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Efficient methods for a bi-objective nursing home location and allocation problem: A case study

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ABSTRACT

In recent years, due to more and more serious pension issues, nursing home construction becomes an important project. Meanwhile, it is crucial for decision makers to determine the location of a nursing home before its construction. An effective location planning could achieve reasonable resources allocation and social fairness. This paper considers a nursing home location and allocation problem with two objectives. The first objective is to minimize the total construction costs from the perspective of the government. For the elderly people, their expectations are their allocated nursing homes close enough to their children's communities. Therefore, the second objective is to minimize the total weighted distances. To obtain exact solutions within reasonable computation time, valid equalities are proposed to enhance exact ε-constraint method. For large-scale problems, a non-dominated sorting genetic algorithm (NSGA-II) is applied, in which a new chromosome representation is used and a heuristic method is designed for the allocation subproblem. A multi-objective simulated annealing (MOSA) algorithm is also adapted to the problem. Finally, a case study with two data sets is conducted and computational comparisons are made with both exact methods and the algorithms. The results show the promising performance of the proposed enhanced ε-constraint method and the modified NSGA-II.

1. Introduction

In 2000, China became an aging society according to internationally recognized standards, since the number of people aged 60 and older reached 10% of the total Chinese population [7]. Since then, with the increasing pace of China's entry into the aging society, the number of the people over 60 has been increasing largely. According to the data from National Bureau of Statistics of China, the people over 60 and 65 make up 13.26% and 8.9% of the population of China in 2010, respectively. These two ratios are increased into 16.7% and 10.8% in 2016. Moreover, it is forecasted that the ratio of people over 65 will rise to 28.81% by 2050. In this context, pension problems become an important issue.

With the improvement of social security system and the decreased availability of family caregivers for day-to-day family care [12], the number of elderly people moving into nursing homes in Chinese cities is soaring [13]. Hence, it is necessary for more nursing home constructions. As defined in [2], nursing home is one kind of long-term cares. It has a mix of medical care (including nursing car) and social services to elderly people and inpatients. It has been well recognized that location is crucial to modern nursing home construction for satisfying the demand of elderly people, since the availability of nursing home services is highly associated with the distance to the facilities.

Facility location has been widely applied in practice including humanitarian facility location [22], emergency response facilities [2,33,4,40] and capacitated facility location for freight transportation [1,21,29]. In general, facility location problems could be encountered in different situations, including deterministic (e.g., [30,34]), stochastic (e.g., [3,47]), robust (e.g., [49,22]) and fuzzy (e.g., [51,39,48]). In general, deterministic means that all data, including the demands, the coordinates of facilities, are supposedly known without uncertainty. Stochastic is capable of taking randomness or uncertainty like demands into account. Usually, uncertain parameters, like demands of customers are assumed to be subject to a probability distribution. Robust is usually response to stochastic and its optimization includes slack in the solution to improve the reliability of the solution. Fuzzy situation usually happens when it is not easy to estimate the probability distributions of uncertain parameters, since in reality, credible and precise data may be absent [22,51,8].

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Moreover, different facility location problems have different considerations and purposes, for instance, plant or warehouse location generally considers the transportation costs, service costs and cover areas. Hospital or health care facility location (e.g., [26,41,44]) should satisfy the demand of patients and minimize the total costs. Waster treatment facility location (e.g., [19,18,14]) usually considers the distances between waster treatment facilities and communities, and the investment costs.

In this paper, driven by a practical problem, we study a deterministic nursing home location problem. The problem has its own special characteristics, on the one hand, the distances between two nursing homes should be large enough to save the construction costs from the perspective of government. On the other hand, the nursing home could not be far away from the community for the convenience of elderly people and their family members. In addition, the service capacity of a nursing home should satisfy the needs of the elderly people that are allocated to it. With these requirements in mind, we study a nursing home location–allocation problem with different levels of facility capacity, to minimize the total construction costs and to minimize the total weighted distances between nursing homes and communities at the same time.

Based on a preliminary version appeared in a refereed conference [42], we extend the study in this paper, emphasizing on the extensions of enhancement of valid equalities for the ε-constraint method, the formulation of the NSGA-II method adaption with a set-based chromosome representation and a heuristic method for allocation subproblem, the MOSA method adaption, and computational experiments on a real-world case study with two data sets. The main contributions of the paper are as follows:

(1) Valid equalities are proposed to enhance the exact ε-constraint method;
(2) A NSGA-II integrated with a set-based chromosome representation and a heuristic method for allocation subproblem is proposed to deal with the large-scale problems. A MOSA is also adapted to the problem;
(3) Performance of the methods are validated by a case study with two data sets from the Kongjiang Road area in Shanghai, China.

The remainder of the paper is organized as follows: Section 2 provides a literature review. Section 3 describes the problem, followed by the introduction of the valid equalities for ε-constraint method. Section 4 introduces the detailed implementation procedure of NSGA-II. Section 5 explains the adaptation of MOSA for the problem. Section 6 conducts the case study with two data sets and shows the computational results. Finally, Section 7 summarizes the paper and points out further research directions.

2. Literature review

Facility location is to locate a limited number of units to provide the best services to the geographical area in question [22]. It is firstly proposed by Alfred Weber in 1909 [28]. Since facility location problems have been studied for more than a century, the literature on this direction is vast. Here we review only the papers on the public service facility location problems in the deterministic situation, more specifically, on multi-objective optimization, which are highly related to the study treated in this paper. For detailed surveys on facility location problems, we refer the reader to [17,27,37,38,31,20,11,2] and references therein.

Public service facility location problems concern about locating public facilities such as emergency medical services (EMS), libraries, temporary relief centers, hospitals, fire stations, public electric vehicle charging facilities to optimize a single objective or to obtain efficient solutions satisfying several objectives [6]. Many models including integer linear programming (ILP) and mixed integer linear programming (MILP), and various meta-heuristic methods, like genetic algorithm (GA) and simulated annealing (SA) have been developed for this direction ([2]).

Teixeira and Antunes [45] developed a discrete hierarchical location model for public facility planning with the features including several levels of demand, several types of facilities, and a nested hierarchy of facilities. A GIS package with an optimization program was used to solve the model. The method was applied to a real-world school network planning for a district of Portugal. Syam and Côté [44] investigated a specialized medical center location and allocation problem with the objective of total costs minimization. A 0-1 ILP model was formulated and an SA method was developed, which can solve large problems involving up to 100 candidate medical center locations and 15 open treatment units within 20 min. Shariff et al. [41] studied a health care facility planning problem in Malaysia and they formulated the problem as a capacitated maximal covering location problem with the objective of maximizing the population assigned to a facility within the coverage distance. They proposed a GA to solve the problem. Kim and Kim [26] considered a health care facility location problem to maximize the number of served patients while considering preference of the low-income, middle- and high-income patients for the public and private facilities. An ILP model was formulated. A heuristic algorithm based on Lagrangian relaxation and subgradient optimization methods were proposed. The computational experiments on randomly generated instances and real-world instances in Korea showed the great performance of proposed algorithms. However, in their model, only one objective is considered, the budget for public facilities establishment is used as a constraint. For facility location in both public and private sectors, Pereira et al. [34] investigated a probabilistic maximal covering location–allocation problem to maximize the total served demand. A hybrid algorithm that combines a metaheuristic and an exact method was presented to deal with the small- and medium-size instances. Also, they developed an adaptive large neighborhood search (ALNS) heuristic to tackle the large instances. The promising performance of the proposed hybrid algorithm is demonstrated. McCormack and Coates [30] applied a GA and a trace-driven simulation model to optimize an EMS vehicle fleet allocation and base station location problem. A real-life case from London Ambulance Service call data is used to validate the method.

In recent years, there are more and more studies on multi-objective public facility location problems in deterministic setting, due to the nature multi-objective requirements. Doerner et al. [16] considered a public facility location problem with three objectives in terms of coverage, risk and costs. A heuristic approach based on the NSGA-II algorithm was proposed to solve the problem. Coutinho-Rodrigues et al. [14] investigated an urban sorted waste containers location problem to minimize the total investment costs and the dissatisfaction of residents. A bi-objective MILP model was established and the ε-constraint method was adapted to obtain the Pareto solutions. A case study based on the data of Coimbra was conducted and the results demonstrated that the model and the approach can be applied in practice. Harris et al. [23] studied an actual capacitated facility location–allocation problem with two objectives: minimize the financial costs and the CO_2 emissions simultaneously. Lagrangian relaxation models and multi-objective evolutionary framework were applied to solve the problem. Eiselt and Marianov [18] considered a landfill location problem with two objectives: cost and pollution minimization. An MILP model was formulated and the weighted sum method and the ε-constraint method were adapted to solve the problem. Afterwards, Eiselt and Marianov [19] reviewed landfill location models, more specifically, they discussed different classes of models, including a generic cost-minimization model and multi-criteria decision models. Zhang