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A heuristic approach to solve the preventive health care problem with budget and congestion constraints

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ABSTRACT

Preventive health care is of utmost importance to governments since they can make massive savings on health care expenditure and promote the well-being of the society. Preventive care includes many services such as cancer screenings, vaccinations, hepatitis screenings, and smoking cessation programs. Despite the benefits of these services, their uptake is not satisfactory in many countries in the world. This can be attributed to financial barriers, social issues., and other factors. One of the most important barriers for preventive care is accessibility to proper services, which is a function of various qualitative and quantitative factors such as the distance to travel, waiting time, vicinity of facilities to other attractive facilities (such as shopping malls), and even the cleanliness of the facilities. Statistics show that even a small improvement in people's participation can save massive amounts of money for any government and improve the well-being of the people in a society.

This paper addresses the problem of designing a preventive health care network considering impatient clients, and budget constraints. The objective is to maximize the accessibility of services to people. We model the problem as a mixed-integer programming problem with budget constraints, and congestion considerations. An efficient variable neighborhood search procedure is proposed and computational experiments are performed on a large set of instances.

1. Introduction

Efficient management of the health care supply chain is becoming a more active research field every passing day. Scarcity of resources, increasing customer expectations in terms of quantity (due to the aging population) and quality, increasing costs (both due to the increase in demand and investment costs of new health-related technologies and drug discovery) are among the factors which make this topic a significant one for health care service providers, insurance companies, as well as governments who are constantly striving to become as efficient as possible in delivery of their services. Various methods from mathematics and operations research fields have been used to facilitate management of health care systems, such as Markov chains, mathematical programming, and simulation.

Many costly, and disabling problems such as cancer, cardiovascular diseases, diabetes, and chronic respiratory problems are linked by some risk factors which are preventable to a rather high extent and/or better managed by regular checkups. A preventive health care program is the set of actions taken to avoid or to delay the onset of diseases. The old idiom "an

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ounce of prevention is worth a pound of cure" summarizes the benefits of preventive health care in a perfect way. Generally speaking, there are three categories in preventive health care. Primary interventions are those that reduce the risk of disease for healthy individuals (e.g. immunization programs, diet schemes, autism screenings for children, etc.). Secondary interventions are those that are designed for early detection of diseases for the individuals who are in the risk groups (e.g., screening for breast cancer for females over a certain age, cholesterol control, screenings for osteoporosis, colonoscopies, consultancy services provided for pregnant women, audiometric tests). Neither the individuals who receive primary prevention services nor those who receive secondary services have any obvious sign of the disease. On the other hand, tertiary interventions are designed for individuals who have been already diagnosed clinically for a disease and the goal of the preventive health care service is reducing the complications that might be caused by it (e.g., for individuals that have diabetes, regular retinal checks are performed). Preventive health care programs can bring about substantial reduction in the overall health care spending of the society (Maciosek et al. [1] report savings of $3.7 billion for USA in 2006). Efficient management of preventive health care programs and increasing the public participation would definitely benefit the society and patients simultaneously. For instance, studies in USA show that for every HIV infection prevented, an estimated $355,000 is saved in the cost of providing lifetime HIV treatment [2]. Moreover, a 5 percent reduction in the prevalence of hypertension would save $25 billion in 5 years [3].

Preventive health care is inherently different from programs for acute ailments. In contrast to sick people who need urgent medical attention, people who seek preventive services have more flexibility as to when and where to receive preventive health care services. Even though the benefits of preventive services are clear both in terms of cost and health, most of the people are reluctant about their own health status and often prefer not to participate. Therefore, the achievement of the desired participation level continues to be a challenge to many preventive health care programs. The maximal participation levels lead to economies of scale in the operational costs of preventive health care facilities. An increase in participation levels in such preventive programs reduces the overall burden of health for the society and increases the expected benefits from the health care delivery.

Preventive health care Facility Network Design Problem (PHFNDP), briefly speaking, which deals with where to locate the facilities and determination of their capacities, is among the most significant strategic level decisions in any preventive health care program. The goal is to establish a set of facilities among a set of potential locations, so that the participation level is maximized. Empirical research in health economics literature deals with the concept of attractiveness of health care facilities and suggests that there are various factors that influence attractiveness. For example, Biørn and Godager [4] as well as Gravelle et al. [5] demonstrate that the attractiveness of health care facilities is not only influenced by the proximity but also by other qualitative factors such as quality, availability of other facilities in the neighborhood (e.g. shopping malls, restaurants, etc.), amenities near the facility, etc. On the other hand, Muller et al. [6] determines that in urban areas, distance influences the decision on which kind of medical services (e.g. a medical doctor or a hospital) the patients use, whereas in rural areas of developing countries, distance is the decisive factor whether or not to use medical services at all. Other research such as Varkevisser et al. [7] and Haynes et al. [8] also reveal evidence that distance plays a pivotal role in the attractiveness of facilities. Note that, these empirical evidences are not from studies that focus particularly for preventive health care services but for general health care services. Normally, in the literature of the PHNFND problem, distance is used as the only factor affecting the attractiveness of a facility (e.g., Zhang et al. [9]; Zhang et al. [10]; Zhang et al. [11]; Gu et al. [12]). The relation between distance and attractiveness can be modeled as linear or non-linear based on some demographic issues, traffic conditions, etc. Fig. 1 depicts a network with four facilities established on a plane and an exponential attractiveness function in which darker areas are areas with good accessibility to facilities and the accessibility wears out as clients move away from the facilities. As it is clear from this figure, the attractiveness of facilities can decrease dramatically by an increase of the distance (Distance can be replaced by travel time which is a more realistic measure for our problem like many other health care related problem, both in rural areas owing to possible difficulties of access and in urban areas because of the traffic conditions. For more information, interested readers can refer to various sources such as Phibbs and Luft [13], Schuurmann et al. [14]).

Chronic diseases such as cancer, diabetes, and heart diseases in US account for 75% of the country's health expenditure as reported by the Centers for Disease Control and Prevention while they are largely preventable. An optimal provision of preventive health care services can save money up to $590,000/QALY for governments as the health care providers [15]. As discussed by Daskin and Dean [16], the implications of poor location of health care facilities can be well beyond cost and customer service considerations, increasing the prevalence of diseases, and mortalities. That said, health care providers can benefit massively from a higher participation rate of individuals in addition to citizens. The main goal of the problem in this paper is to maximize the participation level of people as a measure of the distance between facilities and population centers in order to efficiently manage the health care spending, and promote the health status of a society. We contribute to the literature by proposing an efficient heuristic procedure to solve the PHNDP with budget and capacity constraints.

The outline of this paper is as follows: It proceeds with a literature review of relevant publications in Section 2. The mathematical model of the paper is presented in Section 3. In Section 4, our proposed solution procedure is elaborated. Numerical experiments and some analysis appear in Section 5, and finally, conclusions and some future research avenues are provided in Section 6.