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Robust and reliable medical services network design under uncertain environment and system disruptions

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ABSTRACT

This paper addresses an efficient mixed integer linear programming model for a robust and reliable medical service (MS) center location network design problem (RR/MSL/NDP), which simultaneously takes uncertain parameters, system disruptions, and investment budget constraint into account. The proposed model is formulated based on an efficient robust optimization approach to protect the network against uncertainty. Furthermore, a mixed integer linear programming model with augmented P_R-robust constraints is proposed to control the system reliability under unforeseen situations. A practical case study is presented in detail to illustrate the application of the proposed model.

1. Introduction

Nowadays, the robust and reliable design of medical services (MS) systems has attracted significant attention by different scientific societies. In recent years, providing a suitable service level is an attempt for many MS systems, but it is of special concern in the context of MS centers locating and also link constructing/improving. Despite the recent progress in accessibility, answer improvement to customers, availability of more advanced equipments, some pressing problems, which have been mentioned a few, are worth to be further investigated. They can be included the reduction of the investment costs for MS centers locating, link roads constructing/improving and also customers transfer costs. Recently, MS systems in most countries in the world primary endeavor to maximize the populations' health, equity, efficiency and quality, and, at a second level, to control and/or minimize different health care costs. On the other hand, the reliability of the designed MS systems and also several demands uncertainties are very important and a robust and also efficient MS systems can be significantly affected on provided MS for populations of a region especially in uncertain crisis situations. But considering of system reliability and also different parameter uncertainties make the design and the management of efficient MS systems very difficult and merits specific attention by the health care planners.

In order to achieve these efficient goals, governments need to have accurate plans for locating, allocating and improving the efficiency of MS systems. Accordingly; several related decisions need to be made as follows: where should MS centers be located so as to improve the geographic equity of access? What is the optimal structure of the MS center network? How should the link network be constructed/improved? What are the costs required to improve access, and are these acceptable?

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How should the design of MS systems be changed to increase the reliability of MS systems? How much should the extra spending have to improve the reliability of MS systems? (Mestre et al., 2011) How can a robust design be proposed such that the several demand uncertainties can be covered in the best way?

Such long term strategic decisions about MS centers locating and MS systems networks organizing regarding to the different actual and practical conditions have suitable and efficient tradeoffs to follow the above objectives, such as the tradeoff between equity, efficiency, investment, and costs (Current et al., 1990). For example, enhancing the geographic equity of access might mention the building of small MS centers close to populations, which leads to inefficiencies in scale and higher costs.

As another considerable view, the significant investment cost of some medical equipment and the poor availability of highly skilled human or particular drug resources (such as specialized doctors or special drugs) might imply that the supply of services is delivered to large populations, which might have an unpleasant impact on geographic access. In addition, reducing the costs of MS centers locating and demands allocating to them may increase the failure costs of MS centers. Also, excessively increasing in costs of locating and allocating of MS centers, in order to reduce the failure costs and subsequently increase the reliability of MS systems, may be not economically and possible for majority of governments. Moreover, ignoring the demand uncertainty, in the model formulating, can be considerably reduced the efficiency of the obtained optimal solution. So an accurate and efficient planning and modeling of MS centers locating and demands allocating them can be caused to an enough confidant and practical approach to reach the mentioned objectives.

Some studies have focused their efforts on the strategic planning, others on tactical support (including routing of MS vehicles for non-urgent calls), and on operational control (MS vehicles dispatch and relocation). Although some improvement areas can be identified, some researches should proceed for stronger movements from the strategic level to the operational one (Beraldi and Bruni, 2009). This paper focuses on the strategic level and proposes a new mathematical model that can act as a support tool to help MS systems planners. Moreover, it can improve the geographic equity of access, reduce transfer costs, and also failure costs of MS centers under some uncertain conditions. The proposed model can obtain optimum MS centers location and link construction/improvement to minimize cost while also taking into account the expected transfer cost regarding to the failures of MS centers and also demands uncertainty. The goal is to choose facility location, link construction/improvement, and demand assignment such that the objective function of the model is minimizing the nominal costs, while reducing several disruption risks and robust flowing of the transfers among nodes. In other words, the model provides an enough confidant, effective approach to be applied in MS systems regarding to the uncertain environment (including demands and transportation costs uncertainty) and also the failure probability of the system (including MS centers and links disruptions).

The rest of the paper is organized as follows: In Section 2, a brief review of the relevant literature of the robust and reliable planning of MS systems are proposed and the description of research gap and our contribution are explained as follows. In Section 3, the mathematical model description for the robust and reliable optimizing of MS systems is presented. In details, in Section 3, at the first, the assumptions and notations are described. Then, the reliable mathematical model is proposed and at the following, a brief description of the applied robust optimization method is presented and finally the robust and reliable model formulation is proposed. In Section 4, a case study that illustrates the application of the model formulation is demonstrated and solved by the proposed model. Sensitivity analysis of the model key parameters is discussed in Section 5. Finally, conclusions and future works are explained.

2. Literature review and research gap

There are two wide categories of risk that impress the facility location and network design topics: (I) the risk originating from the difficulties in coordinating facility and demand (parameter uncertainty), and (II) the risk originating from a threat of disruptions to normal activities (system disruptions), which includes the issues related to the natural disasters, strikes, economic disruptions, and terrorist attacks.

In order to place our contribution in the right perspective, we briefly review four main streams of literature that may be of interest for comparison: (1) the literature on MS location problems, (2) the literature on the facility location problem regarding to network design, (3) the literature on facility location with system-including facility and transfer links- disruptions, and (4) the literature on facility location with demands uncertainty. Definitely, these four research areas, with the discussed topic in this paper, are strongly related; having the location of MS centers inspired a significant amount of research in facility location theory considering in the network design, system disruptions, and demands uncertainty topics.

2.1. Related location models to MS systems

There have been research results on facility location problems in various areas such as distribution systems, telecommunication networks, transfer networks and healthcare systems (Brandeau and Chiu, 1989; Eiselt, 1992; Owen and Daskin, 1998; Hale and Moberg, 2003; ReVelle and Eiselt, 2005; Daskin, 2008). When a set of demand locations and a set of candidate facility locations are given, the facility location problems are usually concerned with the decisions on where to locate facilities in order to minimize the total cost for locating facilities and satisfying the demands subject to a set of constraints. These