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An integer programming approach to the bloodmobile routing problem

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ABSTRACT

Every day, a blood center must determine a set of locations among a group of potential sites to route their vehicles for blood collection so as to avoid shortfalls. In this study, a vehicle routing problem is modeled using an integer programming approach to simultaneously identify number of bloodmobiles to operate and minimize the distance travelled. Additionally, the model is extended to incorporate uncertainty in blood potentials and variable durations in bloodmobile visits. Optimal routings are determined using CPLEX solver and branch-and-price algorithm. Results show that proposed algorithm solve the problem to optimality up to 30 locations within 3600 s.

1. Introduction

Every year, blood donations collected for transfusions or for manufacturing processes of biopharmaceutical medications save millions of lives (American Cancer Society). In the United States, blood is mostly donated on a voluntary basis although most plasmapheresis donations come from paid donors (United States General Accouting Office). The general process for blood donation (as shown in Fig. 1) starts when an individual visits a blood center or an off-site (bloodmobile) location. If via bloodmobile, where about 80% of all donations are made (American Red Cross), units collected are then delivered to a blood center. At the center, units are processed and separated into components and eventually delivered to a hospital or clinic upon demand. Given that no alternative for human blood has been approved by the US Federal Drug Administration (FDA) (American Cancer Society) it is critical to have a seamless process to collect and store this scarce resource.

Whole blood, as extracted from the vein, could be mechanically separated into multiple components. Alternatively, an apheresis device may be used to separate and store the desired components (e.g. plasma or platelet) and to return the rest of the blood components to the donor. The typical whole blood donation amount in the U.S. is approximately 450 ml (American Cancer Society) which can save up to three lives (American Red Cross). Donations are classified based on the recipient of the donor's blood (Brecher and Bethesda, 2005). There are four main types of donations: allogeneic, directed, replacement, and autologous donations. In allogeneic (or homologous) donation, blood is donated for transfusion to an unknown individual. When the recipient of blood is known, a directed donation is made (Mayo Clinic). This type of donation is not practical when blood inventory is piled up and established. A hybrid of the allogeneic and the directed type is known as replacement donation which is common in developing countries (Brown, 1998). This type of donated blood is used to replace

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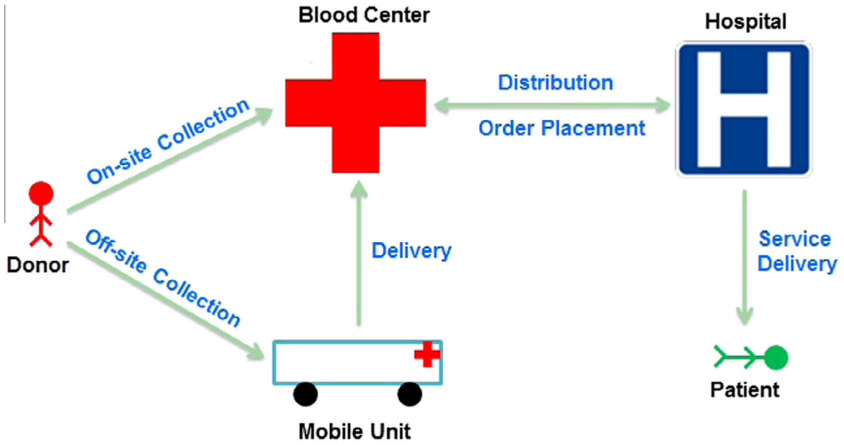

Fig. 1. Blood collection to transfusion process.

a stored blood unit transfused to a family member or a friend. Finally, in an autologous donation, a person donates his or her own blood to be stored until it is transfused back to the donor at a later date (AABB).

All blood products are highly perishable ranging from 5 days (for platelets) to 42 days (for red blood cells). Thus, it is crucial for a blood center to sustain reasonable inventory levels that guarantee meeting the demands for the procedures scheduled and having a buffer for unanticipated medical activities. For the off-site/remote locations, which are the focus of this work, this translate to the challenge of: (1) determining the right number of bloodmobiles to operate every day; and (2) strategically deploying bloodmobiles to various location to collect enough units while minimizing the distance travelled. Given that each bloodmobile represents an investment of $250,000 which includes a fully equipped vehicle that complies with government standards (San Diego Blood Bank), logging the minimum amount of mileage will delay depreciation and increase lifetime of the vehicles. Moreover, deploying the minimum necessary number of bloodmobiles to operate daily (as no all available fleet might be necessary to operate to fulfill the estimated blood demand) will reduce fixed costs.

The remainder of the paper is organized as follows. In Section 2, relevant literature is discussed. The model formulation and solution method are explained in Section 3. Numerical results of the models are discussed in Section 4. Concluding remarks and opportunities for extensions to this work are presented in Section 5.

2. Literature review

This section focuses on the research related to the challenges associated with the supply and demand problems of blood products, blood collection, and related vehicle routing problems (VRPs).

2.1. Supply chain problem of blood products

Supply chain management of blood products was initiated by van Zyl (1964) in 1960s, in a dissertation related to perishable products. Since then, a limited number of publications has become available but the field caught more attention in recent years. In the early 1980s, Nahmias (1982) studied the inventory ordering policies for perishables including blood bank management. Additionally, Prastacos (1984) reported a review paper on the theory and practice of blood inventory management.

A wide range of solution methods have been implemented to improve the supply chain problems of blood products. The most commonly used techniques include: integer programming (Hemmelmayr et al., 2010; Jacobs et al., 1996; Nagurney et al., 2012; Sahin et al., 2007; Sapountzis, 1984), simulation methodology (Alfonso et al., 2012; Kamp et al., 2010; Katsaliaki and Brailsford, 2007; Katsaliaki, 2008; Kopach et al., 2008; Madden et al., 2007; Mustafee et al., 2009; Pereira, 2005; Rytila and Spens, 2006; van Dijk et al., 2009), mathematical proofs (Jagannathan and Sen, 1991; Kaspi and Perry, 1983; Pierskalla and Roach, 1972; Prastacos, 1978) and dynamic programming (Blake, 2009; van Dijk et al., 2009). Published research could also be classified based on the applications which generally include individual hospitals (Blake, 2009; Carden and DelliFraine, 2005; Delen et al., 2011; Erickson et al., 2008; Haijema et al., 2009; Heddle et al., 2009; Katsaliaki, 2008; Mustafee et al., 2009; Novis et al., 2002; Pereira, 2005; Perera et al., 2009; van Dijk et al., 2009) or regional blood centers (Bosnes et al., 2005; Carden and DelliFraine, 2005; Custer et al., 2005; Davis et al., 2009; Delen et al., 2011; Denesiuk et al., 2006; Glynn et al., 2003; Haijema et al., 2007; Hemmelmayr et al., 2010; Katsaliaki, 2008; Kendall and Lee, 1980; Kopach et al., 2008; Mustafee et al., 2009; Nagurney et al., 2012; Sahin et al., 2007; van Dijk et al., 2009).

Some of the most relevant work associated with our study include: Haijema et al. (2007) which applied Markov dynamic programming and simulation to a real life case of a Dutch blood bank. Their paper focused on the production and inventory