METHODS FOR REDUCING THE OUTDATING ATTRIBUTED TO OVERORDERING

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ABSTRACT

This paper identifies the relationship between overordering and outdating in a hospital blood bank and introduces the usage to order ratio users. New policies called adaptive policies are introduced to minimize the impact of overordering for users with a low usage ratio. Two major policy classifications are considered corresponding to altering or not altering the usage to order ratio. In classification one the FIFO versus LIFO issuing policies were considered. In the second classification double crossmatching and delayed crossmatching policies were considered. The impact of these policies on the patients physician and the operation of the blood bank are discussed.

To test the various policies data was obtained from the obstetrics-gynecology department of a large medical center in Chicago. The analysis was carried out using a digital computer simulation of the blood bank system.

I. INTRODUCTION

The reduction of outdating of blood and components is a problem
requiring continuous reassesment by the Blood Bank management. This
reassessment has become even more necessary with the growth of both thera-
peutic and prophylactic uses of blood accompanied by the usual difficulty
of maintaining sufficient blood inventories. Indeed, the recent pressure
to change from paid to volunteer donors has made it even more difficult
to maintain sufficient supplies. In yet another direction, physicians
tend to overorder in an attempt to deal with uncertainties in the needs
of their patients. To deal with these problems the management of available
units must become more sophisticated and adaptive. Techniques and pro-
cedures which reduce outdating will augment other management policies and
make management more efficienct.

Before new management policies can be introduced or existing techniques can
be improved to reduce outdating it is necessary to understand the relationship
between outdating and various factors in the logistics of hospital blood
banking.

There are three primary logistical factors related to the cause or control of
outdating. The first factor is the amount of inventory maintained in the blood
bank. Since the needs for blood are random it is difficult to maintain the
exact inventory to meet these needs. When the inventory sufficiently exceeds
demand, many units may outdate simply due to underutilization !Cohen and
Pierskalla, 1978].

The second factor is the issuing doctrin (FIFO or LIFO) used to choose
these units from inventory to be crossmatched. In general, outdating can

be effectively controlled by issuing the oldest units first (FIFO) [Cohen and Pierskalla 1975].

The third factor is the length of time units are left on reserve after crossmatching (crossmatch release time). It has been shown that the cross-match release time should not exceed two days in order to keep outdating at a minimum [Cohen and Pierskalla 1975].

The issuing doctrine and in particular the crossmatch release time are important primarily because physicians routinely overorder. Again, un-certainties in the needs of patients force physicians to be cautious; the result is that they tend to order more, not less, then they will probably administer.

It is important to clarify the concept of overordering by classifying blood users according to the degree by which they overorder. To do this the concept of usage ratio is employed. The usage ratio for a user is computed by dividing the average number of units transfused by the average number ordered (this is the inverse of the crossmatch to transfusion ratio introduced by Mintz et al [1976]). Thus this ratio assumes a value between zero and one. Application of this ratio leads to two general categroies: A small ratio means that only a small proportion of the blood ordered is used and a large ratio means that a large proportion of blood ordered is used. Within the small ratio category, there are two sub-groups: A large absolute number ordered with a relatively small number tranfused and a small absolute number ordered with a still smaller number of units transfused. In the large ratio category, there are also two categories. There are those with a large absolute number ordered with large utilization; and those in which a small absolute number of units are ordered which invariably get transfused.

Into which category a given usage will fall depends on the nature of the associated medical problem or surgical procedure. Medical situations, where need is generally predictable, by and large lead to a large usage ratio in spite of the size of the absolute number ordered. However, in the surgical use of blood, there will be greater variability as demonstrated by Mintz et al [1976]. Certain surgical procedures will fall into predictable categories, for example, cardiovascular procedures tend to have a large usage ratio. Obstetrical and gynecological procedures fall into categories of low usage ratios, due to their unpredictability. It is also evident from Mintz et al [1976] that while general categories can be determined, there is large variation within a category and overlap between categories.

Because of this variation and overlap, it is not likely that a single blood component allocation policy applied universally will produce the most reduction in outdating and may have selective disadvantages to some subgroup of users. This suggests the need for developing a more diversified managerial policy, one which can adopt to the usage ratio of users. The analysis presented later in this article demonstrates that significant savings can be realized by treating the users in the second ratio category.

The concept of adaptive blood management is, therefore, at odds with the general guidelines set forth in the AABB Procedure Manual [1974]. The following is quoted from the manual:

"Hospital Inventories

.........Additional aids to controlling the blood inventory include:

1. "FIFO--"first in, first out," i.e., using the oldest blood first unless contraindicated medically.

In general there are two adaptive approaches for reducing the outdates attributed to overordering users with a small usage ratio. The first is to leave the ratio unaltered but issue newer blood. This suggests using a LIFO as apposed to the traditional FIFO policy or perhaps a blend of the two policies. The second approach consists of policies which directly or indirectly alter the usage ratio. By immediately crossmatching only a fraction of the units ordered while postponing (delaying) the remainder leads to the delayed crossmatching policy. This method directly alters the ratio. A second method requires units be crossmatched to more than one patient simultaneously. This type of policy is referred to as multiple crossmatching, and is an indirect means of increasing the usage ratio.

These policies are interpreted as adaptive policies since the are to be implemented selectively not universally. Some of these are also in agreement with the AABB guidelines stated above.

However before any of these policies can be implemented it is necessary to consider the impacts on the patients, the physicians and the hospital blood bank they may have. A policy should not reduce the quality of service nor unnecessarily delay delivery of blood products to the patients. After all, the mandate of hospital blood banks is to address the needs of the patient in the best possible way.

In many ways, though, the most for reaching consequences of the proposed policies may involve the physicians. The first category, in affect, penalizes those physicians who accuractely predict usage and rewards those who do not because the freshest blood will always be allocated to the low usage ratio user. This means that the high usage ratio physician will routinely receive the older blood.

The second category of policies change the usage ratio of the physician. The implication of this is very clear: the physicians ability to prescribe treatment is being questioned by the blood bank management. If physicians frequently experience delays because the blood bank has crossmatched only a portion of what the physiu vans order, hostilities may develop between physicians and blood bank personnel. Clearly there should be an effort to maintain a positive working relationship between the medical staff and the blood bank in order to best serve patients.

It is not unreasonable, therefore, to expect physicians to resist accepting the proposed policies due to the reasons stated above. The physicians is the person who must bear full responsibility for the well-being of his or her patients. It is possible for some of the policies to make it difficult for the physician to remain fully accountable for the care his or her patient receives.

Finally it is important to consider how the proposed policies affect the efficiency and cost of blood bank operation. The primary benefit derived from these policies is the reduction in outdating (see section 5), thereby reducing costs. Very little will change in the routine operation of the blood bank since little extra work is required and there will be no reduction in the number of crossmatches performed.

In delayed crossmatching policies (category two) there are two possible benefits and some costs. The number of immediate crossmatches is decreased and the number of outdates is reduced (see section 5). The cost, savings due to reduced outdating is obvious, but it is not obvious how reducing crossmatches will affect costs. If the blood bank can either reduce the number of technicians it employs or can reassign them to other tasks then costs are sure to be cut. Otherwise, it is not clear what the real benefits of

reducing the number of crossmatches will actually be realized. There are several different interpretations delayed crossmatching and the cost benefits will vary. The reader is referred to section 5.

Multiple crossmatching policies (category two) leads to reduced outdating at the expense of performing more crossmatches. It is shown in section 5 that these policies are not cost effective for reducing outdates but they are useful in stretching available units to handle more demands than would otherwise be possible.

The purposes of this paper are to investigate how overordering causes outdating, proposing and analyzing policies to reduce outdating attributed to low usage ratio services and to discuss the ramifications and beneftis derived from these policies.

In reviewing the literature, it is apparent that there are many prior studies concerning policies for the reduction of outdating. In recent years Rabinowitz [1970,1973] analyzed double crossmatching policies, assignment of older blood to patients with high probability of transfusion, and use of older Rh negative blood for compatible Rh positive patients. He found that each of these policies leads to reduction in outdating; with the attendant disadvantage of increasing the number of crossmatches performed. Cohen and Pierskalla [1975], Pierskalla and Yen [1978] and Pinson [1973] analyzed ordering, issuing and crossmatch release policies for a regional blood bank and hospital blood banks. They found that use of the oldest blood first, minimization of the crossmatch release time and following optimal ordering policies reduced outdating and shortages. Other recent studies investigating ordering policy (theory and practice) are Jennings [1968,1973], Nahmias and Pierskalla [1973, 1974, 1976] and Bodily [1973]. Pegels and Jelmont [1971] considered a Markov Chain Study of a blood bank system and they

recommend issuing LIFO as opposed to FIFO. The applicability of the recommendation must be questioned because it appears that they advocate using the LIFO policy universally, rather than selectively, which is in opposition to Cohen and Pierskalla [1975]. Some less recent studies are listed in the references.

2. RELATIONSHIP BETWEEN OVERORDERING AND OUTDATING

Intuitively, it appears that when excessive overordering routinely occurs the hospital blood bank must counter by carrying an inventory larger than

However, the optimal amount of inventory to maintain actually decreases as the usage ratio decreases. Cohen and Pierskalla [1976] were the first to recognize this phenomenon and they provide a full analysis as to its cause. We provide a brief explanation here. The optimal inventory level is chosen to minimize the total average outdate plus shortage cost. Suppose the optimum level say 45 is chosen for some usage ratio, say 0.9. Now, consider a smaller usage ratio, say 0.6 but with the inventory at 45. The average number of outdates will probably increase since the efficiency of the system has diminished. Attendant with the additional outdates may be an increase in shortages since the effective inventory is smaller; i.e. those units which outdate are no longer available. Hence, both the outdates and shortages increase which imply that the optimal inventory level should decrease.

Therefore, if the blood bank manager uses the results found in Cohen and Pierskalla [1978] he or she will actually decrease the blood inventory to negate the influences of overordering. WE must conclude, then that overordering must cause outdating in a less direct way.

The likelihood of a unit eventually getting transfused is certainly a function of how often the unit is crossmatched but not transfused. The more often this occurs the less likely the unit will be transfused. This is especially true if units are issued (crossmatched) using the FIFO (oldest first) policy. For Example, supposse a unit is crossmatched when it is 19 days old. If this unit is not transfused, it wil surely outdate. A preliminary study by two of the authors done at Evanston Hospital and Rush Presbyterian St. Luke's Medical Center (RPSL) indicated that, for 0-positive blood, a unit faces on the average of three to five crossmatches during its twenty one day lifetime. This estimate is consistent to that presented by Pegels and Jelmeri [1971]. to see the importance of this, suppose we follow a new unit (freshly drawn) through a sequence of crossmatches none of which lead to transfusion. The first such occasion reduces the average useable lifetime by 20%. The second reduces the useable lifetime by 25%. Similarily, the third and fourth reduce the lifetime by 33% and 50% respectively. If the unit is crossmatched a fifth time but not transfused, there is virtually no chance of the unit being transfused.

Using the number of crossmatches a unit has undergone leads to the concept of crossmatch age. The development of the computer simulation use x in the study exploits this concept. The reader is referred to the Appendix for more details.

Apparently, the primary relationship between overordering and outdating is the significant reduction in the likelihood of transfusion due to wasted crossmatches. The key is the relatively small number of crossmatches a unit may have during its lifetime.

3. DISCUSSION OF THE POLICIES

3.1 Category one - LIFO versus FIFO

In this category, it is recommended that all units crossmatched to OBGYN patients be chosen freshest first (LIFO) rather than oldest first (FIFO). The main idea of this policy is to maximize the future possibility of transfusion for those units crossmatched to OBGYN, but not transfused there. The fewer the number of crossmatches that a unit has undergone previous to its assignment to an OBGYN patient, the better its chances are to be ultimately transfused (See the Appendix).

3.2 Category two - Delayed Crossmatching

An obvious method for reducing the outdating attributed to services with low usage ratios is to only crossmatch a portion of the number of unit ordered. For example, on the average OBGYN physicians order two units and transfuse one or less. It is reasonable to recommend a policy which would routinely crossmatch one unit and perhaps not crossmatch the other unit. For reasons to be made precise below, this policy is called a delayed crossmatching policy.

There is a risk associated with the policy described above since it is possble that the patient may require both or even more units. To hedge against the possibility that more than one unit will be needed, the blood bank manager may wish to choose from a variety of variations or extension of the above policy. All of these involve forms of delaying the crossmatching of a portion of the number ordered.

The first possibility is to wait until the first unit (of those initially crossmatched) has begun to be transfused. When this occurs, the balance of the requested units can then be crossmatched. In this way one can avoid delays and at the same time eliminate a significant number of crossmatches.

The second possibility is to immediately crossmatch some units and perform only a type and screening on the remainder. When the latter group of units are needed, they can either be transfused directly or the remainder of the crossmatch can be performed. This policy has been recommended by Mintz et al [1976]. They advocate this policy because modern screening procedures appear to be almost as sensitive as the crossmatch procedure, and thus it is safe to transfuse these units directly. Unfortunately, this has not yet become an accepted medical practice and the possible legal and medical ramification have not yet been explored.

Clearly these three policies can all be considered as delayed crossmatching policies but they differ by the methods used to process those units required beyond the initial amount crossmatched. For sake of completeness, these methods are: The emergency crossmatch (done on demand) the simple delayed crossmatches (which begins after the first transfusion)) and the type and screen.

For the purposes of this paper, we will not differentiate between the three policies, since our interest is primarily in the amount of reduction in outdating which will result by following a delayed cross- matching policy. It will merely be assumed that the appropriate number of unit will eventually be made available. Unfortunately, the impact on the efficiency and cost of operation associated with these policies is beyond the scope of this study.

4. Methodology

The study focused on the obstetrics-gynecological department (OBGYN) at RPSL which had a usage ratio of roughly 0.1-0.2 whose total demand was only a small portion (8%) of the hospital demand. Data from OBGYN was used to compute the empirical probability distributions of the following seven characteristics:

(1) the number of patients demanding blood on any given day (by blood group),

(2) the daily surgical procedures,

(3) the daily number of physicians performing the surgical procedures,

(4) the daily number of units demanded for each surgical procedure,

(5) the daily number of units transfused to a patient based upon the number of units ordered for the patient and the surgical procedure used,

(6) the daily number of units demanded by each physicians, and

(7) the daily number of units transfused by each physician based upon the number he ordered.

Although each of these seven data sets were collected for the analysis, the two most important data sets were: number-(7) the daily number of units transfused by the physician based upon the number ordered, and number (5) the daily number of units transfused to a patient based upon the number of units ordered and the type of surgical procedure being followed.

In order to measure the effectiveness of the various policies, a computer simulation model was developed which captures the essence of the demand - crossmatch - transfusion process of a hospital blood bank. (See appendix for a discussion of the simulation model and the accompanying outdate projection model).

The method of analysis was to implement the various policies in the model
and run the simulation for 500 days. Two runs were made with each policy,
using each of the two patient data sets mentioned above. The output of
each simulation was the projected average number of outdates. In this manner,
it was possible to observe the relationship between the policy, surgical
procedure, physician and the resulting outdates.

5. RESULTS

As previously mentioned, the analysis was conducted using two data
sets -- one physician based and the other surgical procedure based. Unless
otherwise specified, the redsults presented are based on the daily number of
units demanded by the physician. There are two reasons for not presenting
the procedure based results here. First, it was determined that the surgical
procedure had little effect on the number of units demanded; the results
obtained using the procedure based patient data set were virtually
identical to those using the physician based patient data set. Second, only
those policies which are simple and unambiguous are feasible to implement in
the blood bank, since it is necessary to minimize both the possibility of
error as well as any extra effort on the part of the technician. Policies base
based on physician's name are less ambigous than those based on the name of
the surgical procedure. Often surgical procedures are identified by
synonyms on the order form and this information is frequently tentative.
Thus, the technician might have to make an arbitrary judgment to follow
such a policy.

Analysis of the results will be according to each of the policies
considered. First, the issuing policies are considered. These are regarded

as methods for reducing outdating without altering the usage ratio. Next are the double crossmatching and delayed crossmatching. These are regarded as methods for altering the usage ratio.

5.1 LIFO versus FIFO

The simulation was run first following a FIFO policy and the following a LIFO policy in OBGYN. Table 1 displays the results of the two simulation runs. There were 1753 units crossmatched and of these 164 units were transfused. Using FIFO the projected number of outdates was 643 units whereas under LIFO there were only 130 units outdated by this department.

These results in Table 1 assume that (a) FIFO is followed in the departments other than OBGYN and (b) has a small portion of the total hospital demand.

LIFO versus FIFO

Policy	Total Number of crossmatch Procedures	Projected Number of Outdate	Outdating as a Percent of Total Demands
FIFO	1753	643	37%
LIFO	1753	130	7%

Outdating Resulting from LIFO and FIFO Single Crossmatching in OBGYN (1753 units demanded and 164 units transfused)

TABLE 1

The primary conclusion drawn from this observation is that a LIFO issuing policy results in fewer outdatings than a FIFO issuing policy. This conclusion appears to contradict the stated procedures of the AABB and some prior studies; indeed they advocate strict adherence to a FIFO policy. However these results are entirely consistent with the notion of adaptive policies introduced earlier in this article. Since OBGYN represents a small proportion of the total volume of the blood bank at RPSL the change from FIFO to LIFO in OBGYN will not seriously distrub the general behavior of the inventory system. Therefore the general recommendation of Cohen and Pierskalla [1975] remain valid for the administration of blood units not going to OBGYN.

This policy should not have any major impact on the routine operation of the blood bank since only the issuing policy needs to be changed and this will not be done very often due to the low volume involved. Similarily, this procedure will not have a large impact on the cost of operation except that the outdate costs will be significantly smaller than in the status quo.

5.3 Delayed Crossmatching

Simulation runs of 500 days were again performed. The delayed cross-match policies considered were those where approximately one-half, two-thirds and three-fourths of the total units demanded would be crossmatched the day prior to transfusion. In addition, for thos x units crossmatched when chosen from the inventory using a LIFO policy crossmatching. The results of the simulation are given in Table 3, while the relationship between the degree of delayed crossmatching and the degree of emergency crossmatches (both expressed as the number of units crossmatched) is depicted in Figure 1.

From Figure 1, it should be noted that the emergency crossmatches as a percent of total transfusions is very large except when almost all units are fully crossmatched. Even when one partially crossmatches 82% of the total demand, 5% or more of total transfusions must be met by emergency crossmatches. It is not likely that in most hospitals the delay of transfusions 5% or more of the time would be acceptable to the medical staff. Furthermore, crossmatching 82% of the demand versus 100% of the demand in this department which grossly overorders saves only 309 crossmatches in 500 days or less than one crossmatch per day. In addition, the number of outdates is only reduced by 50 units.

At this point it is important to recall from section 3.3 the different types of delayed crossmatching schemes. The above discussion directly applies to the first policy discussed there. The second policy would have less negative impact because the additional units would be crossmatched as soon as the first transfusion begins. Thus the delays would all but be eliminated. The third policy would be much the same as the second except that the so called "emergency" units would be transfused with only a type and screening. As mentioned in section 3.3, the legal and medical consequences of this are not yet understood.

The remaining question, of which we can only provide a partial answer, is what does delayed crossmatching do to the effeciency and cost of operation of the blood bank? For sake of discussion, suppose the second delay policy from section 3.2 is followed at the 50% level. Then, there will be 910 crossmatches performed routinely and 62 performed later (initiated at the instant the first crossmatch begins). This represents a savings of 781 crossmatches or 45% over a 500 day period.

Under the normal LIFO policy (section 3.1) all 1753 crossmatches would be done during the evening prior to the scheduled surgery. Under the delayed policy, 910 crossmatches would be performed at night and 62 during the day, over the 500 day test period.

The delayed policy will represent positive economic benefits only if the night technicians can be effectively assigned other duties, or in the extreme case laid off, and if the emergency crossmatches do not seriously effect the normal day -time routine of the blood bank. If the delayed policy is apptied only to OBGYN the answers are fairly straight forward, since the numbers are so small. It is clearly economically beneficial to follow this policy. However, if the policy is applied to other groups as well, the problem becomes quite complex.

This study was concerned with developing procedures for reducing the outdating attributed users with a small usage to order ratio. The relationship between overordering was discussed and several adaptive policies were suggested and their ramifications discussed.

The study showed the following conclusions:

1. Issue by LIFO to the small department which have a small usage ratio and issue by FIFO to the other departments. This policy reduced outdating in this OBGYN from 37% to 7% of total demands and negligibly affects the out-dating in the other departments.

2. Use delayed crossmatching with LIFO issuing provided that technicians performing routine crossmatches can be efficiently reassigned and emergency crossmatches can be performed without delay and routine blood bank opperations are not significantly disturbed. If these criteria are met, this policy is the best means to reduce outdating.

The implementation of the adaptive LIFO policy or the LIFO-delay policy when applicable gives the blood bank manager additional flexibility for controlling low usage to order ratios but without infringing on the physician's freedom to treat his patients nor jeopardizing the well-being of any patient. This is in complete agreement with the purpose of a hospital blood bank-- to provide the best service to the physicians and their patients.

APPENDIX

This appendix provides a brief description of the computer simulation model that was used as an instrument for comparing different inventory issuing and crossmatching policies. The computer program is written in FORTAN IV and was run on the CDC 6400 digital computer at Northwestern University.

Any comparison between issuing and crossmatching policies will involve comparing the level of system performance achieved by following each policy over some extended period of blood bank operation. The simulation model is used to determine measures of system performance as an alternative to the impractical method of actually implementating such policies in the blood bank for extended periods of time.

The model simulates 500 days of the blood bank activity pertaining to OBGYN (by blood group and Rh factor) in accordance with the following scheme.

DATA (A)   Read in the number of patients to
                            process today.

DATA (B)   Read in the number of units ordered
                            for each patient.

CLASSIFY[1]   Classify each patient as a DCM[2]
                            or SCM[3] candidate.

CROSSMATCH[1]   Determine appropriate number of units
                            to SCM and DCM to each patient.

                            Determine the appropriate number of units
                            to issue FIFO and LIFO to each patient and
                            for DCM units.

DATA (C)   Read-in the number of units to transfuse
to each patient.

TRANSFUSION[1]   Count the number of DCM, SCM, FIFO, and
LIFO units transfused and not transfused.

STATISTICS   Tabulate all relevant statistics.

GO TO THE NEXT DAY

The simulation requires various data sets: (A) the number of patients to process each day; (B) the number of units ordered for each patient, and (C) the number of units transfused to each patient. These data sets were generated using a psuedo-random number generator in conjunction with the empirical probability distributions discussed in the Methodology section of this article.

The final output of each simulation run is the total number of units transfused, not transfused by SCM, DCM, LIFO and FIFO. This output is then used to compare the various policies in terms of their relative system performances.

System performance is measured in three main categories: (1) total number of crossmatches; (2) number of emergency crossmatches; and (3) projected number of outdates. The first two have rather immediate interpretations and are easy to compute. The third is more challenging because it requires a method of predicting the number of outdates that result as a consequence of following a particular policy.

The outdate model estimates the expected number of units that will outdate given the issuing policy, the total number of units transfused and the transfusion probabilities. It turns out that a new concept of blood unit age provides the basis for the model. Rather than defining the age of a unit in days we propose an alternative approach. Specifically, the age of a unit is defined to be the number of crossmatches performed on it. For example, if a unit has been crossmatched twice, it is 2 crossmatch age units (CMA) old. In this context, the lifetime of a unit is the maximum number of crossmatches (MNC) that can be performed in any unit. Then, a unit will outdate if it does not get transfused during its final crossmatch.

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1. See the Results section of this paper for descriptions of the policies.
2. CM stands for crossmatch.
3. DCM stands for double crossmatch.
4. SCM stands for single crossmatch.

Unfortunately, the total number of crossmatches actually performed on each unit is a random variable that is affected by the length of tine between crossmatches, the demand rate, the daily supply and other factors. Therefore, we approximate the MNC by the average total crossmatches (ANC) performed

on all units. At RPSL, ANC was 4 which means that on the average a unit will be crossmatched 4 times provided it does not get transfused. Therefore, each wasted crossmatch reduces the effective age of a new unit by 25% . This is to be contrasted with the reduction of 9% (2 days from 21) of effective age using the traditional age measure. Clearly, the CMA approach provides a better measure of the outdating attributed to wasted crossmatches than does the traditional approach.

The outdate model uses the CMA concept in conjunction with transfusion probabilities to approximate the outdate probability of each unit crossmatched to OBGYN. Data from RPSL indicates that the transfusion probability associated with any crossmatch outside department A is 0.51. The corresponding probability for OBGYN is 0.11. At this point, we make the assumptio n that no unit is crossmatched more than once to OBGYN. The data indicates that only a very small fraction of those units crossmatched to OBGYN return at a subsequent time. The following examples indicate the logic behind the outside model.

Suppose a unit (at RPSL) has already been crossmatched 3 times so that OBGYN gets the remaining crossmatch. Then, the outdate probability is .89. Now, suppose the unit has been crossmatched twice so that OBGYN gets the third crossmatch. Referring to Figure 5, outdate probability is (0.89) x (0.49) = 0.41.
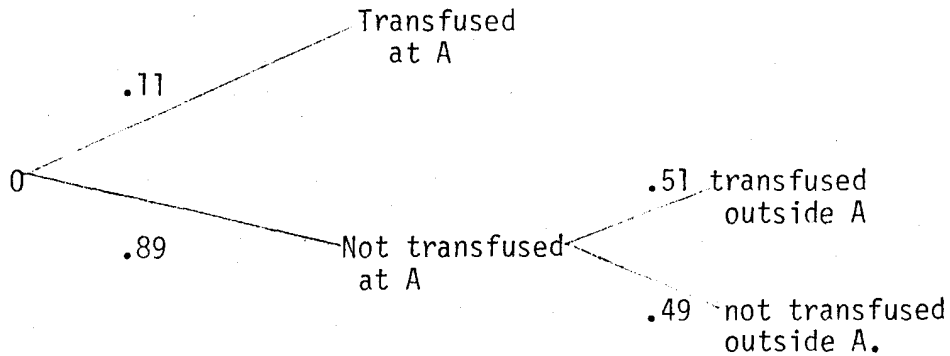
Figure 1

In general, if a unit has x crossmatches remaining (on the average) after OBGYN the outdate probability is

$$P_x = (.89)(.49)^x \ , \quad x = 0, 1, 2, 3.$$

Notice that $P_x \geq P_y$ whenever $x \leq y$. Hence, units issued to OBGYN by FIFO have a larger outdate probability than those issued by LIFO. Unfortunately, the exact value of x in either of these cases is a random variable having a very complicated distribution. Based on empirical evidence, we used the following conventions: Units issued by FIFO were assigned x = 2 while x = 3 was assigned for LIFO.

The outdate model is given by the expression.

$$\text{Predicted outdates} = N_F \ (.89)(.49)^2 + N_L \ (.89)(.49)^3$$

where N_F and N_L are the total number of units issued by FIFO and LIFO respectively. The simulation provides the values N_V and N_L for each policy implemented. This model appears to be quite accurate and provides an interesting

means of relating unnecessary crossmatches and outdating. Further

verificatjion can be found in Pierskalla and Yen [1978].

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