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Accessible, stable, and equitable health service network redesign: A robust mixed possibilistic-flexible approach

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ABSTRACT

This paper addresses a multi-period three-level health service network redesign problem. The problem involves strategic decisions on locating, closing or expanding the capacity of network's facilities over the planning horizon, (re)designing an efficient referral system and (re)allocating patient zones to facilities while aiming at achieving an accessible, stable, and equitable network. A robust mixed possibilistic-flexible programming approach is devised to cope with imprecise parameters and soft constraints. Afterwards an improved augmented ε-constraint method is proposed to find the Pareto front. Finally, a real case study is provided to illustrate the performance of the proposed model and its solution procedure.

1. Introduction

The healthcare systems are being challenged by increasing demand for healthcare services while escalating costs. The increase in demand is deeply rooted in the recent global trends such as aging populations, decreasing mortality rate, advances in medical knowledge and technology, heightened expectations for healthcare, the growth of emerging markets, and an increasing dependence on medicine to solve human problems (Lian, 2003). In addition, as Table 1 shows, the dramatic increase in the healthcare expenditure is not limited to few countries and could be regarded as a global trend. As a result, the pressure to curb costs is affecting the operations of healthcare systems/organizations and they have no choice but to become as efficient as possible in all features of their operations (Syam and Côté, 2010).

Providing both cost-efficient and qualified healthcare services could be realized through using systems engineering models especially in complex cases. Operations research (OR) science is one of the most popular system thinking principles that is a fast-growing area of research in the healthcare context (Brailsford and Vissers, 2011). Health service network (re)design is among the highly complex cases that can greatly benefit from OR models. It is evident that health service networks are much more extensive than three decades ago; however, many groups are not properly covered yet. As is expressed by World Health Organization (2008), civil strife and war have partly or completely destroyed the healthcare infrastructures in some countries. Although the health service is available in other countries, the provided services are not those services that are necessarily needed (i.e. some supply gaps still exist). In addition, the phenomenon of the aged society will put the pressure on the governments to build new healthcare facilities and/or installing new social insurance systems for the aged in the years ahead (Kim and Kim, 2010). As a result, dealing with the health service network (re)design problem is still the main concern, as was the case many years ago.

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Table 1
Global trend in healthcare expenditures (refined from World Health Organization (2015)).

Groups	Total expenditure on health as % of GDP			Per capita total expenditure on health (PPP int. $)		
	2000	2012	Increase	2000	2012	Increase
African Region	4.2%	5.6%	33.3%	$110	$208	89%
Region of the Americas	11.0%	13.6%	23.6%	$2055	$3768	83%
South-East Asia Region	3.6%	3.7%	2.8%	$88	$208	136%
European Region	7.9%	8.9%	12.7%	$1216	$2402	98%
Eastern Mediterranean Region	4.0%	4.6%	15.0%	$260	$561	116%
Western Pacific Region	5.8%	6.6%	13.8%	$315	$857	172%
Low income countries	2.9%	5.1%	75.9%	$32	$83	159%
Lower middle income countries	3.9%	4.1%	5.1%	$108	$235	118%
Upper middle income countries	5.3%	6.0%	13.2%	$263	$766	191%
High income countries	9.6%	11.6%	20.8%	$2392	$4516	89%
Global	*7.7%*	*8.6%*	*11.7%*	*$597*	*$1173*	*96%*

In light of above discussion, we develop a multi-objective mixed integer linear programming model for redesigning a three-level health service network in a multi-period planning horizon. The proposed model determines the location of the different healthcare facilities (i.e. the primary health centers, clinics, and hospitals), closing the existing facilities, the capacity of facilities, allocation of patients to operating facilities, and referral pattern between the operating facilities in each period. These decisions are made regarding the three health-oriented objective functions, i.e. maximization of access to the health network, minimization of the total health network instability, and maximization of the equity in the people's utilization of the health services.

The remainder of this article is organized as follows. The related works are reviewed in Section 2. In Section 3, the problem definition and model formulation are described. In Section 4, the devised uncertainty programming method for handling different sources of uncertainty is elaborated. In Section 5, the improved augmented ε-constraint method for solving the proposed multi-objective model is provided while application of the model to the case study is discussed in Section 6. Finally, Section 7 presents some concluding remarks and paves the way for the further research.

2. Literature review

A health service network generally consists of three levels which provide different levels of health services including, (1) the preventive health services, the first aids, and the primary health services at the primary health centers (PHCs)/community health centers (CHCs), (2) some curative and therapeutic procedures at the clinics/regional health centers (RHCs), and (3) more specialized and curative services at the general or specialized hospitals/district health centers (DHCs). Low-level service providers are not much expensive to be established, are visited frequently, and attract short trips while high-level service providers are highly expensive to be established, are referred to less frequently, and attract long trips (Yasenovskiy and Hodgson, 2007).

The number of healthcare facilities to be established, the optimal location of these facilities and their designed capacities are among the key strategic decisions when (re)designing a healthcare network (Stummer et al., 2004). However, the optimal location of facilities should be determined taking into account the potential flows of patients (i.e. the optimal allocation of patient zones to the healthcare facilities) as well as the interactions between the health service providers (Mestre et al., 2012). In these cases, location–allocation models could be a practical option in which both decisions are made simultaneously.

The location-allocation models have been broadly applied in healthcare settings, i.e. the location-allocation of health service providers for nomadic populations (Ndiaye and Alfares, 2008), rural areas (Smith et al., 2009), city areas (Harper et al., 2005), and highly developed cities (Zhang et al., 2016), preventive healthcare facilities (Zhang et al., 2012), primary care providers (Güneş et al., 2014), community healthcare facilities (Griffin et al., 2008), clinics (Beheshtifar and Alimoahmmadi, 2015), public hospitals (Kim and Kim, 2013) perinatal facilities (Galvão et al., 2006), specialty care providers (Benneyan et al., 2012; Syam and Côté, 2010), and long-term care providers (Song et al., 2015).

However, due to the hierarchical structure of health service networks, hierarchical location-allocation models could be suitably used. In these models, interactions between different facilities belonging to different levels (layers) of the network are also taken into account when designing an optimal network. To the best of our knowledge, the papers in hierarchical healthcare location-allocation context, covering more than two types of the healthcare facilities are scarce. Among the rather related papers, Galvão et al. (2002) proposed a 3-level hierarchical model that addresses the location of basic units, maternity homes and neonatal clinics as well as the flow of mothers from demand zones to healthcare facilities and between a group of healthcare facilities. Their work has been extended by Galvão et al. (2006) in which load balancing and equitable distribution of existing facilities were the main concerns. Mitropoulos et al. (2006) proposed a model for locating primary healthcare centers and hospitals with respect to two objectives, i.e. (1) minimization of distance between patients and facilities, and (2) equitable distribution of the facilities among the population. Yasenovskiy and Hodgson (2007) addressed the optimal location of healthcare providers and the optimal allocation of geographical zones to these facilities in a three-level hierarchical system including the local health centers, community health centers, and medical centers. In another study, Mestre et al. (2012) determined the optimal location of two types of healthcare facilities, i.e. central hospitals (CHs) and district hospitals (DHs) in a bi-level hierarchical multi-service model. Along with location decisions, the optimal