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Dynamic supply chain network design for the supply of blood in disasters: A robust model with real world application

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ABSTRACT

This paper presents a robust network design model for the supply of blood during and after disasters. A practical optimization model is developed that can assist in blood facility location and allocation decisions for multiple post-disaster periods. The application of the proposed model is investigated in a case problem where real data is utilized to design a network for emergency supply of blood during potential disasters. Our analysis on the tradeoff between solution robustness and model robustness arrives at important practical insights. The performance of the proposed 'robust optimization' approach is also compared with that of an 'expected value' approach.

1. Introduction

Typical supply chain network design decisions involve determining optimal location and capacity of facilities to satisfy the market demand at the lowest cost (Esmaeilikia et al., in press). Static network design models assume that the location and capacity of established facilities would remain unchanged during the planning horizon regardless of variations in input parameters. In contrast, dynamic models aim to consider adjustments in location and capacity of facilities to address potential demand fluctuations and variations in key input parameters. The planning horizon in a dynamic network design is divided into several time periods and location and capacity decisions are made periodically (Melo et al., 2009).

Dynamic supply chain network design is essential for emergency logistics planning in disasters (Sheu, 2010). A 'disaster' is referred to as an event that causes damage, destruction, loss of human life, human suffering and/or deterioration of health and health service in a supply chain (Najafi et al., 2013). Such events may include natural disasters (e.g. earthquakes and floods), epidemics or man-made disruptions (e.g. wars and terrorist attacks) (Jabbarzadeh et al., 2012). One common type of problem in this context is planning for the supply of blood during and after disasters when a sudden boost in blood demand occurs (Schultz et al., 1996; Hess and Thomas, 2003).

Recent disasters have shown how external disruptions can affect the supply of blood and the effective operation of blood services. For instance, the Great East Japan Earthquake in 2011 and the subsequent tsunami disrupted the blood supply on

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the Pacific coast of Tohoku (Nollet et al., 2013). Likewise, the deadly 2008 Sichuan earthquake resulted in several quality and wastage concerns facing the Chinese blood management system (Sha and Huang, 2012). National Blood Transfusion Service in Sri Lanka had difficulty coordinating its blood supply chain after 2004 tsunami to avoid the excessive blood collection from an influx of blood donors (Kuruppu, 2010). In another example, due to ineffective blood supply chain design and planning, from 108,985 donated blood units in devastating Bam earthquake in Iran in 2003, only 21,347 units (about 23%) were actually supplied to the affected residents (Abolghasemi et al., 2008).

These examples highlight the need for innovative design and planning of blood supply chains that can function effectively during and after disasters. The design of a blood supply chain that is robust to such disruptions is highly complex due to the unique characteristics of the network including blood demand's dependency on multiple externalities such as disaster severity (Nagurney et al., 2012; Pierskalla, 2004; Sheu, 2007). While blood shortage during disasters can have various consequences such as increased mortality rate (Beliën and Forcé, 2012), the appropriate preparation for effective blood supply may also incur substantial costs to locate a number of blood facilities only in case a disaster occur. The dynamic nature of blood demand (demand variations during different phases of a disaster) may add to this complexity. Demand during the first 24 h of an earthquake occurrence is typically higher than demand in the next day or so (Tabatabaie et al., 2010). Other concerns for the design of blood supply chain networks are the restrictions on the storage and transportation of blood products. For example, blood products have specific expiration dates and must be stored in an appropriate storage temperature range (Delen et al., 2011). This increases the risk of blood wastage in the aftermath of disasters when blood collection facilities face a huge influx of donation within the early days of disaster (Kuruppu, 2010).

Motivated by a blood supply chain design problem facing Iranian Blood Transfusion Organization (IBTO), this paper develops a robust stochastic optimization model that aims to address the aforementioned concerns. The proposed model consists of blood donors, blood facilities and blood centers and aims to determine the number and location of blood facilities (both permanent and temporary facilities), the service areas of blood facilities, the required blood collection at each facility, and inventory levels of blood at the end of each period. The objective is to minimize the total cost of the network (the combined costs of locating blood facilities, transportation and holding), while ensuring that the network is robust to major disasters (i.e. how best to coordinate supply and demand during and after disasters). The uncertain and dynamic nature of blood demand is explicitly addressed in the proposed model. While incorporating a realistic range of assumptions, variables and constraints, our model is yet simple to implement enabling a decision maker to explore for optimal location/allocation decisions without the need to develop and run complex optimization algorithms.

The remainder of the paper is organized as follows. Section 2 briefly reviews the relevant literature. Section 3 provides a background of robust optimization formulation. The robust supply chain network design model for blood products is presented in Section 4. The application of the proposed model in a real world context is presented in Section 5 including the practical and managerial insights obtained from the numerical results. Concluding remarks and directions for further research in the area are presented in Section 6.

2. Review of the existing literature

Since the pioneering work of Ballou (1968), dynamic facility location problems have been extensively studied in various disciplines. Nevertheless, in the supply chain context, the literature of dynamic network analysis is relatively scarce (see for example the comprehensive review of Arabani and Farahani (2012)). Here, we refer to some of the more recent and related articles in this area. Hinojosa et al. (2000) study a multi-period two-echelon multi-commodity location problem, demand, transportation costs and capacities of plants and warehouses vary from one period to another. A mixed integer programming model is presented that aims to minimize the total cost of demand fulfillment at different customer locations. More recently, Correia et al. (2013) investigated the design of a two-echelon multi-period supply chain seeking optimal location of new facilities in the upper and intermediate echelons and storage areas holding different product families. None of these studies incorporate inventory considerations.

Melo et al. (2005) present a mathematical modeling framework that captures many practical aspects of network design problems including inventory management issues, dynamic planning horizon, and distribution and storage limitations. Hinojosa et al. (2008) develop a model for a dynamic two-echelon multi-commodity capacitated plant location problem with inventory and outsourcing aspects dealing with many practical network configuration issues. Both models operate in an environment with deterministic demand and cost parameters.

Despite the rigorous modeling efforts and demonstrated applications of dynamic facility location modeling, investigating the design of blood supply chains intending the emergency supply of blood products in disasters has been a rare occurrence. A recent review of the literature of supply chain management for blood products by Beliën and Forcé (2012) shows that scanty literature exists on the strategic facility location decisions, especially with a focus on dynamic network analysis. Pierskalla (2004) proposes an overview of models for allocating donor areas and transfusion centers to community blood centers, determining the number of community blood centers in a region, locating these centers, and matching supply and demand. The study also reviews tactical and operational models focusing on blood collection, inventory management, assignment to hospitals and final delivery.

Daskin et al. (2002) and Shen et al. (2003) present nonlinear integer programming models for a single-period joint location-inventory problem of supplying blood to hospitals. They develop an integrated approach to determine the number and