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A robust possibilistic programming approach to multi-period location–allocation of organ transplant centers under uncertainty

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ABSTRACT

This paper presents a novel robust possibilistic programming model for a multi-period location–allocation problem in an organ transplant supply chain under inherent uncertainty of input data. The minimization of total costs is considered as objective function to elevate the efficiency of the studied supply chain network. The significance of applicability of the developed model is demonstrated via numerical experiments and some sensitivity analyses on the data inspired by a real Iranian organ transplant supply chain.

1. Introduction

Supply chain management (SCM) is usually considered as a process of planning, implementing and controlling the operations of the supply chain based on an efficient basis (Melo, Nickel, & Saldanha-Da-Gama, 2009). The supply chain network design (SCND), as one of the most important subsets of strategic decision making of SCM, plays an important role in the overall economic performance of the supply chain, which determines the locations and numbers of network facilities and the allocation of flows between them (Pishvaee & Razmi, 2012). Among the different kinds of facilities, location of healthcare facilities is very crucial in ensuring that the chosen location network serves the purpose of minimizing the social cost or equivalently maximizing the people's benefits. Similarly, the allocation of demands to these facilities has a direct impact on the whole system's efficiency. Thus, location–allocation models play a critical role in health service planning, as it provides a framework for investigating accessibility problems, comparing the quality (in terms of the efficiency) of the previous location decisions, and providing alternative solutions to change and improve the existing system (Rahman & Smith, 2000; Shariff, Moin, & Omar, 2012).

Many previous studies have been devoted to facility location problems (see Drira, Pierreval, and Hajri-Gabouj (2007) and Farahani, SteadieSeifi, and Asgari (2010) as review papers); While, the significant survey of implementation of operational research on healthcare facilities are done by Papageorgiou (1978) and Rais and Viana (2010). In this field, several researchers have presented different models for location–allocation of healthcare facilities. Syam and Côté (2012) proposed a model for location–allocation of a treatment department related to traumatic brain injuries. A common resource constraint is also assumed and minimization of the total cost is considered as objective function. The derived data from the Department of Veterans Affairs (DVA) have been used for testing applicability of the model. They also examined the effects of five critical factors, such as the degree of service centralization, service level mandates by acuity, lost admission cost by acuity, facility overload penalty cost by acuity and target utilization level by acuity and treatment unit. Shariff et al. (2012) formulated a capacitated maximal covering healthcare location problem and applied it to one of the districts of Malaysia. For determining the percentage of coverage of the existing facilities, they proposed a new genetic algorithm. Benneyan, Musdal, Ceyhan, Shiner, and Watts (2012) presented a multi-period model for location–allocation of Veterans Health Administration. In their paper, a multi-period mathematical integer programming model with consideration of trade-offs between costs, coverage, service location, and capacity is proposed. Sha and Huang (2012) focused on multi-period location–allocation of healthcare systems (i.e., emergency blood supply systems) for a case study in Beijing. They proposed a heuristic algorithm based on the Lagrangian relaxation method.

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One of the most vital subsets of healthcare systems is organ transplantation, which has become a successful treatment for many diseases that otherwise would have been fatal (Belien, De Boeck, Colpaert, Devesse, & Van den Bossche, 2013). Since the transplant centers directly deal with surgical operations and the human lives in consequence, the importance of this topic has been highlighted. The transplant surgical process involves a donor (i.e., a person who donates an organ) and a recipient (i.e., a patient who receives the organ). Despite all the advances and sophisticated technologies in operations and transportation methods in such systems, management on location–allocation of organ transplant centers in some districts has remained far from being efficient on a consistent basis.

The network of the transplant system consists of donors (D), recipient regions/zones (RZ), hospitals (H), transplant centers (TC), and shipping agents (Sh.A). Volunteers for donating an organ or brain-death patients are kept in donor hospitals, while in TCs, registration, blood sampling and surgical operations for transplanting the applicants are being accomplished. Finally, shipping agents are in charge of transporting the organs and required supplies from the hospitals to the TCs.

One of the main differentiations between the typical supply chain and the organ transplant one is perishability of the concerned products. According to Uehlinger, Beyeler, Marti, and Immer (2010), each organ is constrained by a specific cold ischemia time defined as the maximum period the organ can be kept outside the body.

The complexity of the organ transplant network and the intense interaction between facilities necessitate the better administration of location–allocation of such systems in order to maximize the benefits of the involved people with the minimization of the network's total costs and provide some other alternative solutions to better management of the concerned system.

In this area, Bruni, Conforti, Sicilia, and Trotta (2006) presented a mixed-integer linear programming (MILP) model to obtain an efficient system and equalize the waiting lists in Italy. To optimize their transplant system, they assumed that special centers (referred as OPO-Organ Procurement Organization in the USA) play critical rules in managing and procuring the organs. Kong, Schaefer, Hunsaker, and Roberts (2010) utilized a branch-and-price approach aiming at the maximization of the efficiency of the liver allocation systems in the USA. The study benefits from clinical data for computational experiments. Belien et al. (2013) proposed an MILP model for defining the optimal location of transplant centers that minimizes the total weighted time as the objective function. They took five different organs (i.e., kidney, liver, lung, heart and pancreas) into consideration and linked them by a budget constraint. The model is then been applied to Belgium as a case study. Furthermore, Belien, De Boeck, Colpaert, Devesse, & Van den Bossche, 2011 also considered optimal locations of shipping agents solved with limited numbers of potential locations. A numerical example was obtained from real data in Belgium.

In this paper, we develop a generalized network model for an organ transplant supply chain considering perishability and differentiation of the organs to identify the optimal locations of centers and allocation of each facility to another. The high degree of inherent uncertainty of some parameters of such a problem has led to consider the imprecision of input parameters in the model formulation. Thus, a novel robust possibilistic programming approach is developed to cope with uncertainty in determination of the optimal location of each facility.

Although location–allocation under uncertain environment is not a novel content (e.g., Wen & Iwamura, 2008; Wen & Kang, 2011), but to the best of our knowledge, applying it to the organ transplant supply chain has not been focused yet. The main contribution of this paper consists of considering recipient regions as another component of the supply chain. Fluctuation and differences in demands have led to consider a multi-period model, in which in each period, the interaction between each facility can be determined. In addition, another aspect of the proposed model is to determine location–allocation of each mentioned center under uncertainty via a novel robust possibilistic programming approach. To provide more responsiveness and encounter the total costs, facility integration for some specific centers is also applied.

The rest of the paper is organized as follows. Section 2 represents problem definition and mathematical formulation. In Section 3, the proposed solution methodology is provided. An application of the model is given in Section 4. Finally, Section 5 is dedicated to conclusion and future research.

2. Problem definition and mathematical formulation

Fig. 1 shows the schematic view of a generalized organ transplant supply chain network and the interactions between facilities. As soon as a donor get volunteer for donating an organ (1), the shipping team will be sent to the donor hospital (2) to transport the needful information with the donor's blood sample to the TC for testing the blood and the required analyses (3). Then, the transporters will return to the hospital (4). The arrows for these processes are demonstrated as dashed arrows to indicate that they are the information flows. In case of the operation, removal process in the hospital will be occurred and the organ will be sent to the TC for transplantation (see arcs No. 5 and 5′). In the meanwhile, the accepted recipient is notified and has to get present at the TC as soon as possible for the operation (6).

As an international organ supply chain, both domestic and foreign surgical operations have been taken into consideration with a little difference. In case of a foreign recipient or donator, the organ should be delivered to the airport to arrive at the TC for the operation (see arc No. 5′ in Fig. 1). As mentioned before, TCs are in charge of registration, blood sampling and transplantation of the recipients. The brain-death patients or donors directly refer to hospital for donation. However, some TCs can provide the same services as hospitals. In that case, integration of some hospitals to some transplant facilities seems to be quite applicable.

In this section, a multi-period location–allocation model is proposed, in which location and assignment decisions for each period have been taken into consideration with the aim of minimizing the total cost.

The sets, variables and parameters used to formulate the proposed problem are presented below. Noteworthy, imprecise parameters are differentiated from the crisp ones with a tilde on.

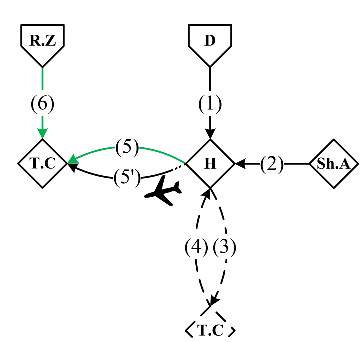

Fig. 1. Organ transplant supply chain network.