Applied Mathematical Modelling 39 (2015) 7680–7696

Contents lists available at ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

Blood collection management: Methodology and application

B. Zahiri [a], S.A. Torabi [a,*], M. Mousazadeh [a], S.A. Mansouri [b]

[a] School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran
[b] Brunel Business School, Brunel University London, UK

ARTICLE INFO

Article history:
Received 10 September 2013
Received in revised form 6 April 2015
Accepted 17 April 2015
Available online 24 May 2015

Keywords:
Blood supply chain
Healthcare
Location–allocation
Robust possibilistic programming

ABSTRACT

Blood supply chains play a key role in the healthcare systems. Any improvement in the management of these chains will have a direct impact on the supply of blood as a life-saving product. This paper presents a mixed integer linear programming model to make strategic as well as tactical decisions in a blood collection system over a multi-period planning horizon. A robust possibilistic programming approach is applied to cope with the inherent epistemic uncertainty of the model's parameters. Several numerical examples are solved to demonstrate the robustness of solutions and to provide managerial insights. Finally, the applicability of the proposed model is demonstrated using a real case study in Iran.

1. Introduction

Supply chain management (SCM) deals with the process of planning, implementing and controlling the operations of a supply chain in an efficient way [1]. Supply chain network design (SCND) is one of the strategic decisions in SCM, which plays a critical role in the performance of supply chains. In general, SCND involves determining the optimal numbers, locations, and capacities of the required facilities and the aggregated material flows among them over a long and multi-period planning horizon [2]. SCND is a relevant problem for many sectors such as healthcare [3–8], energy [9–14], waste management [15–18], and humanitarian logistics [19–21].

An optimal blood collection and distribution network could be configured through mathematical formulation in order to optimize the blood supply chain network design (BSCND) problem. In such supply chains, both shortage and surplus of the product should be regulated. If demand of blood is not met, lives may be lost [22]. According to the American Red Cross (ARC), approximately 28.9% of hospitals reported the postponement of surgery in the United States for one or more days due to blood shortages in 2007, which approximately affected 412 patients [23]. Using operational research (OR) methodologies can significantly improve the efficiency and effectiveness of blood supply chains.

Improving blood supply chains has significant importance for countries such as Iran that are prone to natural disasters. Fig. 1 illustrates the current blood supply network in Iran, which is similar to the network presented by Nagurney et al. [24]. The network includes seven echelons starting from regional donors as the first echelon through to the demand points such as hospitals and clinics as the last echelon. In more details, the top level (i.e. supply nodes) represents regional donors and the connecting links to the next echelon denote the supply/donation. The second and third echelons of the network consist of mobile/temporary centers and main facilities, respectively. Donors can visit either mobile/temporary centers or the main

* Corresponding author.
E-mail addresses: b.zahiri@ut.ac.ir (B. Zahiri), satorabi@ut.ac.ir (S.A. Torabi), mousazadeh@ut.ac.ir (M. Mousazadeh), afshin.mansouri@brunel.ac.uk (S.A. Mansouri).

http://dx.doi.org/10.1016/j.apm.2015.04.028
0307-904X/

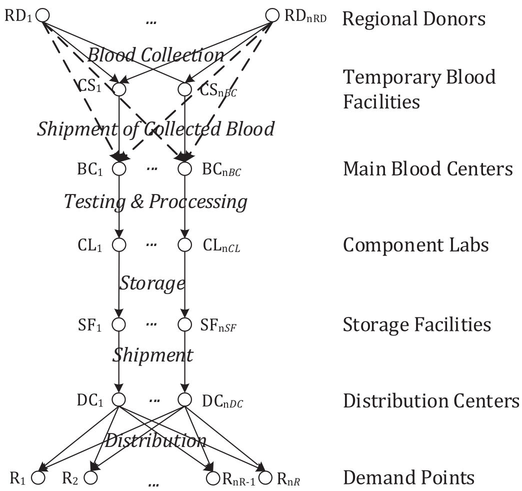

Fig. 1. Regionalized blood supply network in Iran.

centers for donation. The collected bloods in mobile/temporary centers are then shipped to the main centers at the end of each period. Temporary centers facilitate the donation by reducing the distance traveled by donors, but have limited capacities. The main blood centers have more capacity, benefit from higher technology and are responsible to meet the total demand in each period. The connecting links between the first three echelons of the network represent the "shipment of collected blood". The next echelons include the component/processing labs, storage facilities, distribution centers and finally hospitals as end users. The links between successive echelons represent shipments [24]. As can be seen in Fig. 1, donors can also donate blood to the main centers (dashed arrows), which is not the case in the network presented in Nagurney et al. [24].

Optimizing all echelons of the above network through a single mathematical model is extremely difficult or even impossible in some cases. On the other hand, this network can be logically split into two sub-networks: (i) echelons 1 to echelon 4 that deal with the collection and (ii) echelons 4 to echelon 7 that are responsible for the distribution. Notably, echelon 4 plays a mediatory role between the two sub-networks and could be included in either part. In this paper, we address the decisions regarding the first three echelons (i.e. those involved in the collection process). This includes strategic decisions regarding the location of mobile/temporary centers in each period and the fixed location of main blood centers. In the tactical level, we address the allocation of regional donors to open centers in each period and the amount of flow between each pair of nodes in each period.

In our problem setting, it is assumed that some critical input data such as quantities of donations and demands are tainted with the epistemic uncertainty (i.e. lack of knowledge in estimating precise values). Accounting for the epistemic uncertainty of main parameters leads to the robustness of the final solution as well. This is of particular importance for decisions about the locations of main and temporary centers which cannot be changed easily during the planning horizon.

Noteworthy, in most of real situations, there might be not enough historical data to model uncertain parameters as random data. Practically, reasonable estimations for such imprecise parameters are often provided according to the experts' judgmental data. Naturally, these judgmental data are mainly based upon the experts' experiences, and their professional opinions and feelings. Accordingly, these parameters could be formulated through the possibility theory as a complement to the probability theory. In this way, a suitable possibility distribution could be adopted for each possibilistic data typically in the form of triangular or trapezoidal fuzzy numbers. Possibilistic programming approaches are applied to solve the optimization problems involving such imprecise data.

In this paper, we apply a recently developed robust possibilistic programming approach to cope with the epistemic uncertainty in the demand and supply data. In this way, we benefit from both fuzzy and robust programming approaches within a unified uncertainty programming framework. More details about the epistemic uncertainty and the adopted robust possibilistic programming approach have been provided in Section 3.2.

The remainder of this paper is organized as follows: Section 2 presents a comprehensive review of the literature. The proposed model and its mathematical formulation are developed in Section 3. In Section 4, the model and the solution technique are applied to a real case. Finally, future research directions are highlighted in Section 5.

2. Literature review

The extant body of literature on blood supply chains as an important topic in healthcare management is quite limited. In this section, we first review the relevant literature including the location–allocation, set covering and maximal set covering