A SURVEY OF HEALTHCARE FACILITY LOCATION

Abstract

Healthcare facility (HCF) location has attracted considerable attention from the operations research community over nearly four decades as one of the most important strategic issues in healthcare systems, disaster management, and humanitarian logistics. However, the lack of a comprehensive review in the last decade is a serious shortcoming in the literature of HCF location. This survey presents a framework to classify different types of non-emergency and emergency HCFs in terms of location management, and reviews the literature based on the framework. The papers on HCF location problems are classified in detailed tables along ten descriptive dimensions, which are consideration of uncertainty, multi-period setting, particular input/setting, objective function, decision variable, constraint, basic discrete location problem, mathematical modeling approach, solution method, and case study inclusion. For each HCF type, research gaps and possible future directions are identified. Moreover, the literature and future research possibilities are analyzed in terms of modeling approach and solution method.

Introduction

Facility location decisions play a critical role in the strategic design of systems for a wide range of private and public organizations (e.g., retail facilities, warehouses, airline hubs, police stations, hospitals, etc.). This is because poorly located facilities or an improper number of facilities can greatly increase capital and inventory costs and degrade customer services. The first theoretical study on the location of facilities began in 1909 when Alfred Weber [1] introduced a warehouse location problem to minimize the total distance between a warehouse and a set of customers. Thereafter, location theory and its applications were developed in different research areas along with a variety of models.

In healthcare, incorrect facility location decisions have a serious impact on the community beyond simple cost and service metrics; for instance, hard-to-access healthcare facilities are likely to be associated with increased morbidity and mortality. From this perspective, facility location modeling for healthcare is more critical than similar modeling for other areas. In addition, because of globally pervasive trends, such as decreasing birth rates, higher longevity and associated growth in elderly population, and increasing environmental

problems (e.g., sound and air pollution), healthcare and the associated healthcare facility (HCF) location problems have become noticeably more critical and important to society. Due to this, HCF location modeling continues to attract keen interest from the operations research (OR) community.

Perhaps the earliest location-allocation study in the field of healthcare facilities (HCFs) was presented by Gould and Lienbach [2]. In this study, the problem of locating hospitals and determining their capacities was considered as a *p*-median problem in the western part of Guatemala. The transportation algorithm was used to solve the problem. From 2000 onwards, researchers reviewed different parts of the literature of HCF location from various perspectives (see [3], [4], [5], [6], [7], [8], [9], [10], [11]). The scopes of these review papers are summarized in Table 1 and explained in more detail subsequently.
The use of location-allocation models in development planning of health services in developing nations was reviewed by Rahman and Smith [3]. They classified studies into four categories: (i) finding a set of optimal sites, (ii) locating optimal sites in a new area, (iii) measuring the effectiveness of past location decisions, and (iv) improving existing location patterns. Brotcorne et al. [4] investigated the evolution of ambulance location and relocation models over the course of thirty years. For this purpose, they classified models into deterministic and probabilistic categories, and summarized the literature in two corresponding tables. Furthermore, they noted the introduction of dynamic models in ambulance location.

Daskin and Dean [5] classified the location models used in healthcare literature into three categories: accessibility, adaptability, and availability models. In their view, accessibility models are extensions of location models whose goals were predominantly to maximize coverage or to minimize average distance. Adaptability models attempt to find solutions that perform properly across a range of possible scenarios and conditions. Availability models are divided into deterministic, queuing-based and probabilistic models. These models address very short-term changes that result from facilities being busy.

The literature of covering models and optimization techniques for locating emergency response facilities was studied by Li et al. [6]. Rais and Vianna [7] briefly surveyed several applications of operations research in healthcare planning (e.g., demand forecasting, location selection, and capacity planning), healthcare management and logistics (e.g., resource and staff scheduling), and other applications (e.g., disease diagnosis and treatment planning). Wang [8] presented a literature review regarding three issues related to inequality in healthcare accessibility: measurement, optimization, and impact, with emphasis on methodological advancements and implications for public policy.

Gutiérrez and Vidal [9] reviewed the literature of home healthcare logistics in terms of a three-dimension framework. In the first dimension, home healthcare planning levels were distinguished according to the time horizon, namely strategic, tactical, and operational levels. In the second dimension, logistics management decisions were divided into four groups: network design, transportation management, staff management, and inventory management. In the third dimension, service processes were defined as the set of steps performed in the delivery of home healthcare services. These service processes include medical prescription, patient admission, appointment scheduling, visiting patients, and medical discharge. Ingolfsson [10] briefly reviewed research on the planning and management of emergency medical services (EMSs) with emphasis on four topics: performance measurement; location of ambulance stations; allocation of ambulances to stations; and forecasting of demand, response times, and workload. Recently, Gunes and Nickel [11] provided an overview of

facility location problems in health systems with a focus on three main areas in the healthcare context: public facility location, ambulance planning, and hospital layout.

By considering the scope of the recent review papers (given in Table 1), one finds that each paper covers a part of the healthcare services. Thus, the field of OR continues to lack a comprehensive review of facility location in healthcare. In this regard, we decided to provide a thorough classification of HCF location models and survey the literature on HCF location in the last decade. The review considers 18 types of facilities in three main categories (see Section 3.1) along 10 descriptive dimensions (see Section 3.2). For this purpose, we identified approximately 150 articles that have been published since 2004. Note that almost all earlier papers on HCF location published before 2004 have been reviewed in surveys [3], [4], [5], [6], [7], [8], [9], [10], [11].

Furthermore, the scope of this paper is to review only those papers that consider a specific type of HCFs, not a generic type of service facility. Actually, there are papers that study typical (mobile or immobile) service facilities with specific properties, which are not reviewed in this paper unless they provided a case study on a healthcare location problem. For a review of such papers, the reader may refer to the recent survey [12] and references therein. The models developed in such papers can be potentially adapted for different types of HCFs, depending on the assumptions underlying each model.

One should pay careful attention to the point that HCFs are widely considered in many different interrelated research fields. These fields along with related survey papers are listed as follows: healthcare operations management ([13], [14]), healthcare services supply chains ([15], [16]), services supply chains ([17]), pharmaceutical supply chains ([18], [19], [20]), healthcare waste management ([21]), disaster operations management ([22], [23], [24]), emergency logistics ([25]), relief distribution ([26]), humanitarian logistics ([25], [27], [28], [29]), homeland security ([30], [31]), emergency response ([5], [32], [33]), emergency services stations ([34]), emergency services vehicles ([35]), and supply chain with disruptions ([36]). This indicates that HCFs have various types and widespread usages in different fields, which made our survey process more challenging.

The remainder of the paper is organized as follows: Section 2 presents an overview of discrete location problems. Section 3 provides a framework for the classification of HCFs from a location analysis perspective and describes the structure of this review paper. Section 4 and Section 5 are devoted to review and scrutiny of non-emergency and emergency HCF location papers, respectively, based on the framework proposed in Section 3. Section 6 analyzes the literature from different perspectives. Section 7 presents directions for possible future research. Section 8 concludes the review. Appendix A provides definitions and details on different types of HCFs.

Section snippets

An overview of discrete location problems

Facility location theory refers to the modeling, formulation, and solution methods of a class of problems that deal with locating facilities in some given space. Since facility location is a

critical subject at the strategic planning level, location theory and its applications have received increasing attention from the OR community. The study of facility location models has its roots in the pioneering work of Weber in 1909. Thereafter, numerous papers and books have dealt with facility

Scope of literature survey

This section includes two subsections. The first presents the framework that is used to classify the different types of HCFs, and the second introduces the descriptive dimensions considered to analyze each research paper.

Non-emergency HCF location

Following the classification of HCFs illustrated in Fig. 3, content within the non-emergency literature can be classified into several categories. In the following, the reviewed papers in each category are analyzed according to Tables 3 and 4.

Emergency HCF location

We classify the emergency HCFs according to whether HCFs perform under permanent or temporary emergency situations. Permanent emergency HCFs include emergency centers, emergency off-site public access devices, trauma centers, and ambulance stations which provide emergency services all the time. On the other hand, temporary emergency HCFs include temporary medical centers and points of dispensing, which deal with healthcare services in disaster situations.

It should be recalled that emergency

Analyses of literature from different perspectives

We complete our review of the literature on facility location models in health systems by presenting additional information regarding the surveyed papers. For this purpose, we analyze the types of basic discrete location problems corresponding to these papers, specify the modeling approaches and solution methods used to solve the problems, and determine whether a case study is considered or not. Finally, we break down the papers with respect to the subcategories of the survey's descriptive

Future research directions

In general, we have provided most of our suggestions for future research in each section. However, in this section we summarize related discussions and potential future research directions that are drawn from the overall review. We do this with respect to (i) the computational perspective (mathematical modeling approach and solution method) and (ii) different types of location problems in health systems.

Conclusions

In this paper, we have reviewed almost the entire emergency and non-emergency healthcare literature on facility location analysis over the last decade (2004-2016). By analyzing the existing surveys, we show that the lack of a comprehensive review of HCF location is a

significant shortcoming in the healthcare literature. Therefore, we introduced a comprehensive framework to classify HCFs in terms of location management. The optimization models in each classification of HCFs are analyzed in