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Blood Storage and Distribution Systems : A Review

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ABSTRACT

This paper presents a review of the literature on inventory and supply chain management of blood distribution system. First, we identify different perspectives on approaches to classifying the existing material. Each perspective is presented as a table in which the classification is displayed. The classification choices are exemplified through the citation of key references or by expounding the features of the perspective. The main contribution of this review is to facilitate the tracing of published work in relevant fields of interest, as well as identifying trends and indicating which areas should be subject to future research.

Keywords: Health Services, Supply Chain Management, Inventory, Blood Products, Literature Review

I. INTRODUCTION

The management of blood is a problem of specific concern for the human race. Even though there are technological developments in the field of substitutes for blood products, the need for donor blood and its derived products will always exist.

Blood is not an ordinary commodity. The supply of donor blood is fairly irregular and the demand for blood products is at least as stochastic. Matching supply and demand in an efficient manner is not straightforward. Blood products are also perishable, which complicates things even further. Shortages lead to high costs for society, since they can cause increase mortality rates. Outdates on the other hand are not commonly accepted either, since blood donors are a scarce asset of society and donors must respect a certain time period between two donations, depending on the type of donation. Also, only a small percentage (5%) of the eligible donor population actually donates(1)(2). That is why we deemed it necessary to include some papers about donor psychology and motivation in this paper, even though this is not strictly within the field of operations management.

Concerning the supply management of blood products, it is impossible to talk about blood as a product on its own. To put things simply, blood is usually drawn in its whole and undivided form (in the remainder of this paper referred to as `whole blood') from donors. Some components, such as blood platelets, can also be obtained directly from the donor without drawing blood. In this case, the donor is connected to an apheresis device through which the donor's blood circulates. The machine can filter the desired components from the blood while the remaining components flow back into the donor. The extraction of platelets by this process is costlier, however, than obtaining them from donated whole blood (3). The latter method is less usual, but we have included some papers which apply this technique. Once the whole blood is drawn, it is usually centrifuged into three major components: red blood cells, plasma and blood platelets. The different components have different shelf lives and the separation enables one to adapt the use of blood products to the specific needs of a patient. For instance, blood plasma is used to treat burns (4).

We primarily focus on these components in this paper and we have also included papers regarding frozen blood components. The products are further distinguished by means of different blood groups and the Rhesus factor. We did not focus on the areas of cord blood banking and the inventory management of stem cells. These are related products with similar characteristics to the components discussed in this review, but we decided to narrow our scope to the more widespread components.

The papers in this review are particularly relevant for blood banks, which are institutions that collect blood, perform a screening test and label the products with the appropriate blood group. Blood banks can be organized in multiple manners, ranging between the two extremes of centralization and decentralization.

We have encountered only one literature review during our research. This literature review written by Nahmias (5) deals with perishable inventory problems as a whole instead of focusing on blood products. The review is not recent (1982) and deals merely with inventory problems instead of considering the entire supply chain. It does include a brief review of the application of the discussed models to blood bank management. In the book Operations Research and Health Care: A Handbook on Methods and Applications, Pierskalla et al. (3) present a very interesting overview paper, which is probably one of the most widely read papers in the area of blood supply chain management. Pierskalla's paper describes strategic models for assigning donor areas and transfusion centers to community blood centers, determining the number of community blood centers in a region, locating these centers and coordinating supply and demand, as well as models for tactical and operational issues in collecting blood, inventory management, blood allocation to hospitals, blood delivery and crossmatching. Although Pierskalla's paper contains a short literature review section and describes several models, it is not a literature review paper. We believe our paper is relevant in the sense that it is an attempt to classify the existing literature concerning blood supply chain problems, with the purpose of guiding people to papers relevant to their field of interest. As Pierskalla (3) states:

'The entire blood supply chain can be examined as an essentially whole system and not just a subsystem of some larger system as occurs in most other supply chains.'

This statement suggests that the problem is rather different from other supply chain problems, and that it might be worthwhile to investigate how the blood supply chain problem can be decomposed into different sub problems. We try to map the literature according to different criteria. In the meantime, we made an effort to identify trends and lessons learned from various case studies. We did not incorporate a lot of papers dealing with technological issues, though we consider a few of them, because it would be wrong to ignore the possible advantages that might arise from using these technologies. Nevertheless, the focus is merely on the managerial viewpoint.

We searched the databases Web of Science, Pubmed, Academic Search Premier, Business Source Premier, Econlit and SCIRIUS for relevant papers on inventory and supply chain management of blood products. References cited in the obtained manuscripts were reviewed to find additional publications. We ended up with a total set of 98 manuscripts. To illustrate the distribution of the papers according to publication date, we included a distribution diagram in Figure 1. Two peaks are visible in the diagram, i.e. in the period 1976-1985 and more recently in the period 2001-2010.

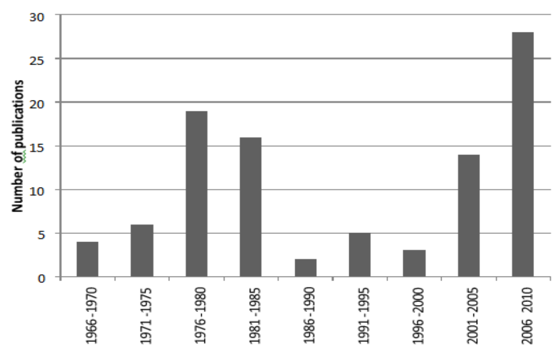

Figure 1. Number of publications by publication period

We structured the literature review using different perspectives. That way, a researcher can query a list of manuscripts according to his specific needs. For instance, a reader wanting to learn more about the virtues of centralization should not use a taxonomy based on type of blood product. And a taxonomy based on hierarchical level is not efficient for a researcher looking for information about blood platelet problems. The classification fields are the following:

Type of blood product (section 2)

1) Solution method (section 3)
2) Hierarchical level (section 4)
3) Type of problem (section 5)
4) Type of approach (section 6)
5) Exact versus heuristic (section 7)
6) Performance measures (section 8)
7) Practical implementation/case studies (section 9)

II. TYPE OF PROBLEM

Supply chain management of blood products consists of various subproblems. We distinguish between inbound and outbound problems. Inbound problems comprise both inventory problems and problems dealing with planning for collections. Outbound problems consider problems regarding distribution scheduling as well as problems related to supply.

2.1 Inbound problems

We encountered two types of ordering policies within inventory management, with the majority focusing on fixed order intervals (order-up-to models).We believe Katsaliaki (1) mentions a min-max model in her simulation study, though the difference from fixed order interval models is not always clear in the literature. Min-max models are a combination of models with ordering points and models with fixed order intervals. Since Katsaliaki(1) draws a distinction between routine (prescheduled) deliveries and emergency (ad hoc) deliveries, the model can be labeled as a min-max model.

Inventory allocation problems concern the efficient allocation of inventory in the supply chain. Sources dealing with the issue of centralized structures, as opposed to decentralized structures, are also included in this category. Carden and Dellifraine, for instance, investigate the advantages and disadvantages of both centralized and decentralized blood centers. They conclude that there are significant differences regarding hospital customer satisfaction. Centralized blood centers proved to be more successful in meeting the overall supply needs of hospitals, while decentralized blood centers appeared to charge lower prices and offer products that are more adapted to local market needs. Federgruen et al. discuss an allocation model for perishable products, distributed from a regional center to a given set of locations with random demands. The paper actually deals with a combined problem, since it also considers the problem of distribution scheduling. Though their focus is not on blood products specifically, applications using blood products are possible since blood is a perishable product.

Cross-matching policies and issuing policies are also included within inventory management. A crossmatching policy reduces to an issuing policy when all cross-matched units are actually used. Since this is only the case for general perishable products and not for blood products, a distinction between the two policies is necessary (6). Dumas and Rabinowitz (12) attempt to reduce blood wastage by an alternative cross-matching policy. Instead of the conventional single cross-matching, they emphasize the merits of double cross-matching. In that case, a single unit of blood is reserved for two potential users instead of one, while ensuring blood is available for both when it is needed. This policy increases the probability that the blood unit will be used during the reservation period, which has the advantage of having fewer unused units reserved that are unavailable to other patients. Another example is the work of

Jagannathan and Sen , which is dedicated to the storing of cross-matched blood. Issuing policies are discussed in detail in Pierskalla and Roach who derive optimal issuing policies for some particular classes of perishable inventory problems. An example about the issuing of whole blood from a blood bank is included to accompany their theory. Another discussion of issuing policies can, for instance, be found in Prastacos (6).

The papers that concern inventory management in yet other fields than those defined in Table 4 are placed in the leftover category 'other'. This category includes studies about efficiency and best practices, emergency management plans, demand forecasting, computer-based information systems, extending the shelf life of blood components and other topics that relate (in)directly to blood supply chain management. Katsaliaki (1), for instance, is placed in this category, because this paper also discusses the benefits of a computer-based information system, even though this paper is already classified in different subcategories of inventory management (min-max inventory model, crossmatching and issuing policies).

A separate category was reserved for those papers that deal with planning for collections, which we also consider an inbound problem. The model of Cumming et al. , for instance, focuses on the planning of blood collections by scheduling and rescheduling bloodmobile operations to achieve the desired targets. Pegels et al. discuss various blood service policy changes, which include the use of a scheduling algorithm to schedule visits to organizations. A simulation study of donor scheduling systems for the American Red Cross can be found in Michaels et al.. Table 4 lists the papers according to inbound problems.

2.2 Outbound problems

The supply category consists of papers dealing with how to maintain or increase the supply of donor blood. Assuming a non-decreasing trend in the demand for blood products, this category is indirectly relevant to our review. Madden et al., for instance, investigate the impact of using a specific red blood cell collection technology on the availability of the product. More specifically, they discover that using a double red blood cell collection device leads to substantial gains in availability compared to conventional whole blood donation. It is also confirmed that the net gain in quantity of red blood cells in the supply is sustained under various policies. The authors are not sure about the economics of the collection system, though. Schreiber et al. discovered that first year donation patterns predict long term commitment for first-time donors. This is relevant in the sense of determining strategies to establish regular donation behavior in the donor reserve. A similar study can be found in Chung et al. . Another study by Schreiber et al. (2) attempts to identify factors that prevent donors from donating, making it possible for the blood centers to address these issues.

Hemmelmayr et al. deal with problems of delivering blood products to hospitals in Austria. They examine the potential benefits of a vendor-managed inventory system compared to the vendeemanaged inventory system currently in use. In addition to the system in use with fixed routes, two alternative solution approaches with a more flexible routing system are formulated to investigate whether a reduction in delivery costs is possible. An extension of this study to deal with stochastic product usage can be found in Hemmelmayr et al. Kendall and Lee formulate rotation policies that optimize the redistribution of blood between hospital blood banks. Redistribution generally occurs from hospitals with a lower probability of transfusion to hospitals with a higher probability. They indicate the increase in performance of multiple criteria that can be achieved by optimizing this process. Brodheim and Prastacos discuss the Long Island blood distribution system as a prototype for a regional blood center and the hospital blood banks that it services. The prototype comprises a Programmed Blood Distribution System (PBDS) model and strategy which would be generally applicable. The PBDS schedules deliveries depending on statistical estimates of the needs of each hospital. Actual requirements are also monitored to adjust deliveries when necessary. Table 5 lists the papers dealing with outbound problems.

III. TYPE OF APPROACH

We distinguish between a stochastic and deterministic approach to the problem. For a lot of papers, classification according to this criterion is irrelevant. For instance, papers dealing with forecasting are always stochastic in view of the nature of the problem. Another example where this distinction is not relevant is studies dealing with benchmarking. We only made this distinction for those papers where different approaches are possible. Papers where simulation methods are used are placed under a stochastic approach. The most obvious example of a different approach can be seen in the two papers written by Hemmelmayr et al. As mentioned before, Hemmelmayr et al. discuss delivery strategies for blood products. The investigation is set in a deterministic setting, but later extended in Hemmelmayr et al. to deal with stochastic product usage. Remarkably, only seven papers are set in a deterministic setting, whereas 42 papers are set in a stochastic setting. This result is understandable, since stochastic settings resemble the practical environment more closely .

IV. DISCUSSION

Our research has led to the detection of some facts and trends that initially were not expected. One surprising find is that the use of a frozen blood reserve is less adequate than one would expect, and that other policies are more efficient in sustaining a firm supply of blood products. A frozen blood reserve can prove useful in isolated cases and is more appropriate for products such as plasma than for other products. Red blood cells, on the other hand, are the component that is most often associated with the term ‘blood’. The overall tendency, as observed by Hess, (8) is that the freezing of red blood cells will continue to exist, but at a decreasing rate.

The PLT ordering problem was extensively covered in both Haijema et al. and van Dijk et al.. At first, their contribution seemed to close a gap in the literature. However, Blake showed that wrong assumptions were made in these papers and that further research is necessary to develop robust and fast heuristics in order to solve the PLT inventory problem.

Worth mentioning is the prominence of papers that concern the supply of blood, often taking human factors into account? These papers relate to the blood supply chain problem in an indirect way, though we deem their inclusion appropriate, considering the special characteristics of blood products in terms of supply.

When considering the classification by type of approach, we observe that only seven papers are set in a deterministic setting, whereas 42 papers are set in a stochastic settings. This outcome is remarkable though understandable, since stochastic settings mimic the practical environment more truthfully. Performance measures that dominate the literature are outdating-related and shortage-related. This is a result we expected, though we would point out that measures concerning safety/quality are not negligible either. Measures related to the latter are not always taken into account when defining policies, though in practice safety is the most important factor. The fact that a loss of life is generally unacceptable, gives safety priority over all costs in the supply chain. Most papers acknowledge this, warning that the policy results could be toned down when practical implementation occurs.

To conclude, we would emphasize that most papers feature some form of practical implementation or case study. Although our classification in terms of this criterion could have been more rigorously applied, this observation identifies the tendency of testing policy results in practice.

V. CONCLUSION

In this paper, we have reviewed the literature on the inventory and supply chain management of blood products. We have tried to identify different perspectives in terms of which to classify the existing manuscripts. Section 2 provides a classification based on type of problem. A distinction was made between inbound problems and outbound problems. In section 3, we examined the type of approach used in the literature. Most papers for which this classification perspective is relevant appear to feature a stochastic approach, while only a few papers are set in a deterministic setting. Papers dealing with optimization problems were classified into two categories depending on whether they delivered an exact solution procedure or rely on heuristic approaches. The main contribution of this review is to facilitate the tracing of published work in relevant fields of interest, as well as identifying trends and indicating which areas should be subject to future research.

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