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Design of a bi-objective reliable healthcare network with finite capacity queue under service covering uncertainty

M. Mohammadi [a], S. Dehbari [b], Behnam Vahdani [c,*]

[a] LGIPM, 12, rue Augustin Fresnel, 57070 METZ, France
[b] Department of Industrial Engineering, Islamic Azad University, South Tehran Branch, Tehran, Iran
[c] Faculty of Industrial and Mechanical Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran

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ABSTRACT

This paper designs a reliable healthcare network. Under limited capacity, queue of patients may deteriorate the condition and leads to risk of death. Consequently, it is vital to investigate a queue system that considers the condition and changes over the time. Besides, treatment units just serve patients that are in their coverage threshold, while this threshold is affected by several factors. This paper considers number of patients and covering threshold under uncertainty. To handle uncertainty, an integrated approach is proposed. Two meta-heuristic algorithms are developed for the given problem. Finally, we carried out experiments to assess proposed model and approaches.

1. Introduction

The Location of the healthcare facilities is very essential to guarantee that the chosen location network meets the purpose of minimizing community costs and impacts, and maximizing community benefits. Correspondingly, the demand allocation to these healthcare facilities directly affects the entire system's efficiency. Moreover, determining the location of healthcare facilities is a strategic decision for healthcare managers because nowadays healthcare facilities are working in competitive markets, meaning that construction or displacing facilities is a crucial decision that cannot tolerate mistakes (Ozcan, 2005). Hence, this problem plays an important role in health service planning, as it presents a structure for assessing accessibility problems, comparing the value of the previous structure, and developing alternative solutions to modify and improve the current structure of the system (Rahman and Smith, 1999).

There are many influential factors in determining the location of healthcare facilities such as region's population, different types of costs, service covering standard, service capacity, resource capacity, changes in demand, etc. It is obvious that most of the activities and occurrences in healthcare services are subject to noticeable uncertainties. Hence, these uncertainties adversely affect the quality of decisions made in strategic, tactical and operational levels of the healthcare service. Therefore, in order to solve these problems, advanced optimization approaches are desired and required. On the other hand, sometimes a number of created healthcare facilities might become unavailable due to disruptions caused by natural disasters, workers' strike, terrorist attacks, changes in management, etc. (Snyder and Daskin, 2005). Therefore, it can be stated that these treatment units do not have the ability to respond to the patients. To the best of our knowledge, no research has been conducted

* Corresponding author.
E-mail address: b.vahdani@gmail.com (B. Vahdani).

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concerning the uncertainty programming and multi-objective programming in the context of healthcare network design. Moreover, there is no research in the literature that applies a reliable facility location model for designing health care service network.

On the other hand, as health centers have limited capacity to serve patients, there is significant risk of deterioration of the situation and death and consequently a queue of health applicants is formed. In this situation, it is vital to assess the risk faced by patients in the queue and design adequate medical capacities in advance to address the patients. In order to cope with such situations, the present paper aims to propose a model and analyze a patient queue, where they are waiting to receive health service to treat an illness or to prevent from suffering. As the condition of patients may get worse over time, modeling and investigation of a patient queue are basically different from a normal queue, where the condition of patients remains constant. Although several papers in the literature have analyzed queues in health systems (Saunders et al., 1989;Brahimi and Worthington, 1991; Vogt et al., 1994), but these papers have applied the most general and simple queuing analyses without considering the special conditions of the patients. To cope with such cases, the operation of a patient queue must be addressed, in which the condition of the patient and its changes over time in the queue should be investigated.

Since the operation of a patient queue is influenced by the patient's condition, the current treatment might be useless (i.e., patient needs another treatment program) when the condition of a patient deteriorates to a certain level (Sobolev et al., 2000). In such a case, the patient is removed from the queue without service. For simplicity of presentation, we refer to all such events as death. Afterward, as the purpose of a healthcare facility is to minimize the risk of patients and preventing them from suffering, the patient's condition is taken into consideration for designing a capable healthcare center in this paper. On the other hand, to make more realistic and efficient healthcare system, patient's health problems are also addressed in the present paper according to their urgent conditions which determine the priority to receive service.

Although several papers have investigated healthcare facility location considering various assumptions (Vallim Fo and Mota, 2012;Shariff et al., 2012; Syam and Côté, 2012), but none of them have studied the effect of patient's condition on designing realistic healthcare facility utilization. Meanwhile, considering patient's condition may change the location of health facilities and allocation of demands to the located facilities where the waiting time and death risk of patient should be minimized. Not only all of the above-mentioned necessities do justify the use of queuing approach to design healthcare location network, but also the queue system is the only method which is able to consider patient's condition over the time and also to prioritize them in urgent and non-urgent classes. Therefore, we investigate a patient queue system in our mathematical model. In this research, the patient queue is modeled in two different ways: consisting of (1) homogeneous patients and (2) patients who are prioritized in two classes of high risk and low risk diseases.

Through a healthcare network, the performance of the network not only depends on the assignment of patient zones to the treatment units, but also depends on the paths that patients must traverse, while due to emergency condition of the patients, they need to be assigned to the nearest treatment unit. Although, treatment units are able to cover just limited area of network. Due to this limitation, a service covering standard (SCS) is considered for each treatment unit. This factor implies that each treatment unit just services patient zones which their traveling distance is less than a given covering threshold. Based on experts' opinion, health service providers can not specify a deterministic value for the SCS and this value is affected by different factor such as capacity of the treatment unit (i.e., higher capacity leads to higher coverage, when treatment units with higher capacity increase their coverage threshold to cover more patients), the location of treatment unit, the path that patients traverse etc, and may be changed over different time periods. On the other hand, determining a specific value at each time period is also challenging. Consequently, we have considered the SCS in the network under the mixed uncertainty (Mohammadi et al., 2014). Broadly speaking, this paper considers the uncertainty in number of patients and coverage of each treatment unit.

With regard to the matters enumerated, the aim of the paper is to introduce a new bi-objective mathematical programming model for designing a healthcare service network under uncertainty with the objectives of (1) minimizing the total costs including total treatment and transportation cost and expected failure cost, and (2) minimizing the sum of maximal accumulated travel time. Besides, the number of patients and system covering standard are considered as uncertain parameters. Furthermore, we develop a new solution approach for better accounting for multiple uncertainties, in order to incorporate queuing theory, interval-valued fuzzy programming, stochastic programming and game theory within a mathematical optimization model. Moreover, we proposed two efficient meta-heuristics algorithms based on simulated annealing (SA) and imperialist competitive algorithm (ICA).

The rest of the paper is organized as follows: Section 2 presents a brief review of the literature on mathematical model for designing health care service network. Problems regarding definitions and formulations are described in Section 3. The proposed hybrid solution approach and meta-heuristic algorithms are given in Section 4. Computational experiments are provided in Section 5. Finally, the paper is concluded in Section 6.

2. Literature review

One of the important issues concerning the patient's decision to have prostate cancer screening is accessibility of treatment units (Zimmerman, 1997).Moreover, the research by Facione (1999) revealed that perceptions of lack of access to treatment units are related to a decrease in mammography participation. Hence, facility location problem (FLP) is one of the major decisions in the field of healthcare management (Daskin and Dean, 2004). Moreover, Baron et al. (2008), indicates that removing structural barriers enhances community access to breast, colorectal cancer screening and etc. Verter and Lapierre