**Plasma donor Application**

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# Introduction

Applying optimization methods to healthcare management and logistics is a devel- oping research area with numerous studies. Specifically, facility location, staff rostering, patient allocation, and medical supply transportation are the main themes analysed. Optimization approaches have been developed for several healthcare related problems, ranging from the resource management in hospitals to the delivery of care services in a territory. However, optimization approaches can also improve other services in the health system that have been only marginally addressed, yet. One of them is the Blood Donation (BD) system, aiming at providing an adequate supply of blood to Transfusion Centres (TCs) and hospitals.

Blood is necessary for several treatments and surgeries, and still a limited resource. The need for blood is about ten million units per year in the USA, 2.1 in Italy and 2 in Turkey; moreover, people still die in some countries because of inadequate supply of blood products (World Health Organization 2014). Hence, BD plays a fundamental role in healthcare systems, aiming at guaranteeing an adequate blood availability to meet the demand and save lives. In Western countries, blood is usually collected from *donors*, i.e., unpaid individuals who give blood voluntarily. Blood is classified into groups (A and subgroups, B, 0 or AB) and based on the Rhesus factor (Rh+ or Rh-), and each donor should be correctly matched with the patient who receives his/her blood. Moreover, as it may transmit diseases, blood must be screened before utilization.

Generally, there are two types of donation: whole-blood donation, in which the whole blood is directly collected in a plastic bag, and *apheresis*, i.e., the donation of specific components in which a mechanical gathering unit decays the required blood parts.

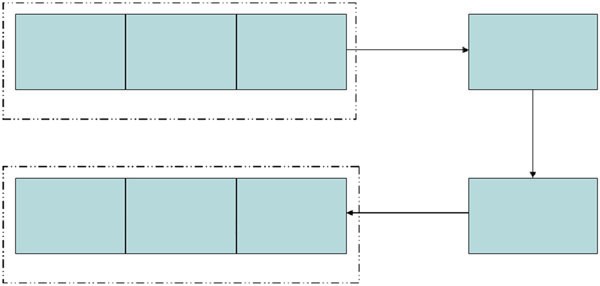
Blood requires particular precautions for collection and storage, and its shelf life from donation to utilization is limited, thus requiring a continuous feeding of the system (Greening et al. 2010). Hence, a successful BD supply chain should meet the daily demand of blood and follow its temporal pattern. According to Sundaram and Santhanam (2011), BD supply chain and the related management problems can be classified based on the main phases of a blood bag life: donor registration, blood collection, blood screening/evaluation, inventory storage and delivery. A slightly different classification is proposed in Pierskalla (2004), according to which the management of BD supply chain concerns both strategic decisions (e.g., location of blood centres) and tactical operational decisions (e.g., production of multiple products, control of inventory levels, blood allocation to hospitals, and delivery to multiple sites). In our review, we refer to the first classification scheme.

Many papers address the management of the BD supply chain (see Belien and

Forcé (2012) for a recent survey); however, there are still some open issues. The aim of this paper is reviewing the literature related to the BD system management and classifying the existing research based on the process phase, in order to highlight unexplored issues and to point out alternative perspectives and possible future research opportunities. In section “Phases of Blood Donation System” we give details about the BD system and survey the existing literature (review updated at December 2014); then in section “Discussion and Open Issues” we discuss the open issues and propose future research directions.

# Phases of Blood Donation System

BD supply chain can be divided into four main steps, as reported in Fig. 1: collection, transportation, storage and utilization. First, the blood is collected: donors are checked in blood centres to assess their eligibility and, if eligible, they make the donation. Once the blood is gathered, tests are independently performed on each individual’s blood in order to prevent infectious diseases (screening process). Afterwards, the blood is transported and stored. Components are then distributed to the hospitals based on their inventory needs. Finally, it is transferred to the final users for transfusion.



Arrival

And Registration

Blood

Gathering (donation)

Screening

Transportation

Collection

Demand Supply

Prediction Management

Distribution

And Usage

Storage

Utilization

## Donors, Blood Collection and Screening

BD process starts with the arrival of the donor at the blood center. Donors can be divided in returning donors, who donate on an almost regular basis, and walk-in donors, who are entering the system occasionally or for the first time. In any case, donations can be made after a defined rest period from the previous one, which is defined by law. As donors have a crucial importance in the system, their availability, frequency and motivation have been studied from both a statistical and a social perspective.

**Social Aspects** The main reasons for blood donation and their relative importance have been studied by Bani and Giussani (2011). Moreover, it is also documented that the organization of blood collection phase may have an impact on donors’ availability. Poor treatment, poor staff skills, and a bad experience are the main reasons of not returning to donate (Schereiber et al. 2003). Also prolonged queuing times are negatively correlated to BD satisfaction (McKeever et al. 2006; Katz et al. 2007). Hence, a well-organized donation management has a strong impact on the availability of blood bags, and also on donors’ motivation, thus possibly increasing/decreasing their availability.

**Donor Arrival and Registration** When a donor enters in the system for the first time, he/she is requested to provide personal (e.g., name, address, age, job, gender) and medical/health (e.g., diagnosis, lab results, treatments) data, which are digitally collected. Digital registration provides a good traceability of the transfusion cycle, from collection to blood distribution and transfusion. The registration also includes a visit from a physician, followed by blood exams. If the donor is eligible, blood collection centres check that he/she makes the first donation within few days from the declaration of eligibility. Sometimes, the first visit is directly followed by a donation. A visit is also made before each donation or exam, during which the donor is re-evaluated and his/her personal data are updated.

Several management problems arise, both at a planning level (e.g., blood collection centre location or staff dimensioning) and at an operational level (e.g., appointment scheduling). However, only few papers focus on optimization issues arising in the registration and donation phase, despite the strong impact of donors’ arrivals on the overall system performance. Michaels et al. (1993) developed a simulation study to evaluate scheduling strategies of donors arriving at a Red Cross blood drive, and compared these strategies in terms of donors’ mean transit time to find out the most effective one.

Other papers focus on estimating the supply of blood from donations, considering annual donor retention rates, donor recruitment rates, and mean numbers of donations per donor and per year (Borkent-Raven et al. 2010). Ritika and Pau (2014) examined different classification algorithms to find out a fair classification technique for the prediction of donations. Flegel et al. (2000) developed a logistic regression model to compute the donation probability within a given time frame, considering different regression coefficients for walk-in and returning donors. Ferguson and Bibby (2002) used a prospective design to predict the number of future blood donations. Boonyanusith and Jittamai (2012) investigated the pattern of donors’ behaviors based on factors influencing blood donation decision using a questionnaire.

Finally, on-line applications and database systems for donors’ and bags manage- ment are also investigated (Chau et al. 2010; Khan and Qureshi 2009; Kulshreshtha and Maheshwari 2011).

**Blood Collection and Screening** Blood collection centres should be located according to their accessibility from hospitals in order to improve the overall system performance. Moreover, centres are generally subject to regulatory control, designed to ensure the maximum quality and safety of blood products. They guarantee that blood bags are produced according to standardized procedures, to achieve consistency of each product (Council of Europe 2007).

Despite the importance of this phase, the literature on blood collection system planning is rare (Ofori et al. 2005; WHO 2008; Lieshout-Krikke et al. 2013). De Angelis et al. (2003) proposed a stochastic methodology to analyse and certify the optimal configuration of servers by integrating simulation and optimization for a transfusion centre in Rome.

After collection, the screening phase starts with few tests performed against infectious diseases, e.g., HIV, Hepatitis B and C, and syphilis. They are repeated on each gathered blood sample, and are generally the same all around the world. Based on screening results, the blood bag is either released for clinical and manufacturing use or discarded (WHO 2008, 2010). An effective, well-organized screening program and a good quality system are essential for provisioning safe blood bags to patients and meeting the transfusion requirements.

## Transportation and Storage of Blood Products

Once collected from donors at regional or community blood centres, blood must be stored in storage centres or TC before it perishes. These locations serve as a depot until the blood is distributed to the demand points and sometimes deal with testing of the blood products.

If collection and storage or TC centres do not coincide, blood must be trans- ported. Although transportation is a rather simple task in this phase because all collected bags are usually addressed to a big TC or storage centre from all BD cen- tres in the related territory, transportation must be carefully performed as the blood must be stored before perishing and requires particular transportation conditions. Inefficient and inadequate transportation may reduce the quality of end user care and increase costs.

## Distribution and Utilization

The last step of the BD chain includes distribution and utilization, which involve several management problems as detailed below. Distribution is highly important for efficient blood usage and should meet the demand, which is often uncertain and requires accurate predictions.

# Discussion and Open Issues

Our analysis points out the high number of papers related to the management of storage and distribution phases. Indeed, Fig. 2 shows the percentage of the existing works for each phase. It can be seen that, even though the arrival of donors and the registration and donation system strongly affect the entire BD chain, only the 1 % of the investigations are devoted to improve these aspects. Hence, we found out the necessity of more adequate analyses and studies for this phase.

In particular, a relevant problem is the management of donors’ appointments and visits, as it has a significant impact on the effectiveness of the entire BD chain and on donors’ motivation. Increasing the number of donations improves the performance of the system, but also an effective management of donors’ arrivals along with the days may optimize the daily production of bags with respect to the demand. Indeed, an unbalanced feeding of blood bags undermines the entire BD chain; this is not only a theoretical problem, but from the discussion with several blood providers this is the actual bottleneck of the entire system in the practice. Returning donors’ appointments could be scheduled in advance, but not all donors are willing to accept pre-scheduled appointments, or they often require appointments at the beginning or at the ending of the day rather than at noon. Thus, an important future research is the development of optimization models and techniques for providing an efficient appointment scheduling, also in the light of balancing the production. The existing studies solved these problems by using simulation models (see, e.g., Lailomthong and Prichanont 2014); however, they do not fit the DB system since they do not take walk-in donors into account. The historical data collected by the BD centres can be exploited in these models, to forecast the walk-in donors’ arrivals and increase the efficiency of the system. An effective application system is also needed in BD, as

in other domains, to combine the registration system with donors’ and physicians’ preferences and their points of view. Such an application system (e.g., an on-line system) could be a solution to join donors and physicians at the same platform and to encourage volunteer donations.

Storage is another important step of the system. A successful storage manage- ment should guarantee a proper balancing between the blood to hold and that to transfer, to keep blood in optimal conditions and to avoid expiring and discharging. This also stresses the importance of an adequate feeding with respect to the demand. The storage problem is widely studied in the literature (the 39 % of the investigations in Fig. 2). Existing models are generally based on the analysis of the normalized stock level, and they aim at predicting and reducing outdated bags and blood shortage. Nevertheless, an integrated management with blood feeding, i.e., with donor appointment scheduling, might increase the efficiency of the whole BD chain and reduce both outdated bags and blood shortage.

As mentioned, demand prediction is another crucial issue in BD system manage- ment. Inaccurate estimations of blood demand may lead to disruptive consequences. For example, underestimation leads to low quality of the service, out-of-stock and additional expenses; on the other hand, overestimation leads to overproduction and overstocking, together with increased costs and clinical and ethical problems in throwing bags away. Demand variation is an important factor to which the entire process must properly react; for example, blood inventory management becomes critical in case of increased demand, and the related decisions must be taken on time. However, meeting the demand is not easy since also the number of donors is difficult to foresee; hence, an integrated approach that considers the variation of both demand and donor arrivals should be required to better manage the BD chain.

Finally, transportation and delivery of blood products are largely addressed by means of optimization tools. Generally, the existing works deal with the routing of delivery vehicles for the distribution of blood components. As a future research line, with the increase in the use of blood components, an emerging logistics problem is the distribution of different products, while taking into account both

their different shelf lives and cost minimization (multi criteria objective).

1% 9%

20%

3%

39%

22%

Arrival and Registration Donation

Screening Storage

Demand Prediction

Supply Management Distribution

6%