and bound algorithm
Genetic algorithm

ABSTRACT

Life expectancy is going up and the demand of long term care facilities is increasing in most countries. This study deals with designing problem of facility networks for long-term care services in a city consisting of a number of regions. Assuming that in each region a candidate site for long-term care facility exists, we seek to identify regions where opening of a long-term care facility is desirable and also determine the type of new facility. For the problem, an integer programming model is formulated with the objective of minimizing the total construction cost. The closest assignment rule is adopted to reflect the preference of patient in choosing long term care facility by assigning patient to an open facility closest from his home. To solve the model, we develop a branch and bound algorithm for exact solution and a genetic algorithm to solve large sized problem. The validity of the mathematical model and the proposed algorithms are illustrated through a number of problem instances.

1. Introduction

Due to the advancement of medicines and improvement in health care services, the average life expectancy has increased continuously in both developed and developing countries. With the decreasing mortality rate, the population of aged people is rising steadily and rapidly and the number of patients which is stricken by the senile diseases such as stroke, Alzheimer's disease has a sharply increasing trend. For instance, as of the year 2009, more than 650,000 aged people were stricken with the age-related diseases in Korea (Korea Insurance Development Institute, 2011). Thus, the treatment of patients who have senile diseases becomes an important social issue and needs to be considered at the national level. Currently, many countries have been trying to make various supportive provisions for these patients but the existing public social infrastructures still do not satisfy the increasing customer demand. Long term care is a variety of services which help meet both the medical and non-medical needs of people with a chronic illness or disability who cannot care for themselves for long periods of time. Due to the coverage rate of the public long term care facilities is only 4.0% in Korea, while that of Japan and Germany is 10.2% and 10.0%, respectively (Doctorstimes, 2009). Thus in countries with not enough facilities for the patient of senile diseases, the government needs to make a plan to establish the additional public long term care facilities that provide rehabilitative, restorative, and skilled nursing care to patients or residents in need of assistance with activities of daily living. In general, the senile diseases patients and their families prefer public facilities rather than private facilities mainly for reliability and economic reason, i.e., public facilities offer reliable services at a significantly reduced fee than the facilities operated by private. Also, they prefer facilities located closely to their home for the patient's emotional stability and easy access of the family members. Nevertheless, most metropolitan cities do not have enough public long term care facilities to serve their citizen and the needs of patients mentioned above are not satisfied. Motivated by the above social necessities, this paper considers regions where additional public long term care facilities of proper sizes need to be built to provide medical services for patients with senile diseases. In 2010, the Seoul city government, the capital city of Korea, built 5 long term care facilities of 3 types, large, medium, and small facilities where the facility types were determined considering regional situations including land availability, land cost and construction budget. Through the development of mathematical model we seek to determine the type and locations of newly built facilities under the constraint of closest assignment rule. To solve the model two algorithms, exact solution algorithm and heuristic algorithm are proposed. The remainder of the paper is organized as follows. Related researches are introduced in Section 2. Section 3 describes assumptions and notations adopted for the study and then a mathematical model is developed whose objective is to minimize the total establishment cost of new facilities. In Section 4, two solution

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http://dx.doi.org/10.1016/j.cie.2015.03.010
0360-8352/

algorithms are presented, one based on branch and bound method and another based on genetic algorithm. In Section 5, we compare the performances of the proposed algorithms and then present the results of sensitivity analysis of the system parameters. Finally, conclusions appear in Section 6 with suggestion on further studies.

2. Literature review

Location problems have been studied for several decades and many research articles appeared in the literature. According to Owen and Daskin (1998), location problems could be classified into four categories. The first category is covering problem. A well known covering problem is to locate emergency service centers such as fire station or ambulances to provide wide service range for people. Set covering problem and maximal covering problem are two different types of covering problem. The objective of set covering problem is to find the minimum number of facilities and their locations while each demand group has at least one facility located within acceptable service distance. Many heuristic approaches were proposed to solve set covering problem. Chvatal (1979) and Beasley and Chu (1996) reported a greedy heuristic and a genetic algorithm, respectively. Balas and Carrera (1996) presented the dynamic subgradient-based branch and bound procedure to find an optimal solution. Maximal covering problem occurs when it is required to maximize the amount of demand covered by locating a predetermined number of facilities. To solve the problem, Galvao and ReVelle (1996) developed a lagrangean heuristic while Marianov and ReVelle (1996) presented probabilistic formulation for locating emergency service facilities. Galvao, Espejo, and Boffey (2000) suggested a heuristics based on lagrangean and surrogate relaxation. Shariff, Moin, and Omar (2012) reported a location and allocation model for healthcare facilities in one of the district in Malaysia. Yin and Mu (2012) suggested modular capacitated maximal covering location problem for emergency vehicles. The proposed model allows several possible capacity levels for the facility at each potential site. More recent information about covering problem can be found in Farahani, Asgari, Heidari, Hosseininia, and Goh (2012). The second category of the location problem is *P*-center problem. It is a minimax problem with the objective of minimizing the maximum distance from any demand node to the nearest facility among p facilities. Unlike the covering problem, allocation of the demand nodes to facilities also becomes decision variable, which lead to two kinds of decision variables, location decision variables and allocation decision variables. Khuller and Sussmann (1996) solved a capacitated version of *P*-center problem. Averbakh and Berman (1997) also solved *P*-center location problem under demand uncertainty. Their objective is to minimize the worst-case loss in objective function. Elloumi, Labbe, and Pochet (2004) presented a new type of formulation and solution method for *P*-center problem. Recently, Huang, Kim, and Menezes (2010) suggested *P*-center facility location problem for large scale emergencies and developed a heuristic for the problem on general network. Recently, Dantrakul, Likasiri, and Pongvuthithum (2014) suggested *P*-median *P*-center algorithms for capacitated facility location problem. The objective of the research is to minimize the sum of setup cost and transportation cost. The setup cost includes the land and facility setup cost which are stochastic since land value varies by the economic condition. Also, the transportation cost depends on the fuel consumption rate which is stochastic.

Third category of the location problem is *P*-median problem where average traveling distance is measured as an objective. In this problem, decision maker has to determine the location of p facilities and allocation of the customers to the facilities. Heuristics, meta heuristics and optimal algorithms were developed for solving *P*-median problem and mainly applied to the location problem of factories and distribution centers. Hakimi (1965) studied optimum distribution of switching centers in communication network. Jarvinen, Rajala, and Sinervo (1972) developed a branch and bound algorithm for solving the *P*-median problem. Recently, Avella, Sassano, and Vasil'ev (2007) provided the computational study about large scale p-median problems. The last one is called fixed charge location problem. Fixed charge is the cost associated with locating facilities at each potential candidate site. The objective of fixed charge location problem is to minimize the total transportation cost and fixed cost. Like the previous problems, location variables and allocation variables are considered as decision variables. Sankaran and Raghavan (1997) designed the location and allocation system of the liquefied petroleum gas in south India considering various types of capacitated facilities. Janacek and Buzna (2008) solved an uncapacitated and single type of fixed charge location problem using branch and bound algorithm. Recently, Avella, Boccia, and Mattia (2013) suggested a branch and cut algorithm for single source capacitated facility location problem.

In some problem situations, allocation variable may not be considered as primary decision variable, which means allocation is determined automatically by some requirements such as closest assignment constraints. Closest assignment constraints force customer or patient nodes to be assigned to the closest open facility. Therefore, once the location decision variables are determined, due to closest assignment constraints patients are forced to visit the nearest facility from patient's location. Many real world situations exist where closest assignment rule is preferred. Rojeski and Revelle (1970) applied the closest assignment constraints to the location problem of public facilities such as medical clinics or public food distribution centers. Hanjoul and Peeters (1987) suggested closest assignment models considering customers preference. Berman, Krass, and Wang (2006) also considered closest assignment constraints in his location problem for the reduction of lost demand. Recently, Kim and Kim (2010) applied closest allocation constraints for determining the locations of public long term care facilities. They considered uncapacitated single type of long term care facility and tried to balance the numbers of patients assigned to the facilities. Someone can find more detailed review about closest assignment constraints from Gerrard and Church (1996).

This study belongs to the fixed charge location problem. We extend Kim and Kim (2010) by allowing more than one type of long term care facilities and also considering the capacity of facilities. It is a type of capacitated location and allocation problem where allocation part can be determined easily from location decision variable information and closest assignment constraints.

3. Mathematical modeling

3.1. Problem situation

The problem in this paper can be described as follows. Suppose it is desired to establish long term care facilities in a metropolitan area that consists of J number of regions. The health care demand data of each region are readily available in the form of estimates by the government. Let the demand centre of a region be a point destination weighted by the health care demand distribution of the region. For simplicity, the location of demand centre in each region is assumed to be already known. Construction design of health care facilities requires the accommodation of conflicting demands from various constituencies, balancing costs and needs, and satisfying stringent regulatory and accreditation rules. Therefore, it is assumed that the government has already selected three types of long term care facilities to economically provide safe and effective health care. These three types are differing in terms of capacity and construction cost. Also, in each region a candidate location for new facility is fixed and known. With the objective