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A multi-objective grouping Harmony Search algorithm for the optimal distribution of 24-hour medical emergency units

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ABSTRACT

This paper presents a novel multi-objective heuristic approach for the efficient distribution of 24-h emergency units. This paradigm is essentially a facility location problem that involves determining the optimum locations, within the existing health care centers, where to deploy 24-h emergency resources, as well as an efficient assignment of patients to such newly placed resources through the existing medical care infrastructure. The formulation of the underlying NP-complete problem is based on a bi-objective distance and cost metric, which is tackled in our approach by combining a Harmony Search algorithm with a grouping encoding and a non-dominated solution sorting strategy. Additionally, the nominal grouping encoding procedure has been redefined in order to reduce the dimension of the search space, thus allowing for a higher efficiency of the searching process. Extensive simulations in a real scenario – based on the geographic location of medical centers over the provinces of *Guadalajara* and *Cuenca* (Spain) – show that the proposed algorithm is statistically robust and provides a wide range of feasible solutions, hence offering multiple alternatives for the distribution of emergency units.

1. Introduction

Accessibility to health-care facilities represents one of the most significant indicators of the social development of a region, and its quantitative assessment contributes to a wider understanding of the performance of the overall health system. Hence, enhancing the availability of health services at the time they are needed is deemed a crucial issue and a major concern for the government of any developed country. In this context, intense research activity has been lately conduced towards the quantification of the geographic accessibility, also referred to as spatial or physical accessibility, by considering the existing relationship between the population distribution and the amount of health care facilities. As such, in Ebener, Ray, Black, and Morjani (2005) a methodology is proposed and analyzed for the measurement of the physical accessibility to health care facilities based on the user's home location, the availability of public transport and the impediments to travel. Another method to quantify the geographic accessibility is to consider the minimum travel time and distance to the closest hospital via a road network. Furthermore, the World Health Organization (WHO) has been involved in measuring accessibility to health care facilities in developing countries by determining the cost surface, i.e. the cost of movement through a region in any direction (Black, Ebener, Aguilar, Vidaurre, & Morjani, 2004).

In the current context of deep economical crisis, efforts are concentrated on improving the access to the existing health services, since the lack of medical and financial resources makes it operationally unfeasible to open new health centers. Therefore facility location problems, which entail determining the optimum sites where to place resources and also the efficient assignment of customers to such resources, have gained momentum in the last few years. Originally Hakimi in Hakimi (1956) introduced the so-called median and center problems, which are based on minimizing the total and the maximum traveled distance, respectively. Likewise, the authors of Church and Meadows (1979) presented a model for finding the locations that maximize the total demand covered by the facilities. Since then, this model has been used in other important works such as Maniezzo, Mingozzi, and Baldacci (1998) and Lorena and Senne (1998). Among the variety of health-care related facility location problems presented in the literature, it is worth to mention the one proposed by Pacheco and Casado (2004), which gravitates on developing a meta-heuristic scatter search procedure for finding the best locations to place special health resources (e.g. diabetic care and geriatric units, among others) in the provinces of *Castilla-Leon*, Spain. Analogously in Alegre, Alvarez, Casado, and Pacheco (2005) a memetic algorithm constructed by combining a genetic algorithm and a local search

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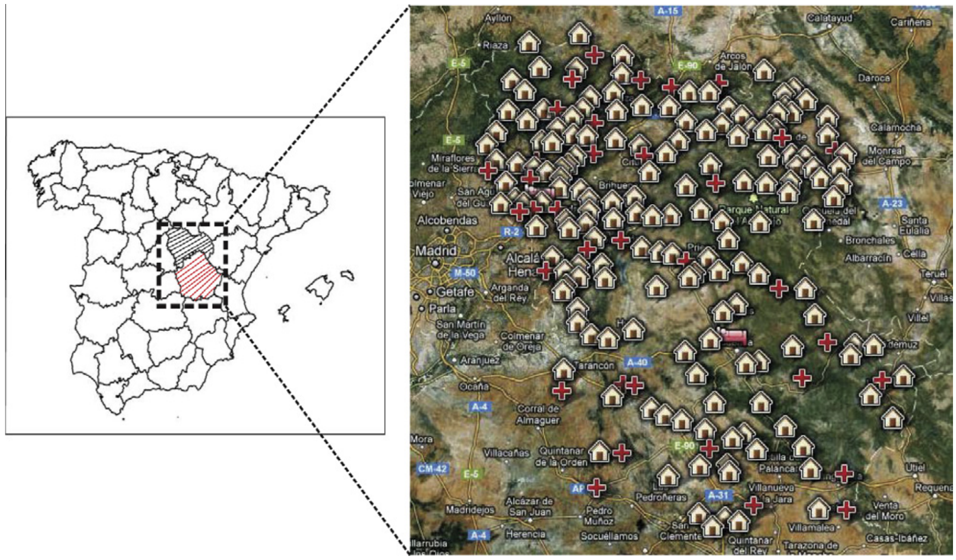

Fig. 1. Current health facilities deployment in *Guadalajara* (highlighted in the map with black stripes) and *Cuenca* (red stripes). *Beds* identify hospitals, *crosses* represent medium-size health centers and *houses* small-size health centers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

operator is used to determine the places where to deploy health resources where patients who have suffered from a diabetic coma can be attended in the province of *Burgos*, Spain. Within this line of research, three algorithms based in the meta-heuristic strategies Scatter Search, Tabu Search and Variable Neighborhood Search are compared to each other in Pacheco, Alvarez, Casado, and Alegre (2008) for solving the aforementioned problem.

The present work joins this research trend by elaborating on the estimation of the best locations in which to place 24-h emergency units so as to guarantee adequate health care to any user regardless of its geographical location. In general, urban areas are well-equipped with hospital and ambulance resources. On the contrary, improving the access to health care services continues being a challenge for rural areas or less populated regions, usually characterized by sparse transportation resources, small local health centers only opening on weekdays and during daylight, and long distances from the users to 24-h emergency centers. This work concentrates on alleviating the operational difficulties of people living in such rural areas – in general, elderly people – when requiring constant (i.e. all day long) health services. Specifically, this paper proposes a multi-objective grouping Harmony Search (MOGHS) approach which efficiently estimates the optimum distribution of 24-h emergency units, considering (1) the existing health care infrastructure; and (2) the cost of the distribution. In addition, a grouping encoding strategy, first described in Falkenauer (1993, 1994), is utilized to represent the iteratively produced solutions, which further reduces the size of the underlying solution space by eliminating inherently redundant solutions.

The performance of the proposed algorithm will be assessed in an emulated practical scenario by considering the Spanish provinces of *Guadalajara* and *Cuenca* (see map in Fig. 1). These are two neighboring regions belonging to the central autonomic region of *Castilla-La Mancha*, which have the highest number of small towns (i.e. less than 2000 inhabitants) in the whole country. In Fig. 1 the current distribution of health centers in such regions is depicted. Note that the majority of health resources corresponds to small-sized health centers. Moreover, medium-sized health centers are only opened during the day and usually not available at weekends. Thus, in case an emergency occurs after any center's opening hours, the patient must be forwarded to the closest open health center (usually hospitals), which may entail severe consequences if hospitals are not properly distributed. This is of utmost importance in those situations where a rapid medical assistance is needed; otherwise, the risk of permanent damage increases significantly. Increasing the number and amount of 24-h emergency units deployed in a certain region would surely reduce this risk; however, the economical cost associated to the deployment would rise accordingly. Our proposed approach renders a set of feasible solutions (denoted as Pareto-optimal set) differently balancing the trade-off between the total distance and the cost of the deployment of 24-h emergency units. The distance from any health center to its associated emergency unit is kept below a specified distance limit; this assumption obeys the intuitive operational constraint that the deployment should not enforce any potential user of any 24-h emergency unit to travel more than a predefined distance threshold disregarding the incurred cost saving.

The rest of the manuscript is structured as follows: the problem formulation of this facility location problem is formally posed in Section 2, whereas Section 3 details the main characteristics of the proposed MOGHS algorithm. Next, Section 4 presents the simulation results obtained in the real application scenario in *Guadalajara* and *Cuenca*, Spain. Finally, concluding remarks are drawn in Section 5.

2. Problem formulation

Let us then mathematically define the problem addressed in this paper by assuming a set of N existing health centers with associated patients' demand rates $\{w_1, w_2, \ldots, w_N\}$ (measured in e.g. patients' consultations per day[1]). If not available in historical databases, these values can be estimated according to the number of inhabitants of the particular town where the health center is settled. Intuitively, higher patients' demand rates will correspond to populated regions, whereas lower rate values will be assigned to low-populated towns. We further define a $1 \times T$ capacity vector

[1] Metrics such as the demand rate or the capacity of a health center can be more realistically estimated by resorting to data such as the number of beds/rooms, patient consultancy records, average age of the population, number of surgery rooms or available medical staff, among many others. However, the problem statement and methodology proposed in this paper is general enough to accommodate any specific metric computation.