Inventory Control Policies for a Hospital Blood Bank: A Simulation and Regression Approach

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병원의 혈액 재고관리를 위한 평가 모형 : 시뮬레이션 및 회귀분석 방법

서정대

〈Abstract〉

The management of blood inventory is very important within the medical care system. The efficient management of blood supplies and demands for transfusions is of great economic and social importance to both hospitals and patients. For any blood type, there is a complex interaction among the optimal inventory level, daily demand level, daily supply level, transfusion to crossmatch ratio, crossmatch release period, issuing policy and the age of arriving units that determine the shortage and outdate rate.

In this paper, we develop an efficient decision rule for blood inventory management in a hospital blood bank which can support efficient hospital blood inventory management using simulation. The primary use of the efficient decision rule will be to establish minimum cost function which consists of inventory levels, period in inventory, outdate and shortage rate for whole blood and various component inventories for a hospital blood bank or a transfusion service. If the administrator compute the mean daily demand for each blood type, the mean daily supply for each blood type, the length of the crossmatch release period and the average transfusion to crossmatch ratio, then it is possible to apply the efficient decision rule to compute the optimal inventory level, inventory period, outdate and shortage rate. This rule can also be used as a decision support system that allows the blood bank administrator to do sensitivity analysis related to controllable blood inventory parameters.

1. INTRODUCTION

The management of blood inventory occupies a critical position within the medical care system. The efficient management of blood supplies is of great economic and social importance to both hospitals and patients. The blood is perishable and is not usable after its lifetime.

The major responsibility of a hospital blood bank is to administer the collection, processing, storage and distribution of whole blood and blood products throughout the hospital in a manner that ensures all

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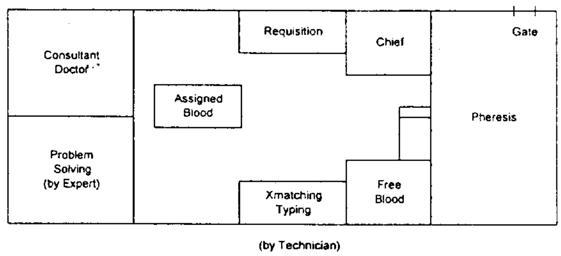
blood-related demands are met. In addition to this primary goal, the hospital blood bank is also concerned with the minimization of wastage through outdates and spoilage, the maintenance of high quality standards and the reduction of shortages. In order to achieve these goals, it is important to set inventory levels which trade off shortage versus outdate rates and minimize total operating costs.

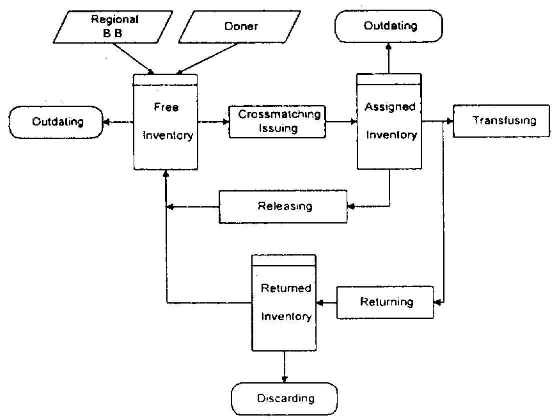
The hospital blood bank operates as an inventory location, storing and issuing the appropriate blood units to satisfy transfusion requests. And order the amounts of blood units which maintain the efficient inventory level to the regional blood bank.

During the course of a day the blood bank receives a random number of transfusion requests for each blood type, each request for a random number of units. Once a request for a patient is received, the appropriate number of units of that type are removed from free inventory(available inventory). In such a case, there are rules of which blood units are removed first from inventory. These rules are called *issuing policy* and is mainly dependent upon the age of blood in inventory. Upon successful crossmatching, they are placed on reserve inventory(assigned inventory) for this particular patient. The number of days after which crossmatched blood is released back to free inventory if not transfused is called *crossmatch release period.* Any units that are not transfused within crossmatch release period are released to free inventory. And any units that are not used within their lifetime are considered *outdated* and are discarded from inventory. The blood units which are issued from assigned inventory whitin crossmatch release period may be transfused to the patients or may be returned. Being issued from assigned inventory, the whole reserved units may be transfused or the fraction of reserved units may be. The fraction of total blood units actually transfused to total blood units crossmatched is called *transfusion to crossmatch ratio.* Any units returned from assigned inventory are put into the returned inventory. Through several test, the units are either returned to free inventory or discarded.

The functional inside layout of the hospital blood bank and the model of blood inventory management process in hospital blood bank is displayed in 〈Figure 1〉 and 〈Figure 2〉.



〈Figure 1〉 The functional inside layout of the hospital blood bank



〈Figure 2〉 A model for the blood inventory management in hospital blood bank

We define *demand* to be the number of blood units requested, and *usage* to be the number of units transfused. Also we define *supply* to be the number of blood units supplied from both external and internal site. *Outdate rate* is the ratio of mean number of blood units outdated to mean number of blood units transfused plus those outdated. A situation when the demand exceeds the number of units of blood in inventory is *shortage.* The long-term fraction of days on which a shortage occurs is *shortage rate.*

For any blood type, there is a complex interaction among the optimal inventory level, daily demand level, daily supply level, transfusion to crossmatch ratio, crossmatch release period, issuing policy and the age of arriving units that determine the shortage and outdate rate.

In this paper, we develop an efficient decision rule which can support efficient hospital blood inventory management by using simulation. The usefulness of the rule is to identify the endogenous and exogenous factors which can affect the inventory level of each blood type and to have the hospital blood bank administrator control the inventory level efficiently. This rule can also be used as a decision support system that allows the blood bank administrator to do sensitivity analysis related to controllable blood inventory parameters.

2. Past Research in the Area

2.1 Policies and Inventory Levels

Jennings(1973) used simulation to evaluate hospital blood bank performance. He derived trade-off curves showing outdating vs. shortages as functions of the inventory level. Brodheim, Hirsch and Prastacos(1976) collected daily demand data of almost each blood type. Through a statistical analysis of these data they showed that the inventory required to meet the daily demand is given by $I(s)=A(s)+B(s) \cdot ED$ where ED is the mean daily demand, and $A(s)$ and $B(s)$ are functions of the shortage rate s, and are common for all blood types and hospitals. Cohen and Pierskalla(1979) assigned unit costs to shortages and outdates, ran extensive simulation tests, and used search techniques to derive optimal inventory levels as functions of all the hospital parameters that affect outdating and shortage. They found that the three most important parameters for setting inventory levels are the mean daily demand ED, the crossmatch-to-transfusion ratio r, and the crossmatch-release period T_0, and that the optimal inventory level is a Cobb-Douglas function.

Crossmatching policy is the rule according to which units are selected from inventory, and are then assigned to patient requests. Because units are perishable, and because not all units issued are eventually transfused, this procedure influences outdating. Under the assumption that all units crossmatched are used(i.e., for general perishable products), the crossmatching policy reduces to an issuing policy.

For this case it was shown by Pierskalla and Roach (1981) that, under certain conditions, issuing the oldest units first(FIFO) minimizes the average quantities short and outdated. Brodheim and Prastacos(1980) developed an algorithm for selecting units in a decreasing age from inventory, and assigning each unit sequentially to the request that maximizes the likeli- hood of using it. They showed that this policy minimizes expected outdating and shortages. Jagannathan R. and Sen T.(1991) developed a model for determining outdates and shortages for crossmatched blood using generally accepted parameters, such as proportion of crossmatched blood that is actually transfused, and the number of days after which crossmatched blood is released if not transfused.

One of the areas of growing importance to blood bank is the use of blood components in transfusion therapy. The management issue that arise is what portion of the daily fresh supply of a hospital or a center should be fractionated, and in what components. Deuermeyer (1976) showed that daily platelet demand is characterized by two random variables, number of requests and request size, each of which can be approximated by Poisson random variables, and that the total demand can be approximated by a Neyman A distribution. He also developed heuristic inventory policies for the platelet process of the whole blood-platelet inventory system.

Freezing red cells is a way of alleviating shortages caused by seasonal drops in supply, or unusually high demand for rare blood types. However, freezing is very expensive, and, if implemented on a significant portion of the fresh units, will increase the operating costs considerably. Cumming et al.(1977), and Kahn et al.(1978) have conducted extensive simulation runs to examine the effect of freezing policies on the hospital's blood inventory behavior. Their studies showed that the main effect of the freezing policy is a more stable operation of the Hospital blood bank with outdating remaining approximately constant.

A related problem is that of examining the impact of extending blood's lifetime from 21 to 35 days through the addition of CPD adenine in the blood bags. Several studies(Elston(1968), Pegels(1978)) have examined this problem, mainly through simulation. They agree that, under the extended lifetime and assuming collections do not change, outdating remains approximately the same. However, if collections change so as to keep inventories the same as under the 21-day lifetime, then outdating could be significantly reduced.

2.2 Implementation Issues

The implementation of models and the overall operation of the system requires the consideration of certain issues that involve subjective decisions and trade-offs.

Setting inventory levels involves making a trade-off between the shortage rate and the outdate rate. The trade-off between shortage and outdate rates generally differs among blood types. Prastacos(1980) indicated through simulation experiment a very significant difference in the outdate rates among different blood types stocked at the same shortage level.

One of the most important factors in the control of outdating is the crossmatch release period(the time elapsed until a reserved unused unit is put back in free inventory). Cohen and Pierskalla(1979) included this as a parameter for the setting of inventory levels. Simulation experiments indicated an increase in outdating when this period increased from 1 to 2 and 4 days.

Another very important parameter in the control of outdating is the transfusion to crossmatch ratio, which represents the ratio of the average demand of a request to the average usage from a request. This ratio can vary depending on the type of operation. A number of authors have suggested guidelines whereby an effort is made to reduce the size of the crossmatch requests for uncomplicated patients, while not imposing limits for exceptional ones.

Another parameter that affects the outdate rate is the age of the blood bank's incoming supplies. Units collected by the hospital are fresh, while units received from other sources(Region Blood Center, or another hospital) could be of any age between 2 and 20 days old. Simulation experiments show that the resulting outdate rate can be affected as we vary the percentage of the quantity fresh. It was assumed that the quantity received from other sources is uniformly distributed between 1 and 10 days old.

3. Simulation Modeling

In this section, we develop an efficient management system for the blood inventory control by using simulation. For this purpose, various conditions and policies for the blood inventory management are designed and specified. An efficient decision rule is developed and evaluated by using simulation.

3.1 The Variables and Levels

We make a selection of the variables and conditions for the blood inventory management. There are many exogenous and endogenous variables associated with any blood banking system. The exogenous factors which are random variables include the parameters specifying the mean daily demand, the parameters specifying the age of arriving units, and the transfusion to crossmatch ratio that is the fraction of total daily demand which is transfused. The endogenous variables which are policy variables include such control factors as the issuing policy, the crossmatch release period and the mean daily supply. The mean daily supply is related to the inventory level in blood bank.

Changes in operating policy will clearly have an impact on the performance of the blood bank. Because the target inventory level is affected by many environment factors, it is necessary to construct a model of the blood bank in order to test the complex interactions and effects of these factors. The model requires specifications of input factors relating to system environment and control policy. The factors considered in this analysis include: parameters to specify the daily demand process, parameters to specify the age(of units arriving at the blood bank) process, the transfusion to crossmatch ratio, target inventory levels, issuing policy and crossmatch release period. 〈Table 1〉 represents the conditions of the experiment.

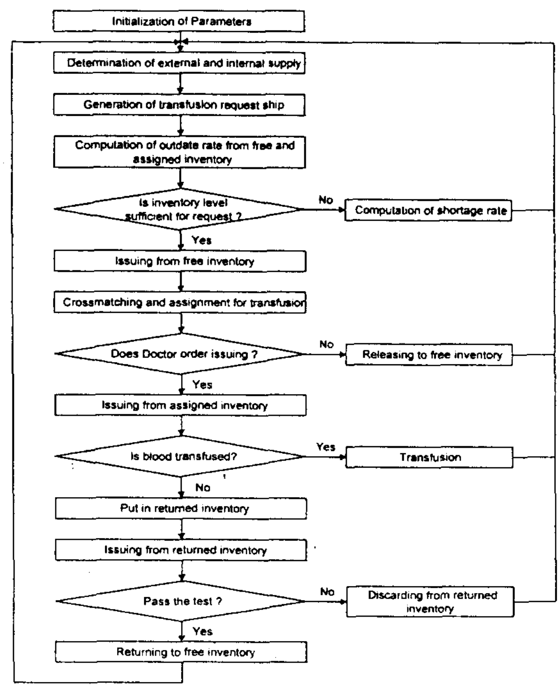
〈Table 1〉 The variables and levels of the experiment

Variable	Levels	unit
Mean daily demand	0.8, 0.9, 1.0, 1.1, 1.2	multiplication
Age of arriving units	1, 6.03	days
Transfusion to crossmatch ratio	0.25, 0.5	ratio
Mean daily supply	0.85, 0.90, 0.95, 1.00, 1.05, 1.10, 1.15	multiplication
Crossmatch release period	1(1440), 2(2880), 3(4320)	days(minutes)
Issuing policy	FIFO, LIFO	policy

The mean daily demand takes the multiple values of the general hospital from 0.8 to 1.2. The lower multiplication of mean daily demand corresponds to transfusion locations with low daily demands. The large multiplication corresponds to large hospitals. The age of arriving supply is drawn from classes of empirical distributions. An empirical distribution estimated from hospital data and a degenerate uniform distribution yielding fresh supply are considered.

3.2 Modeling

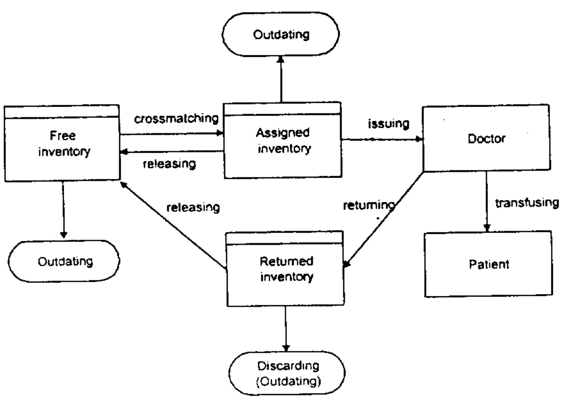
The simulation model is constructed to test the complex interactions and effects of various factors and to determine the efficient decision rule. 〈Figure 3〉 depicts the overall scheme of the simulation model. After the initialization of parameters, the model sets the parameters of external and internal supply, and generates the request slip for blood transfusion. Once the order for a transfusion arrives, the model checks whether the free inventory level is sufficient for the request. If the amount of the order is greater than the inventory level,



〈Figure 3〉 The simulation model for the blood inventory management then a shortage has occurred and the model computes the shortage rate. If there are enough inventory, the ordered blood would be issued from free inventory and reserved at assigned inventory after crossmatching test against the patient's blood type for transfusion.

Not all the blood in assigned inventory are issued to the doctors due to the transfusion to crossmatch ratio and not all the blood issued to the doctors are transfused to the patient. The blood not transfused are returned and put into the returned inventory for 24 hours. If the blood in returned invetory pass the test(such as plasma agglutination fault test), they are returned to free inventory. On the other hand, the blood which does not pass the test is discarded from returned inventory.

⟨Figure 4⟩ shows the blood flow in the hospital blood bank. The outdated blood contains both the outdated blood whose lifetime is exceeded and the discarded blood due to the faults in free inventory, assigned inventory and returned inventory.



⟨Figure 4⟩ The blood flow in the hospital blood bank

We collect simulation data from a general hospital with 1,300 beds for one year. The blood types we consider are A, B, O and AB types and the components are Whole Blood, P.C.(Packed Cell), F.F.P.(Fresh Frozen Plasma), Platelet and P.R.P.(Platelet Rich Plasma). The lifetime of each component types are 21 days, 21days, 1year, 72 hours and 48 hours, respectively.

We set the replication length to be 180 days(259,200 minutes) and the warm-up period to be 30 days(43,200 minutes). The number of total simulation cases are 840.

The distributions of both supply and demand are affected whether the corresponding date is weekend or not. So, the distributions are included in the form of practical distributions according to the date. The distributions of the age of arriving units, the number of pints requested per demand, the transfusion to crossmatch ratio, the crossmatching time and the time required for issued blood to be returned are also included in the experiment in the form of practical distributions.

We define performance measures to compare and evaluate each conditions of the experiment in blood inventory management as follows:

· *Outdate rate* = the amount of outdated blood / (the amount of transfused blood + the amount of outdated blood)
· *Shortage rate* = the amount of shortage blood / the amount of requested blood
· *Average age of blood transfused* = the average age of blood when it is transfused
· *Average period in inventory* = the average number of days between supply and transfusion

The available inventory can be composed of bringing forward inventory, outdated, returned blood, internal and external supply and defined as follows:

· *Inventory level* = bringing forward inventory - outdated blood + returned blood + internal supply + external supply

Model output includes a detailed record of all inventory transactions and the performance measures. For the purpose of decision making we seek to minimize mean daily shortage plus outdate costs. Thus a cumulative record of total outdates and shortages is kept. Upon multiplication by the appropriate unit cost and division by the number of days in the run, the desired average outdate and shortage cost is obtained. We seek for the inventory level S through the generation of average outdate plus shortage costs for a fixed set of inputs over a range of different values.

3.3 Results

The values of inventory level, outdate rate, shortage rate, average age of blood transfused and average period in inventory according to the variance of the mean daily supply from 0.85 to 1.15 in the case of d=1.0, A=1.0, p=0.5, D=3, I=FIFO issuing policy, are represented in Table 2. The unit of inventory level is 'pint' and the unit of average blood age transfused and average period in inventory is 'minute'.

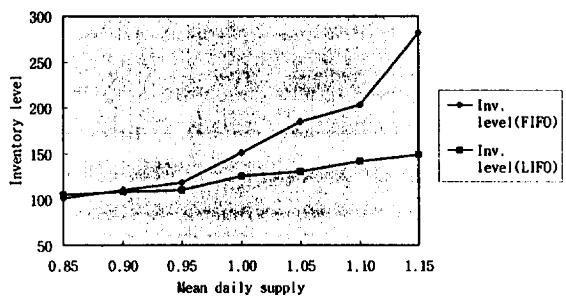
〈Table 2〉 The variance of the performance measures to the variance of the mean daily supply where d = 1.0, A = 1.0, p = 0.5, D = 3, I = FIFO

Mean daily supply	Inventory level	Outdate rate	Shortage rate	Ave. blood age transfused	Ave. period in inventory
0.85	101.23	4.46	17.79	10626.7	6576.7
0.90	110.21	6.10	12.15	11081.6	7126.0
0.95	118.28	6.54	11.39	11298.3	7216.1
1.00	150.97	5.58	3.72	11777.6	7837.3
1.05	184.78	7.41	0.99	12871.0	8892.2
1.10	203.33	8.27	0.45	13138.3	9212.9
1.15	281.49	10.31	0.00	15249.5	11346.3

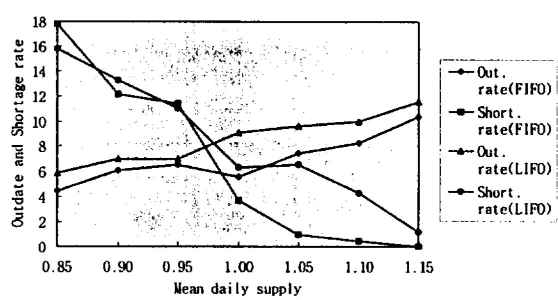
In the case of LIFO issuing policy, the values are represented in Table 3. The units are the same as Table 2. The inventory level, the outdate and shortage rate, the transfused blood age and period in inventory in FIFO and LIFO policies to the variance of mean daily supply are displayed in 〈Figure 5〉, 〈Figure 6〉 and 〈Figure 7〉.

〈Table 3〉 The variance of the performance measures to the variance of the mean daily supply where d = 1.0, A = 1.0, p = 0.5, D = 3, I = LIFO

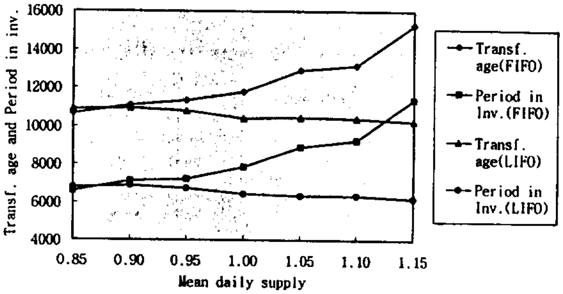
Mean daily supply	Inventory level	Outdate rate	Shortage rate	Ave. blood age transfused	Ave. period in inventory
0.85	104.70	5.84	15.75	10861.4	6781.6
0.90	108.06	6.99	13.23	10931.0	6851.2
0.95	110.37	6.99	11.01	10789.8	6722.3
1.00	125.78	9.11	6.32	10353.7	6413.8
1.05	130.36	9.63	6.57	10435.3	6340.0
1.10	142.09	9.96	4.31	10356.2	6337.3
1.15	148.62	11.52	1.19	10238.7	6159.7



〈Figure 5〉 The inventory level in FIFO and LIFO policies to the variance of mean daily supply where d = 1.0, A = 1.0, p = 0.5, D = 3



〈Figure 6〉 The outdate and shortage rate in FIFO and LIFO policies to the variance of mean daily supply where d = 1.0, A = 1.0, p = 0.5, D = 3



〈Figure 7〉 The transfused blood age and period in inventory in FIFO and LIFO policies to the variance of mean daily supply where d = 1.0, A = 1.0, p = 0.5, D = 3

On these tables and figures, we can observe that the inventory level and the outdate rate are increased as mean daily supply increases. On the other hand, the shortage rate is decreased. The outdate rate and shortage rate are varied in the reverse direction. In the case of average blood age transfused and average period in inventory, those in FIFO issuing policy are increased as mean daily supply increases, but in LIFO issuing policy, those are slightly decreased as mean daily supply increases.

In the case of inventory level, the average inventory level in FIFO policy is 164.33 pints and it is increased up to 278%. In LIFO policy the average inventory level is 124.28 pints and increased up to 142%. So, LIFO policy is of advatage to FIFO policy and the ratio of LIFO to FIFO is 0.76.

In the case of outdate and shortage rate, both outdate rate and shortage rate in FIFO policy are more less than those of LIFO policy. The average outdate rates of FIFO and LIFO are 6.95 and 8.58 pints, respectively, and the ratio of FIFO to LIFO is 0.81. The average shortage rates of FIFO and LIFO are 6.64 and 8.34 pints, respectively, and the ratio of FIFO to LIFO is 0.80. So, FIFO policy is of advantage to LIFO policy in this case.

In the case of average blood age transfused and average period in inventory, both average blood age transfused and average period in inventory in FIFO policy are greater than those of LIFO policy. The average blood age transfused in FIFO and LIFO are 12291.86 and 10566.59 minutes, respectively, and the ratio of LIFO to FIFO is 0.86. The average period in inventory of FIFO and LIFO are 8315.36 and 6515.13 minutes, respectively, and the ratio of LIFO to FIFO is 0.78. So, LIFO policy is of advatage to FIFO policy in this case.

The values of these performance measures according to the variance of the mean daily demand from 0.8 to 1.2 in the case of A=1.0, p=0.5, s=1.0, D=3 are represented in 〈Table 4〉 and 〈Table 5〉. The units of inventory level and the unit of average blood age transfused and average period in inventory are the same as above.

〈Table 4〉 The variance of the performance measures to the variance of the mean daily demand where A = 1.0, p = 0.5, s = 1.0, D = 3, I = FIFO

Mean daily demand	Inventory level	Outdate rate	Shortage rate	Ave. blood age transfused	Ave. period in inventory
0.8	170.32	7.31	0.70	12753.4	8753.3
0.9	216.59	8.88	0.00	13717.5	9872.3
1.0	150.97	5.58	3.72	11777.6	7837.3
1.1	120.72	6.28	10.54	10988.5	6923.3
1.2	118.24	6.15	14.85	10386.3	6399.4

〈Table 5〉 The variance of the performance measures to the variance of the mean daily demand where A = 1.0, p = 0.5, s = 1.0, D = 3, I = LIFO

Mean daily demand	Inventory level	Outdate rate	Shortage rate	Ave. blood age transfused	Ave. period in inventory
0.8	140.62	12.26	1.08	9731.2	5738.8
0.9	126.31	9.47	4.54	10456.3	6340.8
1.0	125.78	9.11	6.32	10353.7	6413.8
1.1	115.33	8.08	13.96	10313.1	6293.9
1.2	113.20	6.26	15.54	10383.8	6369.5

On these tables, we can observe that inventory level and outdate rate are decreased as mean daily demand increases. The shortage rate is increased as mean daily demand increases. These are the opposite results of the variation of the mean daily supply. This fact is the same whether the issuing policy is FIFO or not. The average blood age transfused and average period in inventory are a little decreased as mean daily demand increases in FIFO policy, but in LIFO policy these are not influenced by the variance of mean daily demand.

〈Table 6〉 and 〈Table 7〉 show the inventory levels and their corresponding outdate and shortage rates for a range of crossmatch release period for varying p from 0.25 to 0.5.

〈Table 6〉 The variance of the performance measures to the variance of the crossmatch release period where d = 1.0, A = 1.0, p = 0.25, s = 1.0, I = FIFO

Crossmatch Release Period	Inventory level	Outdate rate	Shortage rate	Ave. blood age transfused	Ave. period in inventory
1	80.61	2.98	9.18	9519.9	5394.0
2	92.24	3.21	8.50	9800.3	5831.6
3	96.38	3.47	13.53	9867.3	5866.9

〈Table 7〉 The variance of the performance measures to the variance of the crossmatch release period where d = 1.0, A = 1.0, p = 0.5, s = 1.0, I = FIFO

Crossmatch Release Period	Inventory level	Outdate rate	Shortage rate	Ave. blood age transfused	Ave. period in inventory
1	122.97	4.44	1.78	10922.8	6873.6
2	153.64	5.28	0.72	11871.6	7833.6
3	150.97	5.58	3.72	11777.6	7837.3

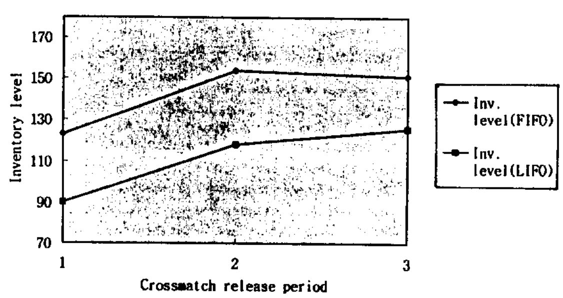
In the case of LIFO issuing policy, the values are represented in Table 8 and Table 9. The unis are the same as Table 6 and Table 7. These results where d = 1.0, A = 1.0, p = 0.5, s = 1.0 in both FIFO and LIFO issuing policy are displayed in 〈Figure 8〉, 〈Figure 9〉 and 〈Figure 10〉.

〈Table 8〉 The variance of the performance measures to the variance of the crossmatch release period where d = 1.0, A = 1.0, p = 0.25, s = 1.0, I = LIFO

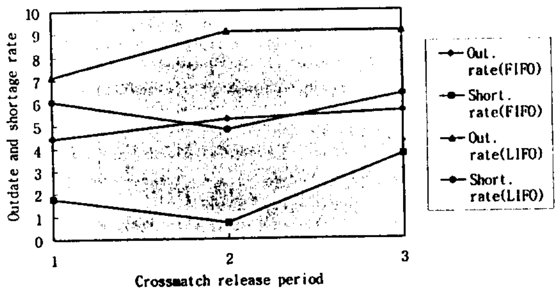
Crossmatch Release Period	Inventory level	Outdate rate	Shortage rate	Ave. blood age transfused	Ave. period in inventory
1	64.10	5.96	15.87	7575.8	3495.0
2	77.58	6.77	16.26	8016.7	4002.5
3	92.40	7.35	14.29	8536.5	4502.4

〈Table 9〉 The variance of the performance measures to the variance of the crossmatch release period where d = 1.0, A = 1.0, p = 0.5, s = 1.0, I = LIFO

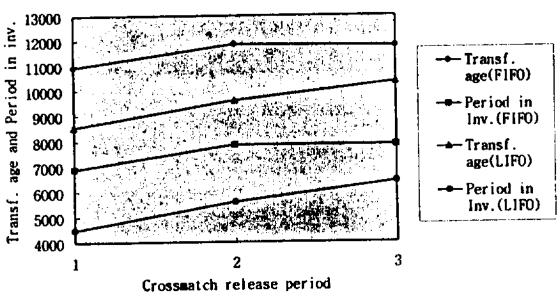
Crossmatch Release Period	Inventory level	Outdate rate	Shortage rate	Ave. blood age transfused	Ave. period in inventory
1	89.95	7.12	6.05	8542.9	4469.3
2	117.94	9.08	4.80	9613.8	5593.6
3	125.78	9.11	6.32	10353.7	6413.8



〈Figure 8〉 The inventory levels in FIFO and LIFO policies to the variance of crossmatch release period where d = 1.0, A = 1.0, p = 0.5, s = 1.0



⟨Figure 9⟩ The outdate and shortage rates in FIFO and LIFO policies to the variance of crossmatch release period where d = 1.0, A = 1.0, p = 0.5, s = 1.0



⟨Figure 10⟩ The transfused blood age and period in inventory in FIFO and LIFO policies to the variance of crossmatch release period where d = 1.0, A = 1.0, p = 0.5, s = 1.0

On these tables and figures, we can observe that all the performance measures except the shortage rate are increased as crossmatch release period increases from 1 day to 3 days. While in the case of shortage rate, it seems to be independent upon the variance of crossmatch release period.

Compared FIFO issuing policy with LIFO policy, the results are the same as the case of the variance of mean daily supply. In the case of inventory level, the average inventory levels in FIFO and LIFO policies are 142.53 and 111.22 pints, respectively. So, LIFO policy is of advatage to FIFO policy and the ratio of LIFO to FIFO is 0.78.

In the case of outdate and shortage rate case, both outdate rate and shortage rate in FIFO policy are more little than those of LIFO policy. The average outdate rates of FIFO and LIFO are 5.10 and 8.44 pints, respectively, and the ratio of FIFO to LIFO is 0.60. The average shortage rates of FIFO and LIFO are 2.07 and 5.72 pints, respectively, and the ratio of FIFO to LIFO is 0.36. So, FIFO policy is of advatage to LIFO policy in this case.

In the case of average blood age transfused and average period in inventory, both average blood age transfused and average period in inventory in FIFO policy are greater than those of LIFO policy. The average blood age transfused in FIFO and LIFO are 11524.00 and 9503.47 minutes, respectively, and the ratio of LIFO to FIFO is 0.82. The average period in inventory of FIFO and LIFO are 7514.83 and 5492.23 minutes, respectively, and the ratio of LIFO to FIFO is 0.73. So, LIFO policy is of advatage to FIFO policy in this case.

All the performance measures except shortage rate in the case of p = 0.5 are greater than those of p = 0.25. On the other hand, we can see that the shortage rate is in the reverse direction.

4. Efficient Decision Rule

4.1 Multiple Regression Modeling

We define some notations:

d = mean daily demand;
A = mean age of supply;
p = transfusion to crossmatch ratio;
s = mean daily supply;
D = crossmatch release period;
I = issuing policy indicator;
c_H = inventory holding cost;

c_O = outdate cost per outdate rate;
c_S = shortage cost per shortage rate;

With these notations, We can express the performance measures as equation(1), (2) and (3).

$$Y = AX \tag{1}$$
$$Y = (S\ P\ Or\ Sr)^T \tag{2}$$
$$X = (1\ d\ p\ s\ D)^T \tag{3}$$
A = coefficient matrix (4 by 5)

All the inventory level, S, the average inventory period, P, the outdate rate, Or, and the shortage rate, Sr are influenced upon the exogenous and endogenous variables. Thus, S, P, Or and Sr can be expressed as equation (4), (5), (6) and (7).

$$S = f_1(d, A, p, s, D, I) \tag{4}$$
$$P = f_2(d, A, p, s, D, I) \tag{5}$$
$$Or = f_3(d, A, p, s, D, I) \tag{6}$$
$$Sr = f_4(d, A, p, s, D, I) \tag{7}$$

The total cost for the blood management can in general be written as equation (8):

$$TC = (c_H \times \text{Inventory level} \times \text{Average Inventory Period}) + (c_O \times \text{Outdate rate}) + (c_S \times \text{Shortage rate}) \tag{8}$$

Equation (8) can be expressed as equation (9).

$$TC = (c_H \times S \times P) + (c_O \times Or) + (c_S \times Sr) \tag{9}$$

Thus the total cost function TC we seek can in general be written as equation (10):

$$TC = c_H \times f_1(d, A, p, s, D, I) \times f_2(d, A, p, s, D, I) + c_O \times f_3(d, A, p, s, D, I) + c_S \times f_4(d, A, p, s, D, I) \tag{10}$$

The functional relationship between the total cost TC^* which minimizes the costs and the various control and exogenous factors will be called the '*efficient decision rule*'. The factors are varied throughout their range and the simulation model is used to compute the TC^*, S^* and P^* value associated with each factor value configuration.

The results of each factor configuration are analyzed by standard regression techniques to determine which input parameters are significant in the computation of TC^*, S^* and P^*, and what the functional form of the decision function should be. Both linear and log-linear functional forms are investigated. The log-linear function gives the same results as linear function.

4.2 Regression Results

The multiple regression is performed with all of the results obtained from the various conditions of factors. The results of the regression run are presented in ⟨Table 10⟩, ⟨Table 11⟩.

⟨Table 10⟩ Multiple regression on simulation model for inventory level under FIFO policy

No j	Variable V_j	Coefficient C_j	Sig T
1	(Constant)	−306.721190	.0000
2	D	5.951714	.1311
3	s	417.109048	.0000
4	p	245.121524	.0000
5	d	−86.679762	.0002

⟨Table 11⟩ Multiple regression on simulation model for inventory level under LIFO policy

No j	Variable V_j	Coefficient C_j	Sig T
1	(Constant)	−147.724381	.0000
2	D	15.035214	.0000
3	s	145.397619	.0000
4	p	112.000762	.0000
5	d	22.694048	.0013

The significant explanatory variables are the mean daily demand, d, the transfusion to crossmatch ratio, p, the mean daily supply, s, in both FIFO and LIFO policy. The crossmatch release period in LIFO policy is also significant. But its coefficient of 15.035214, in the regression equation, indicates that its influence on the optimal S^* is not nearly as large in magnitude as those of the other variables. In FIFO policy, as the significance of the crossmatch release period, D, is 0.1311, the crossmatch release period in FIFO policy is not a significant variable. So, in FIFO policy, multiple regression is repeated with eliminating the unsignificant variable, the crossmatch release period. The results are as shown in 〈Table 12〉. The other independent variable, A, is not significant and also its coefficient is small. Consequently, this last variable is dropped and the rule is induced using only the significant variables.

〈Table 12〉 Multiple regression on simulation model for inventory level under FIFO policy without D

No j	Variable V_j	Coefficient C_j	Sig T
1	(Constant)	−294.817762	.0000
2	s	417.109048	.0000
3	p	245.121524	.0000
4	d	−86.679762	.0002

Using the results of the regression, the inventory level rule can be written by equation (11) and (12):

FIFO policy :

$$S_F^* = -294.82 - 86.68(d) + 245.12(p) + 417.11(s) \quad (11)$$

LIFO policy :

$$S_L^* = -147.72 + 22.69(d) + 112.00(p) + 145.40(s) + 15.04(D) \quad (12)$$

Using above equations, the blood bank administrator can compute the optimal target inventory level for each blood type merely by inserting the mean daily demand for each blood type, the average transfusion to crossmatch ratio, the mean daily supply and crossmatch release period.

Similarly, the average period in inventory, the outdate ratio and the shortage ratio rule can be written by equations:

FIFO policy :

$$P_F^* = -4369.27 - 2961.13(d) + 8621.74(p) + 11083.77(s) \quad (13)$$

$$Or_F^* = -8.62 - 3.18(d) + 10.65(p) + 12.44(s) \quad (14)$$

$$Sr_F^* = 61.31 + 13.55(d) - 20.25(p) - 57.99(s) \quad (15)$$

LIFO policy :

$$P_L^* = 778.02 + 2302.91(d) + 4986.03(p) - 1645.37(s) + 760.49(D) \quad (16)$$

$$Or_L^* = -12.29 - 4.64(d) + 7.25(p) + 19.41(s) + 0.76(D) \quad (17)$$

$$Sr_L^* = 54.04 + 14.32(d) - 25.97(p) - 48.45(s) + 0.97(D) \quad (18)$$

With these equations, the efficient decision rule can be written by equations:

FIFO policy :

$$TC_F^* = (c_H \times S_F^* \times P_F^*) + (c_O \times Or_F^*) + (c_S \times Sr_F^*) \quad (19)$$

LIFO policy :

$$TC_L^* = (c_H \times S_L^* \times P_L^*) + (c_O \times Or_L^*) + (c_S \times Sr_L^*) \quad (20)$$

Cohen and Pierskalla(1979) found that the three most important parameters for setting inventory levels are the mean daily demand, the transfusion to crossmatch ratio, and the crossmatch release period, and that the optimal inventory level is a Cobb-Douglas function of the form $S^* = a_0(d)^{a_1}(p)^{a_2}(D)^{a_3}$. We have tried to find out whether the equation of our study is the Cobb-Douglas function with ln function or not. So the multiple regression is performed with all of the variables using the ln function. We found that, in our study, the Cobb-Douglas function is not so good as linear function to explain the relationship among the variables and the inventory level. The results of the regression run with ln function are given in Appendix.

The shortages and outdates of the ordering policy is minimal for S's in the neighborhood of the optimal S^*.

The insensitivity of the S's in the neighborhood of S^* is important because a blood bank cannot always achieve S^* each day.

The optimal inventory level is relatively insensitive to the value of D. This means that the blood bank administrator can set S^* and then concentrate inventory management control on reducing D knowing full well that S^* will not change significantly.

5. Conclusion

In this paper, we have developed an efficient decision rule for blood inventory management in a hospital blood bank using simulation. The primary use of the efficient decision rule will be to establish minimum cost inventory levels for whole blood and various component inventories for a hospital blood bank or a transfusion service. If the administrator compute the mean daily demand for each blood type, the mean daily supply for each blood type, the length of the crossmatch release period and the average transfusion to crossmatch ratio, then it is possible to apply the efficient decision rule to compute the optimal target inventory level.

Further research will be to extend the model using knowledge of exceptional case arising from the typing and crossmatching process. And another research area is to study the distribution process in a regional blood bank including hospital blood banks.

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96년 2월 최초 접수, 96년 10월 최종 수정

Appendix

A1. The Neyman Distribution

The Neyman Type-A distribution is defined by

$$P_{k(\lambda,\varphi)} = \Pr[X = k] = \sum_{j=1}^{\infty} e^{-\lambda}\frac{\lambda^j}{j!} e^{-j\varphi}\frac{(j\varphi)^k}{k!},\ k = 1, 2, \ldots$$

$$P_{0(\lambda,\varphi)} = \Pr[X = 0] = e^{-\lambda(1-e^{-\varphi})}.$$

The expected value and variance of a Neyman distribution random variable are given by

$$E(X) = m = \lambda\varphi,$$

$$V(X) = v = \lambda\varphi(1 + \varphi).$$

The parameter $\varphi > 0$, provides a good indication of the extent of the non-Poisson behavior. For a Poisson distribution, of course, the ratio of the variance to the mean is one; for the Neyman the ratio is$(1+\varphi)$. If φ is small then the random variable X is approximately Poisson distributed with mean $\lambda\varphi$. Note that the Neyman distribution is a special case of the compound Poisson.

A2. The results of the multiple regression on simulation model for inventory level under FIFO and LIFO policy with *ln* function

〈Table A1〉 Multiple regression on simulation model for inventory level under FIFO policy with *ln* function

Multiple R	.75579
R Square	.57122
Adjusted R Square	.56285
Standard Error	46.67260

	DF	Sum of Squares	Mean Square
Regression	4	594901.47375	148725.36844
Residual	205	446557.89033	2178.33117
F = 68.27491		Signif F = .0000	

Variable	B	SE B	95% Confdnce Intrvl B		Beta	T	Sig T
ln(D)	11.137751	7.095700	-2.852157	25.127658	.071787	1.570	.1180
ln(s)	407.324802	31.718941	344.787627	469.861977	.587304	12.842	.0000
ln(p)	87.543401	9.202043	96.400621	105.686182	.435091	9.513	.0000
ln(d)	-87.801921	22.505431	-132.173707	-43.430134	-.178426	-3.901	.0001
(Constant)	212.799367	10.952361	191.205603	234.393080		19.430	.0000

〈Table A2〉 Multiple regression on simulation model for inventory level under LIFO policy with *ln* function

Multiple R	.85958						
R Square	.73888						
Adjusted R Square	.73378						
Standard Error	14.33210						
	DF	Sum of Squares		Mean Square			
Regression	4	119153.07608		29788.26902			
Residual	205	42108.86988		205.40912			
F = 145.01921		Signif F = .0000					

Variable	B	SE B	95% Confdnce Intrvl B		Beta	T	Sig T
ln(D)	27.148844	2.178930	22.852859	31.444829	.444685	12.460	.0000
ln(s)	142.755107	9.740171	123.551351	161.958862	.523081	14.656	.0000
ln(p)	40.000272	2.825740	34.429034	45.571511	.505213	14.156	.0000
ln(d)	21.458519	6.910910	7.832945	35.084094	.110818	3.105	.0022
(Constant)	118.665865	3.363223	112.034923	125.296808		35.283	.0000