



Robust optimization model for integrated procurement, production and distribution in platelet supply chain



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ABSTRACT

This paper presents an integrated platelet supply chain where demand is age-differentiated according to the type of patient. At first, considering the apheresis method and traditional production platelet method, two mixed-integer programming models are developed based on FIFO and LIFO issuing policies. Since in practice fresh platelets have been preferred, a bi-objective model has been then developed in which the first objective maximizes the freshness of the units delivered and the second minimizes the total cost. To cope with uncertain demand, a robust optimization approach is presented and the application of the proposed model is discussed in a case study.

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1. Introduction

Blood platelets, as a volunteer-based product derived from human blood, are very valuable, with an extremely short lifespan typically of 5–7 days. Platelet transfusions are often required for patients with a low platelet count or those having problems with platelet performance. Platelet transfusions are primarily carried out for patients diagnosed with cancer that are receiving chemotherapy, those receiving bone marrow transplants and those who take medications that interfere with platelet function. Platelet transfusions are also required by patients who have had open-heart surgery (Stroncek and Rebull, 2007). The platelet supply chain includes collection of both whole blood and platelets from donors and the testing, production and distribution of platelets to clinical points.

The primary challenges to inventory control of platelets relate to outdated products and shortages which arise from uncertain demand and a limited shelf life. World Health Organization (WHO) data indicates that 87.5% of developing countries collect less than half of the blood needed to meet their transfusion requirements (Hall, 2010) while the percentage of blood wastage in 2012, 2013 and 2014 were 30.1%, 26.4% and 23.4%, respectively (Kurup et al., 2016).

Medical specialists transfuse platelets into patients as part of scheduled medical therapy or a surgery and also in emergencies. This means that accessibility to the right amount of platelets is critical, because if there is not enough stock, treatments may have to be cancelled, which could result in fatalities. The specifications of platelets and complexity of its supply chain necessitate developing a methodology and a close relationship between all stages of the blood supply chain, including collection, processing and distribution. The platelet supply chain network often includes blood stations, regional blood centers and hospitals as shown in Fig. 1.

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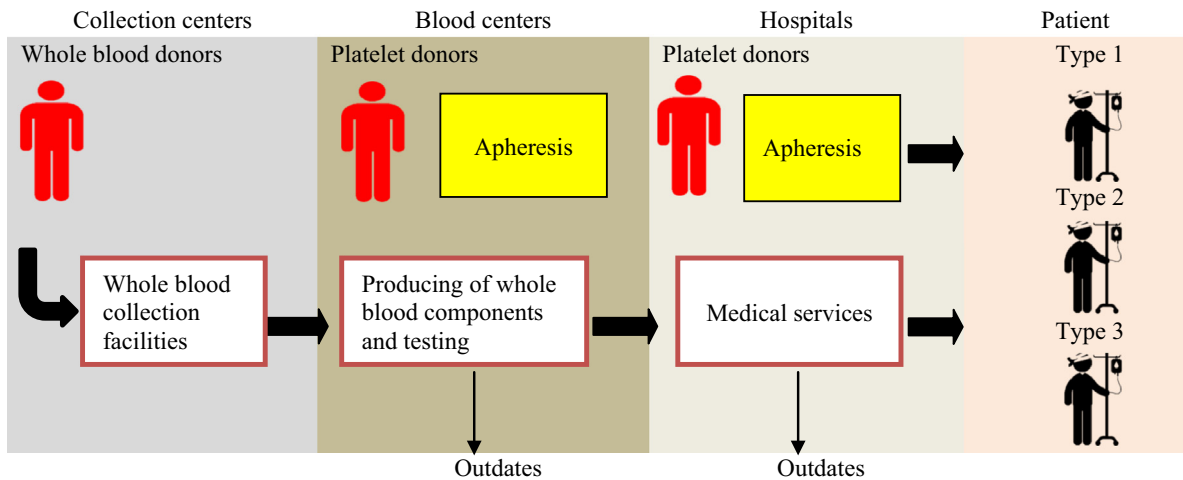


Fig. 1. Platelet supply chain.

Platelets are drawn either from whole blood or through apheresis, which is the withdrawal of blood from a donor's body, separation of one or more components from the blood and transfusion of the remaining blood back into the donor (Simon, 1994).

Veihola et al. (2006) found that 73% of all platelets were produced by the buffy coat method, 23% by apheresis and 4% by the platelet-rich plasma method. Fewer donors are needed with apheresis to obtain the same amount of platelets obtained by the traditional method (the number of platelets taken from one apheresis donation is six to eight times more than that of whole blood donations). Although apheresis platelets are preferable to whole blood platelets, the main problem of apheresis is the high expense of the kits used for collection (Schrezenmeier and Seifried, 2010). In addition, the donation time is much longer than that of the whole blood donation, so many donors are unwilling to agree to this donation procedure (Charbonneau et al., 2016).

According to Jacobs et al. (2011) the third leading cause of transfusion-related fatalities between 2005 and 2009 was bacterial infection. Two days are required to process, produce and test whole blood platelets at a blood center. This interval provides time for bacterial contamination, which can adversely affect the transfusion outcome. The storage time of platelet products negatively affects platelet function, therefore fresh platelets are superior to old platelets for therapeutic use (Caram-Deelder et al., 2016; Jerad and Prane, 1997; Muylle et al., 1992).

Because fresh units are highly preferred, in the current study a practical methodology is developed to model the integrated platelet supply chain with stochastic age-differentiated demand to increase the freshness of the units delivered and their quality and safety.

Furthermore, Platelet demand can be classified by type of patient. For the first type of patients, mainly the ones receiving bone marrow or organ transplants fresh platelets are used. It is preferable to provide the required dose to such patients from an apheresis donor (Champlin et al., 2000). The second type is primarily oncology and hematology cases for which young platelets are preferable. The third type can benefit from platelets of all ages up to the maximum shelf life. Table 1 defines fresh, young and old platelets and shows their related usage. To improve the efficiency and practicality of the platelet supply chain, three types of patients and hospitals have been considered. The primary purpose of this study was to optimize all of the platelet supply chain stages, to improve the use of voluntary donations and increase the quality of service at medical points according to the type of patient and the age of the platelets.

The remainder of the paper is organized as follows: Section 2 reviews related literature. Section 3 presents the integrated models for a platelet supply chain. Section 4 provides the background of revised goal programming and robust optimization and develops a robust integrated platelet supply chain. The practicality of the proposed models in the real world context and managerial insights obtained from the computational results are presented in Section 5. Section 6 evaluates the optimality of the robust optimization by numerical testing. Section 7 presents the final remarks and future research opportunities.

Table 1
Age of platelets and related usage.

| Type of demand | Age | Case of usage |
|----------------|--------------|---|
| Fresh | 1 day old | Bone marrow transplants (Muylle et al., 1992) |
| Young | 2–3 days old | Oncology and hematology (Haijema et al., 2007) |
| Old | 4–6 days old | Traumatology and general surgery (Haijema et al., 2007) |

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