Optimal Inventory Management of a Blood Center

Blood plays an important role in transporting necessary substances such as nutrients and oxygen to the cells as well as defending against infection. People of all ages, from infants to elderly, may need transfusions of different blood products for various medical conditions. In practice, the blood centers are the main suppliers of blood products which contribute to more than 90% of the total supply (AABB 2011). They are responsible for blood collection, processing, storage and distribution. One primary challenge for the blood centers’ daily management is to balance the shortage and waste of the blood products which deteriorate very quickly. Since whole blood (WB) is highly perishable, it is often decomposed into various components shortly after collected. The major three products from this process are red blood cells (RBCs), plasma and platelets that have different lifetimes. Frozen plasma has the longest lifetime of one year; RBCs must be used within 42 days, while platelets must be used within 5 days (Americas Blood Centers 2015). The demands of these products are highly uncertain. The daily number of blood units required can vary from zero to 1,100 units in a single year (Pierskalla 2005). This results in substantial complexity for the inventory management. In reality, we frequently observe both shortage and waste. For instance, 435 surgical procedures were postponed due to blood shortage with an average delay of 2.4 days in 2011, and in the same year, around 10% of the hospitals reported at least one day on which nonsurgical blood needs could not be met (AABB 2011). At the same time, the outdating rate of blood products is surprisingly high. The number of units of WB and all components outdated was estimated to be over 1 million units in 2011. The most perishable platelets have the most severe outdating problem. About 17% of all the WB-derived platelets were outdated (AABB 2011).

The challenge of the blood inventory management also stems from the dependence among the supplies of the blood products. In practice, the most common blood supply is WB donation. A key characteristic of this source is that it produces all blood products at once. This implies that replenishing one blood product might trigger unnecessary replenishment of all other products. On the other hand, the demands for different blood products are mostly independent, as they have different uses for human bodies (Pierskalla 2005). This may result in imbalance inventory levels, which makes coordination among the products necessary. An alternative source is to use apheresis collection that withdraws WB, separates and collects the desired component, and then returns the remainder of WB to the donor (Madden et al. 2007). Currently, apheresis is most commonly used for RBC collection. However, this method requires special machines that are available only at certain blood centers, so it is less flexible than WB donation. In 2011, RBCs obtained by apheresis
constituted about 12.6% of the total WB/RBC collection (AABB 2011). From the management perspective, the presence of this additional supply can further complicate the inventory decisions. Due to the lack of optimization resources, many blood centers still rely on crude and untested rules of thumb to manage their inventories. Avoidable shortage and waste are not uncommon.

In this paper, we study the above blood inventory problem, taking into account product perishability, demand randomness and supply dependence. We formulate a multi-item, periodic-review inventory model with multiple supply sources. Among the three blood components, plasma has a much longer lifetime while being less expensive than RBC and platelet. Hence, we only consider RBC and platelet in our model for simplicity. Moreover, since whole-blood-derived platelets and apheresis-collected platelets have quite different quality levels, the alternative supply in our model is used only for RBC but not for platelet. This large price difference implies very different demand streams for these two products, and thus the inventory management of apheresis-collected platelets can be largely viewed as a separate problem. In each period, the blood center first reviews the inventory levels of RBCs and platelets with different residual lifetimes, based on which it makes the replenishment decision. If WB donation is chosen, WB is componentized into the freshest RBC and platelet inventories. The blood center can also choose to only replenish the RBC inventory by apheresis collection. The demands of the two blood products are independent, and their prices are exogenously given and remain the same for all inventory ages. After satisfying the demands, the blood center has an option to salvage its inventories at a modest price. The remaining inventories with at least one period lifetime left are carried over to the next period incurring a holding cost. On the other hand, any unmet demand is lost. The objective is to maximize the total expected discounted profit for the blood center over the planning horizon.

To formulate this problem, we use a vector of state variables for each blood product to record the inventory levels at each age. Like in Chen et al. (2014) and Li and Yu (2014), our problem has a high dimensional state space driven by the perishability of the products. The complexity advances with multi-products and multi-supplies where the operations of the two products are correlated with the common supply. To tackle this problem, we derive several structural preservation properties based on the multimodularity concept developed by (Hajek 1985). As in prior literature, fresher inventory also has a higher marginal value than the older ones in our model. More interestingly, we find that while the inventories of the same product in different ages have the substitutable property, the inventories across the two different products are complementary. That is, for the same blood product, a higher inventory level of one age reduces the marginal value of the inventory of the other ages; whereas, across the two products, an increase of the inventory of one product
increases the marginal value of the inventory of the other product. These structural properties have direct implications for the fulfillment, salvage and replenishment policies. First, we show that first-in-first-out is always optimal for fulfillment and salvage. Second, a higher inventory level of one product can lead to more salvage of this product but less salvage of the other product. Third, as for WB replenishment, the order-up-to policy is optimal whose level decreases if the inventory of either product increases. Fourth, the apheresis collection will more likely be used relative to WB replenishment when there is more platelet inventory or less RBC inventory. We characterize the regions for sole WB replenishment, sole apheresis collection, and replenishment with both sources. At optimum, replenishment and salvage can simultaneously occur especially when one product has plenty inventory while the other needs to be replenished. The derived insights will be useful for blood inventory management practice and contribute to the broader perishable inventory literature.

References


Madden, E, EL Murphy, B Custer. 2007. Modeling red cell procurement with both double-red-cell and whole-blood collection and the impact of European travel deferral on units available for transfusion. Transfusion 47(11) 2025–2037.