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A multi-objective optimization approach for health-care facility location-allocation problems in highly developed cities such as Hong Kong

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ABSTRACT

Public health-care facilities are essential to all communities, and their location/allocation has long been an important issue in urban planning. Given the steady growth of Hong Kong's population, new health-care facilities will need to be built over the next few years. This research examines the problem of where such health-care facilities should be located to improve the equity of accessibility, raise the total accessibility for the entire population, reduce the population that falls outside the coverage range, and decrease the cost of building new facilities. However, because urban areas such as Hong Kong are complex socio-ecological systems, the aforementioned conflicting objectives make it impossible to find one 'best' solution that meets all of the objectives. Therefore, this research uses a genetic algorithm based multi-objective optimization (MOO) approach to yield a set of Pareto solutions that can be used to find the most practical tradeoffs between the conflicting objectives. The MOO approach is used to optimize the location of new health-care facilities in Hong Kong for 2020. Because the MOO approach provides a set of diverse plans, planners can compare the value of each objective and the spatial distribution of facilities to analyze or select the solution that best supports their further decisions. Comparing the Pareto solutions with other solutions, it indicates that the MOO approach is a sensible choice for solving multi-objective problems of health-care facility location-allocation in Hong Kong.

1. Introduction

The problem of where to locate health-care facilities has long troubled urban planners due to the increasing demand generated by population growth and an aging population. Facility location decisions, referred to as location-allocation problems, are a critical element in the strategic planning of health-care programs (Saaty, 1980). In managing health-care facility location-allocation problems, various objectives, including accessibility(Hodgart, 1978; Langford & Higgs, 2006; Murawski & Church, 2009), equity of accessibility(Ngui & Apparicio, 2011), cost (Landa-Torres, Manjarres, Salcedo-Sanz, Del Ser, & Gil-Lopez, 2013), participation (Gu, Wang, & McGregor, 2010) and so on, rather than just one objective have been considered.

Numerous researches have paid attentions to improving one single objective, but recently more and more scholars began to take problems of locating health-care facility as a multi-objective (MO) problem that commonly face conflicts. It is to say, when just only one objective is concerned, the other objectives will be ignored. As all objectives are conflicting in the system which is named as multi-objective problems, there is no all-best solution at every objective. For MO problems, an optimization approach that provides only one best solution as the final decision and ignores trade-offs between objectives is inappropriate. Within this context, the Pareto solutions have been proposed to cope with the MO problems in different fields. However, most studies on the MO problem of health-care facility location use a sum weighting approach to combine objectives, which provides a single best solution rather than a set of Pareto solutions from which the planners can select their ideal.

Meanwhile, it is obvious that the conflicts are serious in some highly developed cities with high population density. Cities with high population density and limited health-care resources require not only accessibility in health-care facilities but also equity in accessibility; moreover, the cost of building new health-care facility also should be taken into consideration. And in cities with heterogeneous spatial distribution of population or with isolated island, the number of people who fall outside an acceptable travel distance to at least one facility is important. Therefore, for highly developed cities, it is necessary to consider the problem of locating health-care facilities as a complex MO problem where more than two objectives should be considered. While in most of existing studies, even if health-care facility locating problem has

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been taken as a MO problem, just two objectives are considered, which cannot reflect all requirements of locating health-care facility in highly developed cities. Facing up the multiple objectives in locating health-care facility in high developed cities with heterogeneous spatial distribution of population, this research considers multiple objectives which can fully reflect the requirements of locating health-care facility in a highly developed city, attempts to locate the health-care facilities in highly developed cities, find out the trade-offs between objectives, and provide a set of Pareto solutions rather than just one single solution for planners or government.

This research takes Hong Kong, one of Asia's highly developed cities, as the study area to validate the proposed approach. Four objectives in relation to health-care facility location-allocation problem in Hong Kong are selected: (1) minimize inequity of accessibility, (2) maximize accessibility for the whole population, (3) minimize the number of people who fall outside an acceptable travel distance to at least one facility, and (4) minimize the cost of building new public health-care facilities. And, there is one constraint on the total increase in public health-care facility's capacity in the projected year.

There are tradeoffs between the objectives above. Evidently, accessibility and coverage can be increased by adding more new hospitals, leading to an increased cost. Vice versa, cost can be reduced by adding less hospital, which reduces accessibility and coverage. Also accessibility and coverage contradict equity to some extent. A higher accessibility and coverage can be achieved by planning a large number of hospitals at the area with dense population, which, however, results in inequitable solution. Vice versa, to achieve a high equity, hospitals must be spread broadly over the whole region, which increases travel distance in the densely populated areas. Last, accessibility contradicts coverage when health-care resources are limited. In this research, higher accessibility asks for a minimal total distance traveled by population, while large coverage aims at maximal population under an acceptable traveling distance. Since all objectives are conflicting, health-care facility locating problem in Hong Kong is a MO problem.

The rest of this paper is organized as follows. The second section reviews the approaches of locating health-care facilities, and explains why the multi-objective optimization approach should be used. The third section introduces the background of Hong Kong including its economy, population and the data source used in this research. The fourth section describes the objective evaluation and the optimization method in detail. The last two sections discuss the value of proposed method and its benefit to other cities with health-care facility locating problems.

2. Literature review

In problems of locating health-care facility, various objectives have been considered. At first, access to health-care facilities is thought as a crucial issue and a major concern for government planning (Landa-Torres et al., 2013). And the research focuses on the definitions and the measurements of access to medical care (Aday & Andersen, 1974); then, improving the access to health-care facilities is set as one objective in the planning of health-care facility (Hodgart, 1978; Langford & Higgs, 2006; Murawski & Church, 2009; Gu et al., 2010; Wang, 2012). Later, improving the equity of access to health-care has been concerned (Ngui & Apparicio, 2011) and then prompted research on the reasonable allocation of health-care facilities (Wang, McLafferty, Escamilla, & Luo, 2008). Apart from improving the access and the equity of access, reducing the cost metrics (Bretthauer & Cote, 1998; Landa-Torres et al., 2013), increasing flexibility in service location selection (Saaty, 1980), and the number of people within an acceptable travel distance of at least one facility (Gu et al., 2010; Shariff, Moin, & Omar, 2012) are getting more and more concerned, which have been thought as objectives in solving location-allocation problems. Obviously, various objectives have been considered in solving the problem of locating health-care facilities.

As various objectives have been proposed, scholars have concerned more than one objective in locating health-care facility problem early at 1970s. For example, at 1970s, Dokmeci (1979) set reducing cost and increasing utilization criteria as two objectives to determine the sizes and locations at different facility levels. Later, at 1990s, Bailey and Phillips (1990) were aware of the influence of distance, transport and accessibility on the use of health services in Kingston, Jamaica. Current, Min, and Schilling (1990) proposed four objectives, (1) cost minimization, (2) demand oriented, (3) profit maximization, and (4) environmental concern, to decide the facility location. Recently, Cetin and Sarul (2009) made effort on locating blood banks among hospitals or clinics, where three objectives were involved, minimizing total fixed cost of locating blood banks, minimizing total traveled distance between the blood banks and hospitals, and minimizing inequality. Gu et al. (2010) set two objectives, (1) people should have more flexibility to select service location, and (2) each preventive health care facility needs to have a minimum number of clients in order to retain accreditation, to optimize preventive health care facility locations.

Clearly, location-allocation problems of health-care facility have been thought as a kind of MO problem. However, in above research, alternative solutions are calculated by summing the weighted efficiencies in terms of each objective. This approach to solving MO problems has several limitations: (1) the summing weighted approach requires a priori knowledge about the relative importance of the objectives, (2) the summing weighted approach leads to only one solution, (3) trade-offs between objectives cannot be simply evaluated, and (4) the solution may not be attainable unless the search space is convex (Ngatchou, Zarei, & El-Sharkawi, 2005; Yoo & Harman, 2007). Within this context, some scholars have focused on searching for Pareto solutions rather than one best solution in MO problems. The Pareto solution here implies that an improvement in one objective must be achieved at the expense of at least one of the other objectives (Steuer, 1989; Batty, 1998; Miettinen, 1999; Gabriel, Faria, & Moglen, 2006). Pareto solutions are solutions that are superior to the rest of the solutions in the search space when all objectives are considered but are inferior to other solutions in the space in one or more objectives (Srinivas & Deb, 1994). Pareto plans maintain a range of key index values and reflect trade-offs between objectives; thus, planners or decision makers can select from the Pareto plans. Due to the feature of Pareto solutions, more and more scholars search for Pareto solutions rather than one best solution for MO problems.

Even if taking Pareto set as the solutions for MO problems has been popular in various fields, less research searched Pareto solutions for the MO problem of locating health-care facility. Facing up to the MO problem in determining the location of health-care facilities, this research employs the genetic algorithm (GA) based MOO approach to search for the Pareto solutions of health-care facility locations. The GA approach is widely used in solving the MO problems. The GA is a robust and efficient general global optimization algorithm used to search for large, complex, and little-understood search spaces (Garai & Chaudhuri, 2007; Kim & Abraham, 2007). As mentioned above, instead of offering one "best" solution, a number of Pareto optimal solutions are generated by the GA approach. This set of alternative solutions is well suited for practical applications and providing options for planners to choose from. Another alternative plan/solution can be selected from the pool of Pareto optimal solutions if implementing an optimal is difficult or impossible. Given the advantages stated above, the GA approach has been widely used in solving MO problems in field of land use planning (Balling, Taber, Brown, & Day, 1999), surface grinding operations (Saravanan, Asokan, & Sachidanandam, 2002), finance-based construction project scheduling (Fathi & Afshar, 2010), flood control (Qin, Zhou, Lu, Li, & Zhang, 2010), optimal placement and sizing of shunt FACTS controller (Phadke, Fozdar, & Niazi, 2012), and other fields.