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Administrative Reports

Management Policies for a Regional Blood Bank

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This paper considers management strategies for the administration of a regional blood bank. The techniques of management science and mathematical inventory theory are applied to construct a model for the system, identify policy areas, and formulate management objectives. Two simulation models and data collected from both a regional and single hospital blood bank are used in the analysis. The results presented examine the interactions and savings associated with following optimal ordering, crossmatch, and issuing policies. Since each of these policies have an important effect on the number of shortages and outdates, they therefore influence optimal blood bank management. In addition, the question of centralized versus decentralized control is examined.

THE PROBLEMS of blood shortages and wastage through outdating pose a major challenge to blood bank managers. While it is apparent that the need for more donated blood is great, it must be recognized that maximum efficiency in the management of existing units is also needed.[1] This paper considers the latter aspect of the problem by applying the principles of management science to whole blood inventory administration.

Our primary interest is with the situation of a central (regional) blood bank serving a number of hospitals. The major responsibility of the central blood bank is to administer the collection and distribution of blood in its area of jurisdiction in a manner which ensures that all demands are met. In addition to this primary goal, the central bank is also interested in minimizing outdates and emergency shipments, minimizing operating costs, and maintaining a high level of quality for issued units. Many of these objectives are also shared by the member hospital blood banks.

These goals are somewhat conflicting and thus ultimately trade-offs must be made. It is just such trade-offs among competing goals, that form the basis of the analysis in this paper. Thus, we shall examine the implications of various management control policies for the regional bank based on the indicators commonly used to measure the blood system's performance. Many of the results presented in this paper apply equally well to a single blood bank.

In general, for a relatively fixed supply of donors, the inventory system of whole blood units may be controlled in three different ways, *i.e.*, by controlling the ordering policy, the issuing policy, and the crossmatch policy. Although each of these policies interact with one another in obtaining the best performance, it is interesting to see that general policy statements can be made in each case regardless of the policies followed in the other cases. We begin with a brief description of these policy controls.

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Ordering Policy

This policy area is concerned with the manner in which both donated and emergency units are obtained. Of specific interest in this paper is the number of units to order at the beginning of each decision period (defined by order-up-to inventory level, S). Questions of donor campaigns, donor lists, blood plans, and centralized versus decentralized ordering also fall under this heading. These latter topics will be reported on in a subsequent paper since they form the basis of a significant study in their own right.

Issuing Policies

Here we are concerned with the choice (when a choice is possible) of which units to issue from the uncrossmatched inventory to satisfy a particular demand. In most cases, this decision focuses on the age of the unit to be issued. Two well-known issuing policies are FIFO (First In-First Out) and LIFO (Last In-First Out). These terms have come to mean the policy of issuing the oldest available unit or the youngest available unit, respectively. Issuing policies could also include the question of centralized versus decentralized control over issuing. For example, the oldest available unit may be a unit which has been crossmatched at a member bank for six days and the central bank may not know it is available for reassignment or may not have the authority to reassign it. In this case, the central bank may be forced to issue a unit which is not the oldest available; however, we will still call this policy FIFO if the central bank issues the oldest available unit over which it has control.

Crossmatch Policies

In a regional blood bank, it is possible to consider controlling the length of time an issued and untransfused unit can remain assigned to a particular hospital's inventory and thus be inaccessible to demands at other locations. Although this sojourn time of a unit at a hospital does not mean the unit is always on crossmatch at the hospital, this time period will be referred to as the crossmatch period and will be denoted by D days. In a local hospital, where there can be personal contact between the blood bank and the physician, such control of a fixed period of D days may not be necessary. In fact, many hospitals release the units for other patients after a crossmatch period of 24 hours or less. At a further level of complication in the regional bank, one should consider using different crossmatch periods D_1, D_2, etc. for different blood types and different size member hospitals.

Changes in operating policy will clearly have an impact on the total performance of the regional blood banking system. In view of the regional bank's objectives concerning shortages, outdates, and costs, we will measure such performance changes with the following indicators:

1. The number of units transfused (or, alternatively, the percentage of demands met).
2. The number of shortages (*i.e.*, emergency requests and postponed surgery).
3. The number and percentage of outdates.
4. The dollar operating cost for the blood bank (by attributing prices to shortages and outdates).
5. The level of assigned (crossmatched) and unassigned (uncrossmatched) inventory versus daily average demands and transfusions.

The level of the indicators can be expected to vary with different policy choices and combinations of policy choices. The approach that will be taken here is to demonstrate the response of shortages, outdates, transfusions, inventory levels, and costs to a variety of issuing, crossmatch, and ordering policy combinations. This response

TABLE 1. *Blood Flow Data for North Suburban Blood Center (September 22 to November 30, 1972)*

Number of units present or entering the system	2,775
Number of outdates	237
Number of units transfused	2,272
Number of demands not resulting in a transfusion	2,384

will be determined with the aid of two simulation models. The first model is a regional simulation model and was constructed to examine issuing and crossmatch policy combinations. The second model is more extensive and general in terms of data, policy inputs, and performance indicator outputs. Ordering policy and crossmatch policy interactions are examined in the second model. A detailed description of both models may be obtained by writing to the authors.

Work on modeling blood banks and examining management policies has been going on for some time. Other computer simulation models which deal with order policies have been described by Elston and Pickrel[4] and Jennings.[8] Jennings' model was the first to differentiate between unassigned inventory and assigned inventory. A simulation model by Rabinowitz[16] examined double crossmatching and Jennings[9] extended his previous model to analyze various transshipment policies for a regional bank. Bodily[1] used Jennings' original model to analyze the impact of frozen blood.

Hurlburt and Jones[7] used a statistical procedure to quantify the costs of excessive crossmatch release times. In two recent papers, Yahnke *et al.*[17, 18] examined certain aspects of a regional bank and attempted to quantify the contribution of crossmatch policy to system shortages and outdates. A mathematical model was constructed for the regional bank which measures the contribution of each member hospital to total system outdates.[17] The simulation model of Pinson[15] allows for prescriptive analysis by measuring the effect of alternative ordering, issuing and crossmatch release policies. This model forms the basis for many of the results soon to be described.

Data

Data for this project and much of the information on the structure of the regional bank model was made available with the cooperation of the North Suburban Blood Center of Glenview, Illinois. North Suburban is a regional blood bank serving the needs of member hospitals in the North Shore area of Chicago with a volume in the fall of 1972 of about 1,000 units per month. Blood enters this system in the form of donations at all locations or in the form of emergency shipments to the central bank. Donated blood is, of course, fresh, and emergency shipments can be of any age. Blood is issued to satisfy demands at the member hospitals. Approximately 50 per cent of all demands at the member hospitals do not result in a transfusion. The crossmatched units issued to meet these demands are returned to the unassigned inventory from which they may be reissued to different member hospitals.

The raw data consisted of records on each individual blood unit in the system. These records contained information on blood type, date drawn, date transfused (or outdated) and the various dates and locations of interim shipments associated with the unit before its final disposition. Data for all blood types and for all member hospitals were collected for a three-month period.

The raw data represent a limited picture of this particular blood bank's activities. The rules used in issuing and crossmatching of the blood were not retrievable from the data. Moreover, an exact representation of the demands for blood made on the system was not directly available. It was possible to infer information on both demand and supply from the available data. The resulting estimated supply and demand data were used in the simulation models of the blood bank inventory system. In this way, the conclusions of the simulation analysis are relevant to the general class of regional blood banks and not just to a particular bank.

A total of 3,152 units was considered. This number represents the total number of units which entered the blood bank system from September 1 to November 30, 1972. Since the blood bank does not keep records of its total inventory, it was necessary to wait 21 days (when all units which had entered previous to September 1 had passed through the system) to accumulate a reading on the initial inventory of the system. Those units which had already been transfused prior to September 22 were then eliminated from consideration. Daily demand and the breakdown between ultimate transfusion and return for each unit demanded were recorded. Table 1 gives some further summary statistics of the data.

Results

Issuing and Crossmatch Policies

The LIFO and FIFO issuing policies were considered in conjunction with crossmatch sojourn periods, D, of 0 through 7 days at each member hospital. $D = 0$ corresponds to an inventory system where all issued units are transfused. $D = 7$ corresponds to a blood bank where those crossmatched units which are not transfused remain in the assigned inventory for a period of one week. Thus, 16 issuing-crossmatch policy combinations were considered. Table 2 contains data which illustrate the results for the various policies. Figure 1 is a graph of cumulated outdates versus D for both FIFO and LIFO. The following observations can be made from all of these results.

As predicted by the theory of Pierskalla and Roach,[14] FIFO dominates LIFO in the case where $D = 0$. In the simulation, the blood bank using FIFO was able to meet all demands with 0 outdates and 0 shortages while LIFO results in 477 outdates for the sample period. As D increases from zero, the possibility of having crossmatched units returned is admitted. Under FIFO, more outdates are generated and as D becomes sufficiently large ($D \geqslant 7$) the system experiences shortages. It is interesting to note the sensitivity of the system to small changes in D. An increase in D from one to two days results (under FIFO) in an approximate 300 per cent increase in the number of outdates. An increase in D from two to three days results in a 200 per cent increase. The rate of increase is such that by the time D has grown from 1 to 7, outdates have grown from about 16 to 331. The number of units available in the unassigned inventory decreases as D increases and the assigned inventory increases. At $D = 7$, the system begins to experience shortages, since supply is not adequate to meet demands and outdate requirements over the three-month time interval. Simulation runs with values of D greater than seven were made. However, such values no longer correspond to a realistic centralized control blood bank situation and so the associated results will not be presented.

TABLE 2. *Blood Inventory Policy Evaluation Runs for Issuing and Crossmatch Policies**

D	0	1	2	3	4	5	6	7
FIFO Issuing								
Transfused	2,272	2,272	2,272	2,272	2,272	2,272	2,272	2,242.4
Outdated	0	16.3	58.7	117.0	173.1	202.1	272.1	330.8
Unassigned inventory	503	445.7	364.3	272	161.9	121.9	35.9	0
Assigned inventory	0	41.0	80.0	114.0	168.0	179.0	195	201.8
Total	2,775	2,775	2,775	2,775	2,775	2,775	2,775	2,775
Shortage	0	0	0	0	0	0	0	72.5
LIFO Issuing								
Transfused	2,272	2,272	2,267.8	2,266.2	2,257.2	2,254.0	2,241.0	2,234.4
Outdated	477	449.3	428.6	403.6	372.2	366.3	357.5	338.8
Unassigned inventory	26	12.7	0	0	0	0	0	0
Assigned inventory	0	41	78.6	105.2	145.6	154.7	176.5	201.8
Total	2,775	2,775	2,775	2,775	2,775	2,775	2,775	2,775
Shortage	0	0	10.9	14.8	47.6	46.3	74.6	90.6

* The figures in the table represent blood flow averaged over a number of simulation runs (September 22 to November 30).

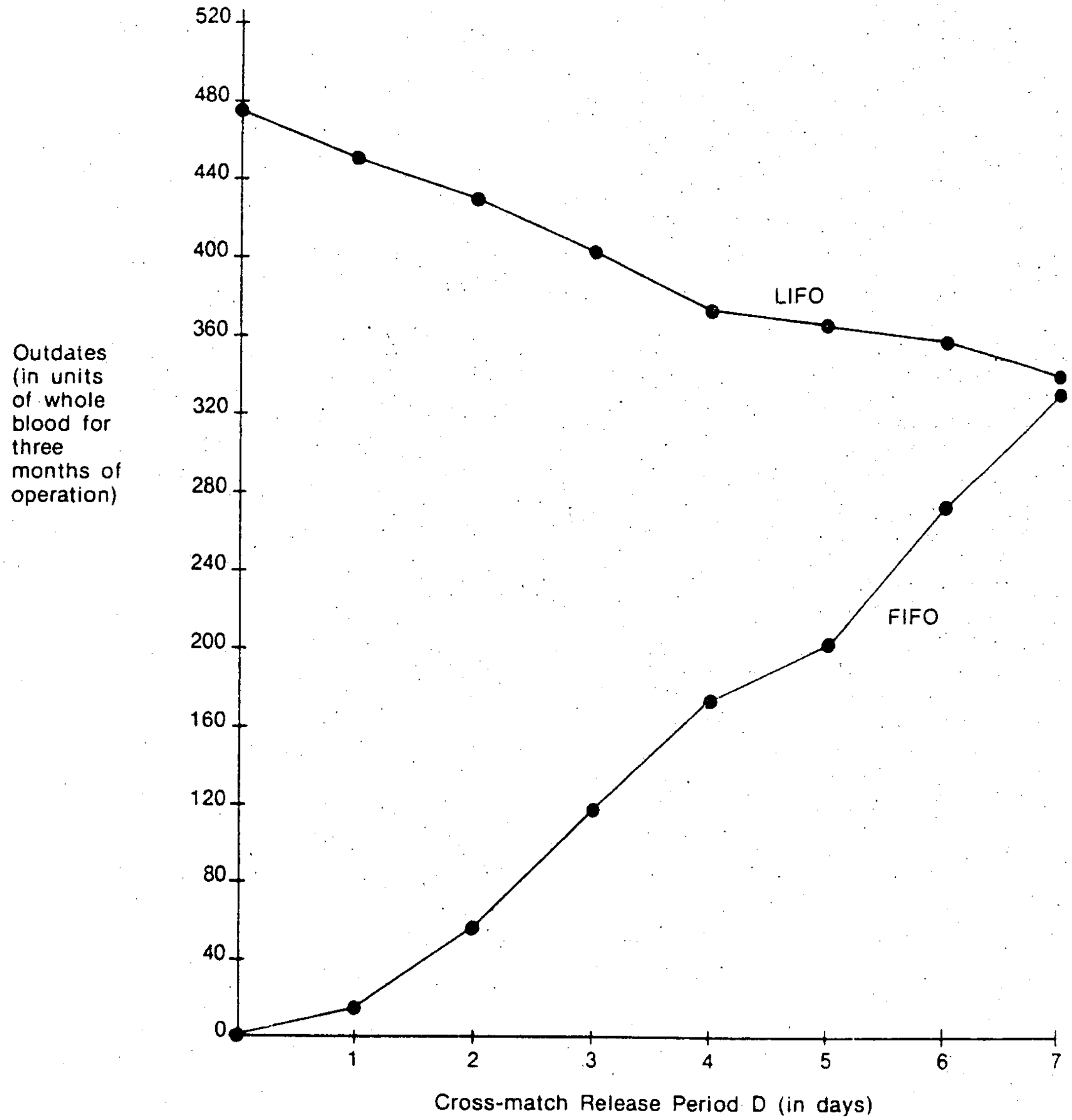

FIG. 1. Outdates and crossmatch release period for FIFO and LIFO issuing.

Intuitively, a LIFO policy seems inappropriate for whole blood since at all times the system experiences a great number of outdates and often a large number of shortages. However, as D grows, a number of interesting phenomena develop. Outdates decrease from 477 to 338.8 units and the number of units transfused decreases from 2,272 to 2,234.4 units. In addition, shortages increase from 0 to 90.6 units and the inventory levels change in a manner analogous to the FIFO issuing situation. It is possible to generate examples with large D where LIFO dominates FIFO in terms of the number of outdates. For our simulated blood bank, this switch occurs (with the given data) at a value of D which must be ruled out as being excessive. Indeed, D = 7 is unreasonable for both LIFO and FIFO, and any central bank with such little control over the crossmatch time will face excessive shortages and outdates.

Katz and Morse[11] described a regional blood bank system with an effective D of 21 days.

TABLE 3. *Blood Inventory Policy Evaluation Runs for Crossmatch Release Parameter D Drawn from a Truncated Normal Distribution with Mean of Four Days**

Variance of D	0	1	2	3	4	6	8
FIFO Issuing							
Transfused	2,272	2,272	2,272	2,272	2,272	2,243	2,173
Outdated	165	183	195	223	254	310	350
Unassigned inventory	170	154	136	91	37	0	0
Assigned inventory	168	166	172	189	212	222	252
Total	2,775	2,775	2,775	2,775	2,775	2,775	2,775
Shortage	0	0	0	0	0	71	211
LIFO Issuing							
Transfused	2,257	2,255	2,258	2,245	2,230	2,198	2,153
Outdated	378	378	367	368	366	369	378
Unassigned inventory	0	0	0	0	0	0	0
Assigned inventory	140	142	150	162	179	208	244
Total	2,775	2,775	2,775	2,775	2,775	2,775	2,775
Shortage	43	49	39	68	100	157	255

* The figures in the table represent simulated blood flow from September 22 to November 30.

A central bank draws blood and ships units to the member hospitals and little or no inter-hospital shipments occur. From the point of view of the central bank, no recycling occurs and hence D is essentially 21 days. These authors[11] note that by changing from a pure FIFO policy to an issuing policy closer to LIFO, they decrease outdates. They did not give data on the change in shortages or emergency shipments. Their results are thus entirely consistent and, indeed, expected from our simulation results.

It is apparent that FIFO dominates LIFO over a range of D of zero through seven in terms of all of the performance indicators: outdates, shortages, and number of units transfused. We may conclude, therefore, that a combination of FIFO with a minimal value of D is most desirable. As D is reduced, savings of 75 per cent to 200 per cent can be realized in outdating and shortages. A central bank probably cannot reduce D to zero, one, or two as is often the case at a member hospital. If the central bank cannot obtain a maximal crossmatch release time D, of four or five days, then the system will be incurring excessive outdates and a high demand for emergency shipments because of the large increase in shortages. Furthermore, if the donor supply is tight, the large amount of additional outdates will put severe strains on the donor system, will lead to a large amount of emergency shipments, and will cause postponement of elective surgery.

Centralized versus Decentralized Regional Control

Centralized control is defined to mean that the crossmatch period D is a constant which is determined and set by the central bank administrator. Decentralization is introduced into the model in two ways: a) by letting D be large, as described by Katz and Morse,[11] or b) by treating D as a random variable. We have already discussed the first way and have shown that lack of central control and large D leads to excessive shortages and outdates. The reasoning behind the second concept of decentralization is as follows. In a decentralized blood bank network, the central bank administrator sends units to each local blood bank and the local blood bank administrator decides when to release the crossmatched units which were not needed. The crossmatch release time D at the local bank looks like a random variable to the central bank administrator since the central bank has very little control over D and D may vary from unit to unit and one local bank to another. A probability distribution for D is specified and the mean of the distribution is considered to be a broad policy guideline for releasing the unassigned blood back to the central bank. The variance is considered to be a measure of

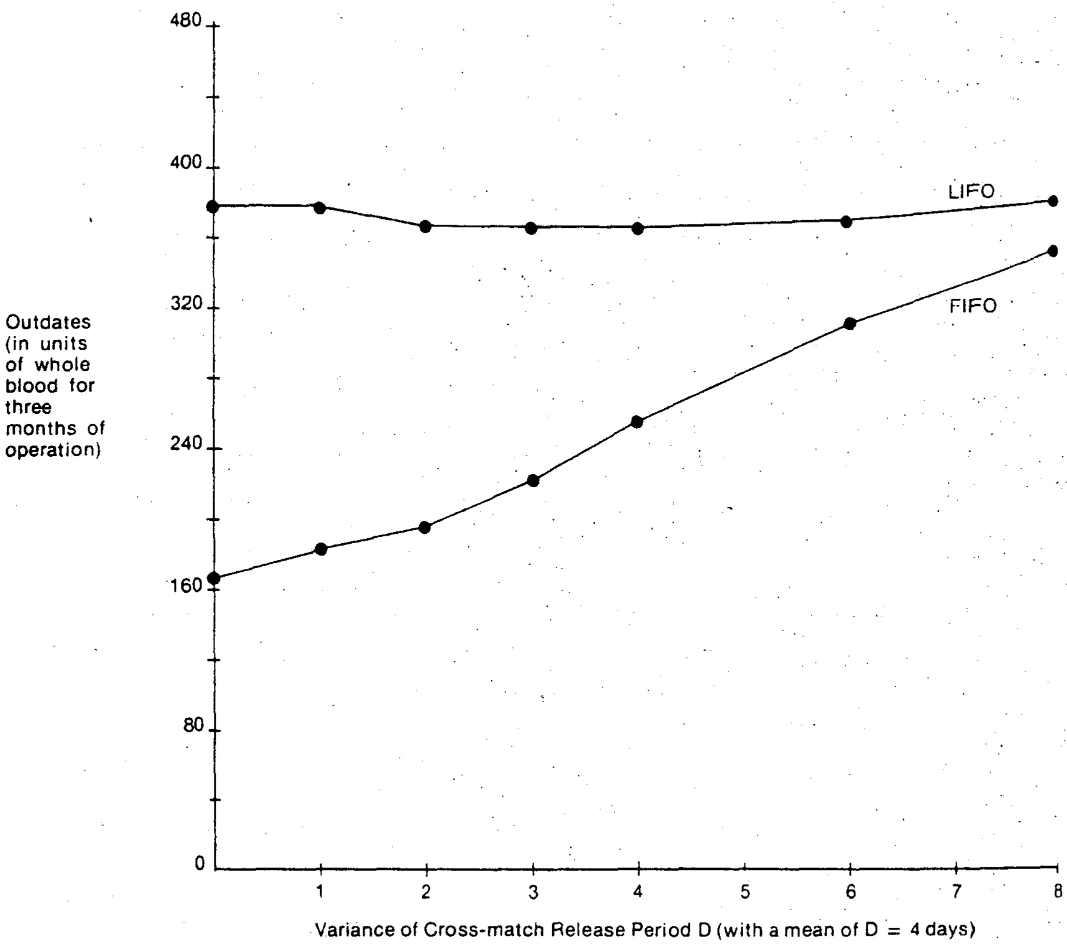

FIG. 2. Outdates and crossmatch release period variance for FIFO and LIFO issuing.

decentralization, *i.e.*, the lower the variance the more the effect of the central administrator's influence. The consequences of decentralization were examined by running the model with a number of distributions for D. The results are given in Table 3 and Figure 2.

These results illuminate the costs of decentralization rather clearly. System performance deteriorates as the variability in D increases, when a FIFO issuing policy is followed. As the variance of D increases from zero to eight, the number of outdates go from a low of 165 at zero to 310 at the variance equal to six. Furthermore, for variances of six and eight, the number of units transfused drops as significant shortages begin to appear. The system is rather insensitive to variability in D under LIFO: however, the system performance for LIFO is uniformly bad (both outdates and shortages are extremely high). The gains achieved by using a FIFO issuing policy can be wiped out merely by the variations in crossmatch release time. This point is clearly seen by the fact that a decentralized blood banking system with a D which has a mean of four and a variance of six is just as bad as a centralized system with a D which has a mean of seven and a variance of zero (see Table 2).

Ordering Policy

In studying optimal ordering policies, the issuing policy was restricted to FIFO and the crossmatch policy to D = two, five, and seven. Upon specification of a value for S, the daily order-up-to quantity, the inventory model is completely described. The optimal order quan

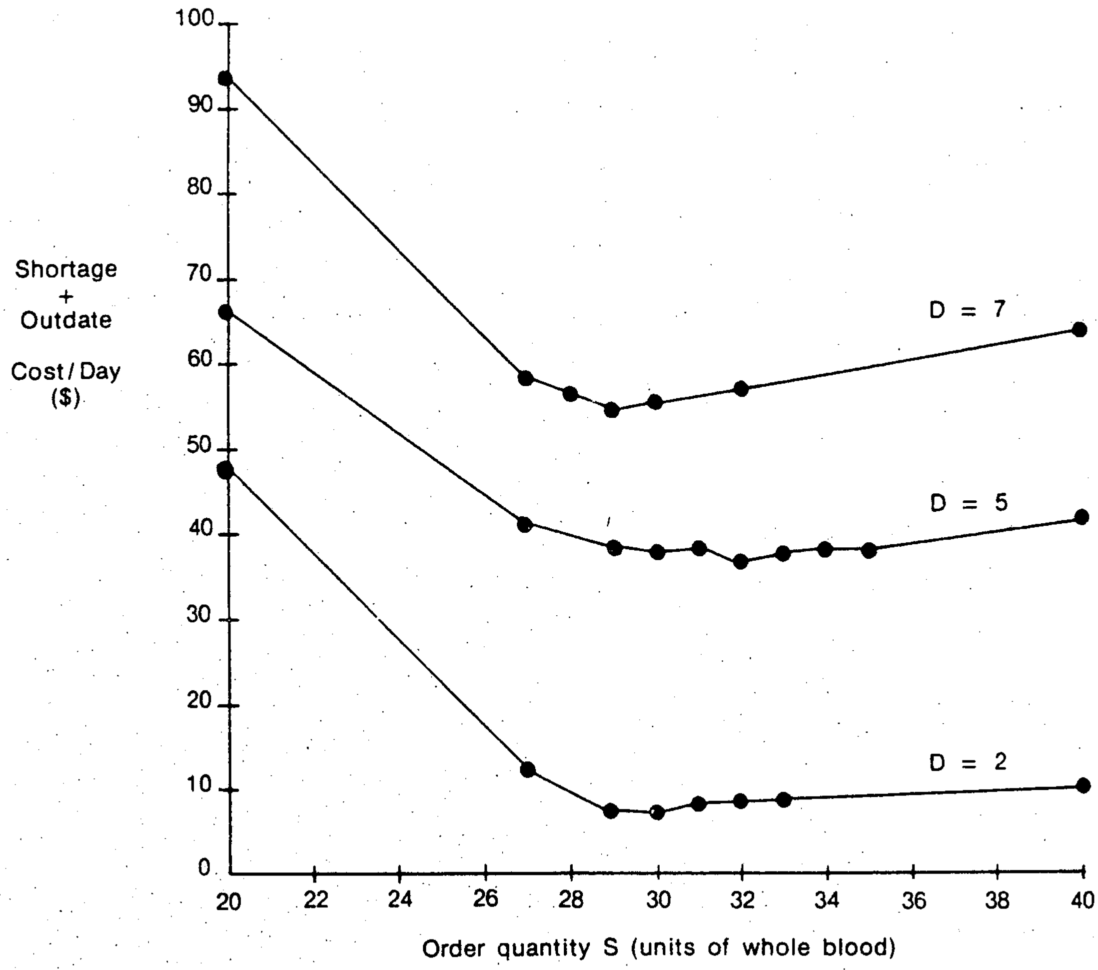

FIG. 3. Average shortage/outdate costs and order quantity for FIFO issuing $55 unit shortage cost, $25 unit outdate cost, and a 100-day simulation period.

tity, S*, is defined to be that value of S which yields a minimum daily cost. The costs chosen were $25 for an outdated unit and $55 for an emergency (shortage) unit. These costs are arbitrary but were chosen because studies have estimated the cost of processing one unit of whole blood at about $25 and a unit of emergency blood at $55. The $55 cost could be an emergency drawing and/or shipping cost or the cost of a frozen unit of packed red cells. In the study by Pinson,[15] other costs were considered and it was shown that the magnitude and shape of the cost curves and the magnitude of the order quantity S* were not greatly influenced by reasonable changes in costs. Table 4 and Figure 3 presents the results of the simulation runs which were obtained by using demand data for a single common blood type from Evanston Hospital, a member of the North Suburban regional bank. The following two key observations can be made from these results: 1) Costs are far more sensitive to crossmatch policy D than they are to the order policy S. (This is seen by the fact that the mean cost/day increases from $7.25 to $36.55 to $54.55 as D goes from two to five to seven days.); and 2) The cost minimizing value, S*, is fairly insensitive to the value of D even though the overall cost level increases significantly with D. This is seen by the relatively flat (near S*) curves of Figure 3. The implications of these two observations are as follows: 1) The effect on shortages and outdates of the ordering policy is minimal for S's in the neighborhood of S* when compared with

TABLE 4. *System Performance at Optimal Order Point S**

Crossmatch Release Period D	2	5	7
S*, optimal order-up-to quantity	30	32	29
Cost/day at S*	$7.25	$36.55	$54.55
Outdates at S*	29	144	216
Shortage at S*	0	1	1
Transfused at S*	493	493	493
Average unassigned inventory at S* (before ordering)	23.99	24.87	21.58
Average assigned inventory at S*	18.77	39.42	53.29

either the issuing or crossmatch policies. The insensitivity of the S's in the neighborhood of S* (the optimal S) is very important because a central bank cannot always achieve S* each day. Indeed, large drawings of blood through donor plans often disrupts the central blood bank policy of achieving S* on a daily basis: and 2) The optimal order quantity is essentially insensitive to the value of D. This also is a very important conclusion in the sense that the blood bank can set S* and then concentrate inventory management control on reducing D knowing that S* will not change significantly.

Conclusions

These observations suggest the following strategy for a regional blood bank. If a unit is crossmatched and not reported transfused within a short time (D equals two or three days), further information on the status of the demand for which the unit was issued should be obtained. If the demand has disappeared, the unit should be made available for possible reassignment either at the same bank or another hospital blood bank. In this manner, the crossmatch release time, D, should be kept as low as possible. As long as D can be maintained below seven days, the FIFO issuing policy should be followed. If D exceeds seven, LIFO will be somewhat better than FIFO but both policies will have excessive outdates and shortages.

The optimal beginning inventory level after ordering, S*, can be computed for a model where D is zero and all issued units are transfused. As the sensitivity analysis of this study shows, the use of this S* will be a very good approximation to the actual optimal policy for the real situation where D is greater than zero. Research is currently under way for simple ways to compute S* as a function of the demand, supply, and organizational characteristics of the particular blood bank.

The overall approach outlined in this paper is contingent on a reasonably efficient information system and an administrative structure which admits some degree of centralized control. Recently, computer technology has been applied to the task of building an efficient blood bank information system.[2, 3, 5, 6, 10, 12, 13] The challenge for implementation of the proposed management strategy is primarily administrative. The need exists since the costs of even seemingly minor deviations from this strategy can be quite high in terms of blood shortages and outdates.

Acknowledgment

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References

1. Bodily, S. E.: Determining the Place of Frozen Blood in Future Blood Banking Systems. Technical Report No. 79, Operations Research Center, M.I.T., January 1973.
2. Bove, J. R., and D. K. McKay: Computer approach to hospital blood bank inventory control. Transfusion 9: 143, 1969.
3. Catassi, C. A., and E. L. Peterson: The blood inventory control system-helping blood bank management through computerized inventory control. Transfusion 7: 60, 1967.
4. Elston, R. C., and J. C. Pickrel: Guides to inventory levels for a hospital blood bank determined by electronic computer simulation. Transfusion 5: 465, 1965.
5. Frankfurter, G. M., A. E. Jelmert, C. C. Pegels, J. P. Seagle, and E. L. Wallace: A regional computer-based blood inventory information system. Transfusion 10: 203, 1970.

6. Hirsch, R. L., F. E. Brodheim, and F. E. Ginsberg: A computer-based blood inventory and information system for hospital blood banks as part of a regional blood-management program. Transfusion 10: 194, 1970.
7. Hurlburt, E. L., and A. R. Jones: Blood bank inventory control. Transfusion 4: 126, 1964.
8. Jennings, J. B.: An analysis of hospital blood bank whole blood inventory control policies. Transfusion 8: 335, 1968.
9. ———: Blood bank inventory control. Man. Science 19: 637, 1973.
10. Katz, A. J., R. S. Holdt, and E. E. Morse: Electronic data processing as an aid to statewide blood management. Transfusion 12: 267, 1972.
11. ———, and E. E. Morse: Distribution of fresher blood in a statewide blood program. Transfusion 13: 324, 1973.
12. Masouredis, S. P., D. R. Roseth, R. T. Stelloh, J. Perine, I. D. Nehama, T. M. Hurst, A. A. Rimm, G. A. Becker, E. A. Stret, S. J. Krenz, and R. H. Aster: Development of an automated blood inventory and information system for a regional transfusion service. Transfusion 10: 182, 1970.
13. O'Hara, M., and A. M. Josephson: Regional automated data-processing system for blood banks. Transfusion 10: 215, 1970.
14. Pierskalla, W. P., and C. D. Roach: Optimal issuing policies for perishable inventory. Man. Science 18: 603, 1972.
15. Pinson, S. D.: A study of decision policies in blood bank inventory control: A computer simulation approach. M.S. thesis, Northwestern University, August 1973.
16. Rabinowitz, M.: Hospital blood banking: An evaluation of inventory control policies. City University of New York, Mt. Sinai School of Medicine, September 1970.
17. Yahnke, D. P., A. A. Rimm, C. J. Mundt, R. H. Aster, and T. M. Hurst: Analysis and optimization of a regional blood bank distribution process. I. introduction and descriptive analysis. Transfusion 12: 111, 1972.
18. ———, A. A. Rimm, G. G. Makowski, and R. H. Aster: Analysis and optimization of a regional blood bank distribution process. II. derivation and use of a method for evaluating hospital management procedures. Transfusion 13: 156, 1973.

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Announcements

International Society on Thrombosis and Haemostasis

The 5th Congress of the International Society on Thrombosis and Haemostasis will be held in Paris from July 21–26, 1975, at the Faculté de Droit, 92 rue d'Assas. Professor J. P. Soulier is President and Professor J. P. Caen is Vice-President and Secretary General.

The main topics of the plenary sessions are as follows: platelets, vessel wall interaction, blood coagulation, thrombosis.

Simultaneous sessions and symposia are scheduled every day in the morning and afternoon.

The participants wishing to present a paper are invited to send us abstracts on the proposed topics: platelets-vessel wall, coagulation, thrombosis (clinical and therapeutic aspects), fibrinolysis, immunohaemostasis, artificial surfaces, and experimental thrombosis.

Unpublished works will be presented, whether in simultaneous sessions or as posters. Speaking time in simultaneous sessions will be limited to ten minutes. A discussion of one hour with the authors of posters will be held every afternoon. The posters will be changed every day.

The abstracts should not exceed 200 words. Deadline for the registration of papers and for submission of abstracts is March 1, 1975. English will be the official language of the Congress.

All scientific correspondence regarding the Congress should be sent to Prof. J. P. Caen, Service Central d'Hématologie, Hôpital Lariboisière, 2 rue Ambroise Paré, 75475 Paris Cedex 10. All administrative correspondence should be sent to Congres-Services, 1 rue Jules-Lefebvre, 75009 Paris.