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Coordinating collection and appointment scheduling operations at the blood donation sites ☆

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ABSTRACT

According to the regulations imposed by the U.S. Food and Drug Administration and the American Association of Blood Banks, in order to extract platelets, donated blood units have to be processed at a processing center within six hours of donation time. In this paper, considering this processing time requirement of donated blood units for platelet production we study collection and appointment scheduling operations at the blood donation sites. Specifically, given the blood donation network of a blood collection organization, we try to coordinate pickup and appointment schedules at the blood donation sites to maximize platelet production. We call the problem under consideration *Integrated Collection and Appointment Scheduling Problem*. We first provide a mixed integer linear programming model for the problem. Then, we propose a heuristic algorithm called *Integer Programming Based Algorithm*. We perform a computational study to test the performance of the proposed model and algorithm in terms of solution quality and computational efficiency on the instances from Gulf Coast Regional Blood Center located in Houston, TX.

1. Introduction

Blood is one of the vital products needed for medical treatments including cancer treatment, orthopedic and cardiovascular surgeries, organ and marrow transplants and blood disorder treatments. In the U.S., every two seconds a patient needs blood or blood products, and more than 41,000 blood donations are needed daily to satisfy the demand (American Red Cross, 2014a). In many countries, people still die because of inadequate supply of blood products (World Health Organization, 2014).

According to the eligibility rules established by the U.S. Food and Drug Administration (FDA), around 38% of the population is eligible for blood donation in the U.S., but only 3% of the population donates blood in a year. Hence, managing this limited blood supply efficiently is as crucial as promoting blood donation.

When a donor donates blood at a donation site, this donated blood (also called *whole blood*) is separated into its components by *centrifugation* (American Red Cross, 2014a). The three main blood products used in transfusion are red blood cells, platelets and plasma. Plasma is used for burn and trauma patients. Red blood cells are needed for any patient requiring transfusion. They are mainly used for anemia treatment, surgery, treatment of blood disorders and for premature babies. Finally, platelets are used to treat cancer patients, accident and malaria victims, asthma patients and others with blood clotting problems. Although all of these products have limited shelf-lives, platelets are the most critical one due to their short life-span (5–9 days).

In the U.S., FDA and the American Association of Blood Banks (AABB) regulate collection, processing and storage of blood and its components. According to these regulations, whole blood must be processed within 8 h of donation to extract platelets (Yi & Scheller-Wolf, 2003). Similar regulations are imposed in other countries such as Austria and Turkey as well (Doerner, Gronalt, Hartl, Kiechle, & Reimann, 2008; Turkish Ministry of Health, 2014). Platelet extraction is generally done at a central processing center. For example, all the blood collected by American Red Cross in Buffalo, NY is sent to Rochester, NY for processing, and then distributed to hospitals in Buffalo (American Red Cross, 2014b). Similarly, in Connecticut, the blood units picked up from donation sites are delivered to headquarters in Farmington (Yi & Scheller-Wolf, 2003). Hence, blood collection organizations have to schedule continuous pickups from the donation sites and deliver the collected blood units to the processing center for platelet production. Since processing takes around 2 h, any donated blood unit that stays at a donation site or in a collection vehicle more than 6 h

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prior to processing cannot be used for platelet production. However, those units can still be used for extracting other blood products. We call this 6-h requirement *processing time limit*.

Most of the blood collection organizations operate on an appointment based schedule in order to improve staff and equipment utilization (Gulf Coast Regional Blood Center, 2012). This also decreases donor waiting time which is important for future donations from the repeat donors. Furthermore, since the time of donations affects platelet production as well due to 6-h processing time limit, synchronizing the appointment and collection (pickup) schedules can improve the platelet supply. For example, assume that there is only one scheduled pickup from a donation site at 3 pm, and the collection vehicle returns back to the processing center by 6 pm. In this case, instead of randomly scheduling the appointments, it is better to schedule as many donations as possible between 12 pm and 3 pm in order to increase platelet production while considering the capacity (bed/staff/equipment) of the donation site.

In this paper, we analyze the collection and appointment schedules at the donation sites while considering the processing time limit on platelet production. More specifically, we study the problem of coordinating the pickup and appointment schedules in order to maximize platelet production. We call this problem *Integrated Collection and Appointment Scheduling Problem* (ICASP). In ICASP, we have multiple blood donation sites and a central processing center with pre-specified opening and closing times. Donation sites have capacities which limit the number of donations that can be performed at the same time. We have a fleet of vehicles to collect the donated blood units from the donation sites. Using the estimated number of donors scheduling an appointment at each donation site daily, we try to determine the pickup and appointment schedules simultaneously for an improved platelet supply.

In ICASP, we assume that the donation sites are partitioned into clusters where each vehicle is assigned to a single cluster and the donation sites in a cluster are visited by the same vehicle. This clustering assumption is more practical and used in real world applications since it eliminates the need for coordinating the visits by different vehicles to the same donation site. We first develop a mixed integer nonlinear programming formulation for ICASP and linearize it. Then, we propose a heuristic algorithm, called *Integer Programming Based Algorithm* (IPBA), to find a "good" solution. In IPBA, we first cluster the donation sites using a variant of the well-known *k*-means clustering algorithm (MacQueen, 1967), and then determine the collection and appointment schedules for each cluster.

Our main contribution in this paper is to develop solution approaches for synchronizing the appointment and collection schedules in blood supply chain in order to improve platelet availability which has not been studied in the literature before. Considering the importance of platelets in medical procedures, the results of this study are expected to have a significant societal impact.

The remainder of the paper is organized as follows. In Section 2, we provide a review of the related work in the literature. We present the formal problem definition in Section 3. We also provide a simple example to illustrate the benefit of coordinated collection and appointment scheduling. We present a mixed integer programming formulation for ICASP in Section 4. In Section 5, we discuss the heuristic algorithm proposed for solving ICASP. To compare the performances of the proposed mathematical model and the heuristic algorithm, we conduct a computational study using the instances generated from Gulf Coast Regional Blood Center's data (Gulf Coast Regional Blood Center, 2012). The results of the computational experiments are presented in Section 6. We conclude the paper in Section 7.

2. Literature review

ICASP is related to the well-known *Vehicle Routing Problem* (VRP). VRP is extensively studied by several authors since the early work by Dantzig and Ramser (1959). We refer the reader to Toth and Vigo (2002) for a survey of exact algorithms and to Cordeau, Gendreau, Laporte, Potvin, and Semet (2002) for a survey of heuristic algorithms proposed for VRP. Finally, Golden, Raghavan, and Wasil (2008) discuss the latest advances and new challenges in VRP. The main differences between VRP and ICASP are the processing time limit for platelet production and the accumulating behavior of the blood donations. Because of these differences, some donation sites can be visited more than once to increase platelet production. Finally, in ICASP the objective is to maximize platelet production whereas the objective in a typical VRP is minimizing the total transportation cost.

Among the variants of VRP, the most related problem to ICASP is the milk collection problem (Sankaran & Ubgade, 1994). Sankaran and Ubgade (1994) study the transportation of milk from milk collection centers to the dairy with the objective of minimizing the transportation cost. Similar to ICASP, there is a limit on the time that milk can spend in a collection vehicle. However, in milk collection problem milk is assumed to be available for pickup at the collection centers early in the day. Hence, the way time limit affects the vehicle routes, the availability of products at the beginning and the objective are the main differences between ICASP and the milk collection problem.

Collection of donated blood units from donation sites is first discussed by Prastacos (1984), but he does not consider the processing time limit. The most related studies in the literature are the ones by Doerner et al. (2008), Ghandforoush and Sen (2010), and Yi and Scheller-Wolf (2003). Although the processing time limit is considered in all these studies and multiple visits to donation sites are allowed in Doerner et al. (2008) and Ghandforoush and Sen (2010), they all ignore the appointment scheduling aspect and assume that the donation times are predetermined.

Ghandforoush and Sen (2010) develop a decision support system to manage platelet production for the units that are donated at mobile blood drives. They assume that shuttles (collection vehicles) make round trips between the blood drives and the processing center. The amount that can be picked up from a blood drive per visit is bounded from above and below. The objective in their model is to minimize the total daily cost which includes production, transportation and yield loss (due to testing, delays in transportation, contamination, etc.) costs while satisfying the demand. The authors develop a non-convex integer programming model to determine the shuttle schedules. Then, they linearize it using linearization techniques (Glover, 1975). They only consider round trips and do not allow visiting more than one blood drive per route. Moreover, they assume that a constant amount is picked up from a blood drive in each visit.

Doerner et al. (2008) also study a related problem where the donations are assumed to be uniformly distributed over the operating hours of a donation site. Their objective is to collect all the donated units for platelet production with minimum transportation cost. They propose a mixed integer programming formulation, an exact method and several constructive heuristic approaches to solve the problem. In both exact and heuristic approaches, the number of pickups from each donation site is fixed at the beginning. The main shortcoming of the study by Doerner et al. (2008) is that even a single donated unit has to be collected. However, in practice not all of the donated units are used for platelet production. Furthermore, they do not consider the availability of the collection vehicles.