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Managing platelet supply through improved routing of blood collection vehicles

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ABSTRACT

In this paper, we study the routing of blood collection vehicles for improving the platelet supply in the blood supply chain. In order to extract platelets, donated blood has to be processed at a central processing facility within six hours of donation time. Blood collection organizations have to dispatch collection vehicles and schedule pickups from the donation sites so that the donated units can be used in platelet production. Because of the accumulating behavior of donations and the six-hour processing time limit, routing of blood collection vehicles is a time-sensitive routing problem. We analyze the routing decisions in such a setting and propose an integrated clustering and routing framework to collect and process the maximum number of donations for platelet production. In our analysis, motivated by the practices in real-life, we cluster the donation sites so that only a single vehicle serves the donation sites in each cluster. In the proposed framework, we make the clustering and routing decisions in an integrated manner so that we can foresee the impact of adding a donation site to a cluster on the routing decisions. For the routing step, we propose several heuristic algorithms, two of which have a greedy nature and the others are based on a priori tour generation and selection scheme. To evaluate the performances of the proposed heuristics, we develop an upper bound by relaxing the number of vehicles so that one vehicle is available for each donation site. Using the proposed heuristic algorithms, we obtain solutions with around 15% optimality gaps with respect to the upper bound.

1. Introduction

Blood is needed for several types of treatments including organ transplants, cancer and anemia treatments, and major surgeries such as open heart surgery. Every year, around 5 million patients in the U.S. receive blood or blood products such as red blood cells, platelets or plasma via blood transfusions (American Red Cross, 2014a). Around 30 million units of blood products are used in blood transfusion each year (American Red Cross, 2014a), and the usage rate of blood products is expected to increase due to increase in human life expectancy and advances in the medical procedures that require blood transfusions (Davey, 2004).

Although there is a continuing research on blood substitutes, these attempts have not been successful yet. Therefore, the demand for blood and blood products is satisfied by the donation of eligible individuals. The most common type of blood donation is whole blood donation. After the blood is donated at a blood donation site, it is separated into components such as red blood cells, platelets and plasma by a process called *centrifugation*, and these products can be used to treat several medical conditions or diseases. Plasma is used for burn and trauma patients, and clotting disorders. Red blood cells are the most used component (more than 60% of units used are red blood cells (South Texas Blood & Tissue Center, 2014)), and needed for any patient requiring transfusion. They are mainly used for anemia treatment, surgery, treatment of blood disorders and for premature babies. Finally, platelets help control bleeding, and they are used in cancer treatments, organ transplants, and other surgeries to prevent massive blood loss.

Platelets have very short shelf life (5–7 days), and their inventory have to be managed efficiently due to high perishability and increasing demand mainly because of aging population and more aggressive cancer treatments (Civelek et al., 2015). Platelets can be either collected via platelet apheresis (Chaudhary et al., 2009; Ghandforoush and Sen, 2010) or extracted from donated whole blood. In addition to the platelets extracted from whole blood, hospitals and blood banks could call registered donors to donate platelets only since a donor donating platelets can donate more often than a whole blood donor. However, the main disadvantage of platelet apheresis is the special equipment required. Hence, in most of the donation sites whole blood donation is still the most

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common type of donation (Stanford Blood Center, 2017). In this study, we analyze the collection and routing operations for whole blood donations used in platelet production.

In the U.S., the collection, storage, and processing of blood and its components are regulated by the Food and Drug Administration (FDA) and the American Association of Blood Banks (AABB). According to these regulations, the collected whole blood must be separated into its components preferably within 6 h and not more than 18 h after collection in order to extract platelets. Similar regulations are imposed in other countries as well (Doerner et al., 2008; The Ministry of Health of Turkey, 2011). Therefore, the donated blood should be collected from the donation sites and delivered to a processing center within 6 h to be separated into its components. For example, all the blood collected by the American Red Cross in Buffalo, NY is sent to Rochester, NY for processing, and then distributed to the hospitals in Buffalo (American Red Cross, 2014b).

In this paper, motivated by the blood collection operations explained above, we study the routing of blood collection vehicles to improve platelet supply. First, we define the general *Blood Collection Problem* (BCP), and then discuss the variant we study in this paper. Based on the regulations imposed by the FDA, and the current setting of the blood donation sites and processing centers, the BCP is defined as routing a fleet of vehicles to collect the donated blood from the donation sites and deliver them to the processing center within 6 h of donation time for platelet extraction. The donations are assumed to occur continuously during the hours of operation, but may not follow a regular distribution/pattern. The novel part of this problem is that blood donated at a donation site has to be delivered to the processing center within a certain amount of time after the donation, and the blood donations accumulate over time, which forces the collection organizations to schedule more than one pickup from a donation site during a day. We explain how these aspects of the problem make it different from the classical routing problems with an example below.

In the literature, two variants of the BCP are studied. Doerner et al. (2008) minimize the total cost while collecting every blood donated for platelet production, whereas Yi and Scheller-Wolf (2003) seek a minimum cost solution while collecting a prespecified amount of blood from the donation sites. In this paper, we study a different variant of the BCP considering the availability of collection vehicles. Given a fleet of vehicles, we try to maximize the amount of blood collected and used for platelet production. This is more realistic not only because of the availability of collection vehicles but also due to the fact that not all of the donated units are used for platelet production in practice (Yi and Scheller-Wolf, 2003). Most importantly, different from Doerner et al. (2008) and Yi and Scheller-Wolf (2003) we assume an arbitrary donation pattern during the day instead of a uniform donation pattern, which is another challenging aspect of the setting under consideration. We call this variant of the BCP the *Maximum Blood Collection Problem* (MBCP). In the current practice, most of the donation sites are working on an appointment schedule (American Red Cross, 2014a; Blood Bank of Alaska, 2014; Gulf Coast Regional Blood Center, 2014; Stanford Blood Center, 2017) in order to plan and utilize their personnel effectively, reduce waste due to the outdated products and increase the donor satisfaction by reducing the waiting times. Hence, most blood donation organizations encourage scheduling appointments in advance and keep only limited (if any) slots for the walk-in donors (National Health Service Blood and Transplant, 2017; New Zealand Blood Service, 2017). Following this practice, in this study we assume that the donation times are known ahead. Based on this assumption, the MBCP can be defined as follows: Given a fleet of collection vehicles, a single processing center and a set of blood donation sites with known donation times and amount, our objective is to maximize the amount of donations collected from the donation sites and delivered to the processing center for platelet extraction within 6 h of donation time. We call this time limit the *Processing Time Limit*. Moreover, we assume that there is no capacity limitation on the vehicles due to the small size of the blood collection bags (Doerner et al., 2008; Yi and Scheller-Wolf, 2003). Finally, we assume that the donation sites are visited by the same vehicle/driver all the time. This assumption makes the solution more practical since a driver visits the same set of locations and knows the area/locations.

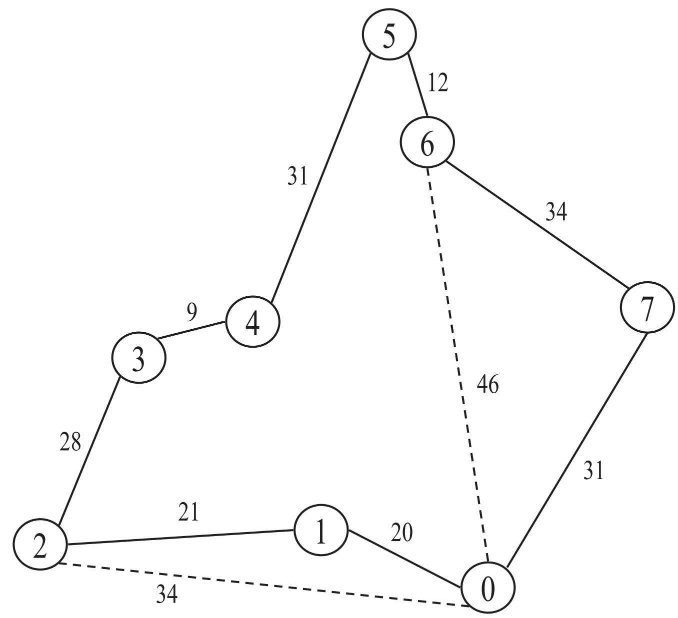

Fig. 1. An example illustrating the complexity of MBCP.

In order to better explain the complexity of the MBCP and the main differences between the MBCP and classical routing problems, we provide a real-life motivated example. In Fig. 1, we provide a graph showing some of the donation sites and the processing center operated by *Gulf Coast Regional Blood Center* in Houston, TX area. Node “0” represents the processing center and the remaining seven nodes are some of the donation sites operated by *Gulf Coast Regional Blood Center*. On each edge of the graph, we provide the travel time (in minutes) between the nodes incident to that edge.

All the donation sites operate between 10:00 and 18:00 during the day (Gulf Coast Regional Blood Center, 2014). The number of donations and their completion times for each donation site are provided in Table 1. To allow enough time (about an hour) for processing at the processing center, we have to deliver the donations to the processing center within 5 h of donation time.

We first consider a tour starting from the processing center at 14:30, visiting donation sites $1, 2, \ldots, 7$ in the same order and arriving at the processing center at 17:36 (note that the length of this tour is 186 min). In this tour, we collect and process 48 donations within 5 h of donation time. In such a tour, if we skip the last donation site, donation site 7, the arrival time at the processing center is 17:17, and the total number of donations collected and processed within 5 h of donation time increases to 62. When donation site 7 is skipped here, the total number of donations collected and processed decreases because of the donated units not collected from donation site 7. However, since the vehicle arrives early at the processing center, we can collect and process more from the other donation sites in this tour. For this specific example, the total number of donations collected and processed increases when donation