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Approximate Dynamic Programming Modeling for a Typical Blood Platelet Bank

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ABSTRACT

In this paper, we have devised a real-time, workable model for solving the practical problems associated with responsible blood platelet inventory. These problems include how to eciently dispense, organize, store, and order platelets that become unusable after 6 days. Stochastic demand and supply, as well as deterministic lead times, are congured into their model. Any shortages or outdates of the 8 major blood types are penalized in this proposal, with revenuw in conjunction with a further emphasis on the age of platelets will maximize ecency as well. A combined model of linear programing and approximate dynamic programming (ADP) was deployed while constructing their practical model. In an environment which emphasizes the need for real-time judgements, this new policy, as advanced here, will lead to substantial shortage, outdate, and cost reductions of these time-stamped platelets. The experimental application of this model produced shortages in the range of apporximately 4.7% with outdates at 5.5%, a vast improvement over existing methods. An ADP approach was found to be practical during this research, and additionally the model showed much promise with respect to enhancing a reward system that simultaneously decreases shortages and the number of expired platelets.

Keywords: Approximate Dynamic Programming, News-vendor, Blood Bank, Perishable Product, Blood Platelet, Inventory Model, Health Care Mang, Resource Allocation, Inventory Management, Supply Chain.

INTRODUCTION

Background

The acquisition of PLTs is itself a problematic concern for blood banks. Because platelets can at present only be acquired through a donation process (allogenic transfusion) bordered by strict parameters, their management is critical for society. For example, due to the age and health requirements of donors, less than two-thirds of the American population are eligible to donate blood USABlood (2011), and currently less than one in twenty of those adults who are eligible actually donate (BloodCenter 2011). A further problematic concern for blood banks is the fact platelets are perishable and generally not used after 6 days of storage. A blood bank's main function is to acquire, store, distribute, and process an adequate supply of blood and blood components for eventual emergency usage. Initially, potential donors are screened, after which the collected blood goes through a categorization, component extraction, and storage process. These processes are activated at the blood banks. Almost 90% of the blood supply in the United States, as well as 80% of transfusions, is co-ordinated through these blood banks, and other publicly-condoned agencies, with hospitals accounting for most of the other blood collection cite BQ2009. Forecasting the amount of blood needed and the number of donors are inexact sciences; when also considering the perishable nature of platelets (generally, they have a shelf life of approximately 6 days), we can see that unlike other supply-demand scenarios, a surplus in blood supply "last year" cannot be used to oset a shortage "this year"(NBD 2003). This makes the development of an ecient model, which considers all the variables, of utmost importance to social safety. The blood type system is composed of eight major blood types that medical professionals care most about: AB+, AB-, A+, A-, B+, B-, O+ and O-. Those that transfuse blood understand matching exact blood types (between the donated blood and the patient) is preferable, but there are possible exceptions as seen in Table 2. A "one-stop" model that considers all of the aforementioned variables is the model that will work best in practice. The proposed model will minimizes both outdates and shortages, while maximizing the PLT bank rewards.

Outlines

The next section of this proposal discusses some of the relevant published work. The 3rd section details the model and includes an algorithm. The penultimate section introduces the results of the experimentation, with a conclusion and list of references and acknowledgments at the end.

Related literature

Ecient public blood management has been studied for almost 50 years (Nahmias 1975a, Nahmias 1975b, and Nahmias 1980), without a fool-proof model being found which includes the 8 major blood types and their shelf-lives. Dynamic programming has proven to be too costly a method for determining this model in a short period of time, leading the majority of researchers to consider approximation or heuristic solutions. Controlling the amount of platelet perishables used at hospitals which drew their blood supply from regional PLT banks reduced shortage and outdate expenses with the application of FIFO (First In, First Out) and LIFO (Last In, First Out) methods with various platelet rotations (Prastacos (1978)). As another example, Prastacos (1979) used a FIFO approach, with respect to a pre-set rotation of blood units, in a multi-echelon model that deployed 2 stages whereby the probability of a shortage is shared equally amongst hospitals. Less outdate units and less shortages resulted. A study focusing on the reduction of shortages and outdates at a hospital PLT bank (Brodheim et al. (1975)) assessed the likelihood of those shortages occurring, as well as the mean age of the inventory and outdated units. A model generating PLT daily orders while determining mean demand (Katz et al. (1983)) over a 24-month period was also able to generate daily orders and calculate the quantity needed, and was accurate assuming a maximum of 5 days of shelf-life, irrespective of production and distribution. Blake et al. (2003) proposed an idea for PLT management with a deterministic supply chain and with the application of a Markov dynamic programming approach, suggesting that such a model could lower costs by almost 20% with a complementary reduction in outdates and shortages. Haijema et al. (2007) used this same approach and simulation method with a PLT bank based in the Netherlands. After a down-sizing of the relevant dimensions, these researchers concluded that an order-up-to- rule policy produces an ecient real-time performance. In their opinion, the addition of the 8 major blood types, and the perishability of the relevant PLT's therein, does not negatively prejudice the nal solution, and the double order-up-to rule, which has two order-up-to levels (one corresponding to younger PLT's and the other to the total inventory), produces very satisfactory results when there are pressing medical reasons to prefer less-aged PLT's. Other research (Haijema et al. (2008)) also concurs that a viable solution for PLT inventory control centers around seeing this as a multi-dimensional Markov Decision Problem (MDP). However, an approximate solution can be obtained by using a stochastic dynamic programming (SDP) method, so as to not fruitlessly pursue research based on the "curse of dimension". For example, Powell (2008) has suggested using an approximate dynamic programming (ADP) method when considering optimal models for PLT bank inventories, concluding this method addresses the potential model state variables while overcoming both dimension and time problems, negating the need to downsize. In Canada, excepting the Province of Qu–ebec, blood products are collected by Canadian Blood Services via donations and provided free-of-charge to regulated health care facilities (Canadian Blood Services, 2002). Total expenditures for CBS in 2001/02 were 687*million*(CAN); CBS collected approximately 20,000 units of platelets via plateletpheresis during that period (IBM, 2002). The necessity of large platelet production amounts can partly be attributed to large outdate rates. PLTs lost due to perishing are common throughout supply chains. Coupled with unpredictable demand scenarios, the short shelf life of blood platelets emphasize the importance of managing economic and human resources at blood establishments.

Research gaps

In a recent article, Blake et al. (2003) points out that it is necessary to develop good, fast, and robust models to study the platelet inventory problem, citing the fact blood type ages are part of the ordering decisions, and their need is too dicult to predict currently. However, due to the number of state variables, outcome space, and action space, a real-life model has been sought by downsizing, simulating or approximating the current problem; however, this method of research has the inherent fallacy of non-realistic experimentation. In addition, most past research assumed supply was deterministic while nowadays it is uncertain. Another obvious gap in the research is the fact no one has apparently attempted to develop an optimal PLT blood bank operation method that considers both the eight blood types and their ages.

Table 1: Blood type percentage

Type	AB+	AB-	A+	A-	B+	B-	O+	O-
	0.035	0.026	0.200	0.029	0.155	0.015	0.230	0.310

Expected contributions

The proposed model will contribute to the resolution of the problems associated with platelet bank management in at least 5 ways: [a]Verifying that an ADP approach to developing an optimized model can be done in such a way as to include the eight blood types while considering their perishability; [b] Developing the prototype model without any downsizing of real-life PLT blood bank situations; [c] Factoring into their proposed model the uncertainty of donation rates and blood types; [g]Reduce both blood platelet outdates and shortages through said model; [e] Minimize both overall costs and inventory levels without aecting ecient delivery.

Proposed algorithm

With the usage of ADP, we have devised a mathematical model for a typical, real-time PLT blood bank. ADP is an extension of Dynamic Programming and Bellman's equation, and was chosen because it is able to solve the problem without downsizing actual real-life variables. Daily optimum inventory levels of each blood type used in this proposal considered a demand distribution type model which would imitate expected daily demand. Then, Linear programming was used to nd the optimal solution at a projected point in time. Canadian Blood Service data helped us to determine both seasonal demand distributions by day, as well as probable percentages of the various blood types needed to be on hand at this real-time PLT bank, as in Table 1. The demand supply relationship between the eight blood types are shown in Table 2. For example, Tuesday's data follows a geometric distribution with mean demand at 8.064, standard deviation at 7.21, a median at 5, and a coecient of variance at 0.894; Friday's data also follows a geometric distribution, but with a mean demand of 8.83, a standard deviations of

7.85, a median of 5.5, and a coecient whose variance is 0.889. So this data is used to generate random demand and random supply. Notice that demand occurs 7 days a week while supply occurs 6 days a week. So, the proposed model suggests that PLT bank would have to order more on Friday to satisfy Saturday and Sunday demand Therefore,the blood platelet supply is six days a week from Monday to Saturday: The optimal demand distribution by day are listed on Table 3. The solution comprised two steps; the rst step solved the single period daily process using linear programming, while the second step solved the multi-period problem using ADP. Finally, the developed model considered the eight blood types with their age range of 1-6 days.

Table 2: Blood platelet substitution relationship

Type	**Demand**							
Donor	**AB+**	**AB-**	**A+**	**A-**	**B+**	**B-**	**O+**	**O-**
AB+	1	1	1	1	1	1	1	1
AB-	0	1	0	1	0	1	0	1
A+	0	0	1	1	0	0	1	1
A-	0	0	0	1	0	0	0	1
B+	0	0	0	0	1	1	1	1
B-	0	0	0	0	0	1	0	1
O+	0	0	0	0	0	0	1	1
O-	0	0	0	0	0	0	0	1

Process overview

In consideration of what that single blood bank's daily schedule most likely is, we assume the following occurs on a daily basis: the perished platelets exit the existing inventory; then the previous day's donations enter the existing inventory after being categorized by blood type and life span; nally,upon the tally of the now new inventory levels, management reviews any known demand and any potential shortages then re-orders accordingly. In our study, what is considered to be the usual day-to-day routine at most PLT blood banks provides the testing scenario for the model developed here and further outlined below. This model also assumes an operational parameter of 730 consecutive days. The award system for this model penalizes negatives such as an inventory's amount/type of PLTs in decit or perished. Conversely, the award system congratulates positives such as an inventory's satisfaction of demand. Overall, the assessment criteria are: measure of unsatised demand, shortages percentage, the measure of platelets more than six day old and not used (i.e. outdate percentage), average inventory levels, and the total reward. While it is understood that each criterion has relevance, the most important one has to be the shortage because it puts human lives at risk. Outdate would then follow as the second most important criterion because the platelets are a unique, expensive, and limited resource. When inventory level is low with a high reward, it will

Table 3: Weekly Demand data distribution

Type **Distribution**	**Mon.** **Poisson**	**Tue.** **Geometric**	**Wed.** **Geometric**	**Thu.** **Geometric**	**Fri.** **Geometric**	**Sat.** **Geometric**	**Sun.** **Poisson**
Parameters	0.1848	0.1100	0.1077	0.1044	0.1017	0.1026	0.1840
Mean	4.41	8.06	8.29	8.85	8.83	8.75	3.37
Variance	14.14	52.02	54.78	56.95	61.69	62.27	8.79
Std. Deviation	3.76	7.21	7.40	7.55	7.85	7.89	2.97

support the policy with the lowest shortage and outdate.

Reward function denition

The objective of this model is to minimize both blood platelet shortage and outdate while maximizing the total rewards and keeping inventory levels to a minimum through satisfying the dierent demand types. The reward parameters are described in Table 4. The reward function can be stated thusly:

$$C_t(I_t) = C_d x_{ijt} - C_u u_t - C_o \sum_i D_{ijt} - C_h \sum_i \sum_j z_{ijt} \quad ...(1)$$

Where *i* is blood type and *j* is blood age and *xijt* is the total number of platelets taken from the inventory to serve demand, and *Dijt* is total outdate, and *ut* is the shortage occurrences, and *zijt* is the current inventory at time *t*. The rst reward parameters represent serving demand. The next three parameters are the shortage, outdate cost, and holding cost.

Model

We have congured their solution with a multi-stage model given that PLT management choices are made step-by-step, as in Figure 1. Thus, platelets of dierent types being are removed from inventory during the day to serve incoming demand. Then at end of the day, all inventory is updated with the actual demand and supply. Next, the up-to-order level inventory decision is taken. Moreover, all inventory at day *t*+1 are aged by one more day, and any blood platelets more than six days old will then be discarded (outdated) while the remainder will be the new inventory at time *t*+1. Also, at day *t*+1, the newly-received blood platelets with an age of 1 day will be added to the inventory. It is also assumed that the transition function is deterministic and that there is no miss-handling of the blood platelet inventory. Figure 2 show the process flow char

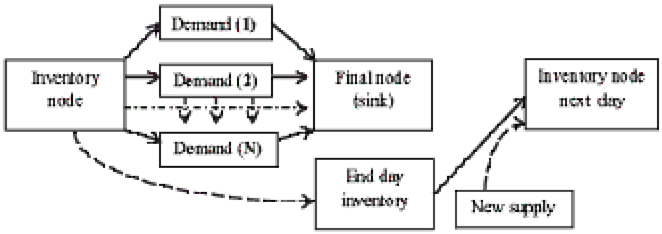

Fig. 1: Detailed blood bank process

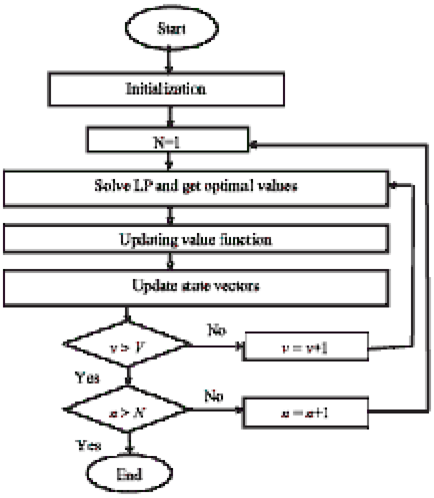

Fig. 2: Process flow chart

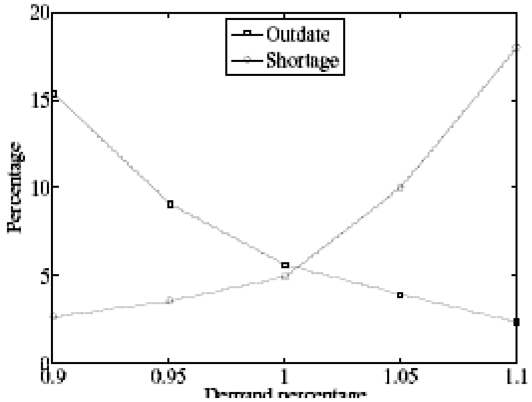

Fig. 3: Demand variation and blood types

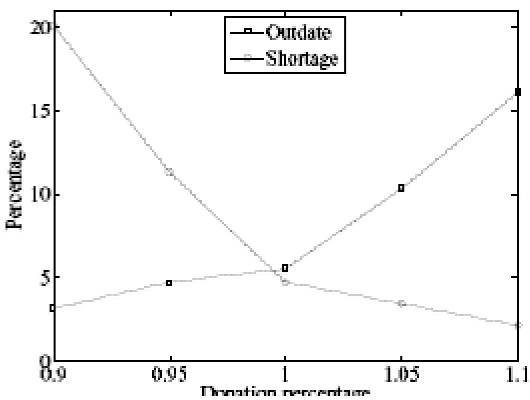

Figure 4: Donation variation and blood types donation vary. this will eect all blood types is in Figure 5

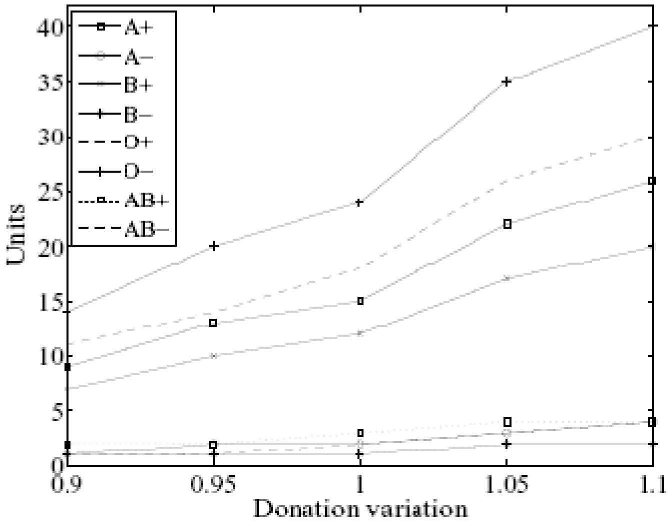

Fig. 5: Donation variation and blood types

RESULTS AND DISCUSSION

ADP methodology helped to develop the working model as it would be applied in real-time, real-life situations. The FIFO concept served demand, a Matlab package coded the model on a Core i3 computer, and a startup inventory's parameter was assumed to be by 1 day of initial need. The FIFO policy give a good result with 5.5% outdate and 4.7% shortage. The inventory level was 78 units and the expected reward was 5.3. Next, dierent sensitivities analysis were processed to evaluate the model, starting by varying the demand percentage between 90% and 110%, as in Figures 3. In Figure 4 we see the eect of donation percentage variation between 90% and 110% on the model. As the donation varied, shortage varied between 2.4% and 18%, while outdate varied between 2% and 15%. So, as the donation decreases, the shortage percentage increases even more quickly, and reaches up to 20%, while outdates decreased to 3%. As demand increased, outdate varied between 3% and 15%, while shortage varied between 3% and 18%. In this model, the shortage is more sensitive to variation than is outdate. Moreover, the inventory vary between 46 and 131 units as There is a potential for getting a less outdate and shortage if the initial inventory and donation variation are calibrated more. In addition, the policies can be enhanced to address the order of how to satisfy blood types and start with serving the most critical needs. Finally, the ndings can be summarized as follows: (1) The demand and supply random variable tries to keep track of the optimal inventory level in order to maximize the eectiveness of platelet banks; (2) The Linear programing gives the optimal daily inventory level at a point in time; (3) The ADP monitors the model daily changes and then optimizes and updates the model's parameters; (4) The developed model will also assist PLT managers to better understand the blood platelet bank process; (5) Maintaining adequate inventory to full demand is of critical importance.

Conclusions and further research

Until articially-produced blood platelets are developed, the eective management, storage, and dispensation of them will remain a top priority for society. This proposal should be seriously considered for the real-life, real-time PLT blood banks for which it is intended, as it was developed using the actual variables that exist, and is an ecient blueprint for eective PLT blood bank management. Previous research in this eld as well as the research that has been the vicim of "the curse of dimension" will be able to use this proposal positively; the multi-period model outlined in this paper considered eight blood types with stochastic demand and supply as well as deterministic lead times. The eects on the overall performance of the model, considered against several alternative inventory control policies, are analyzed. The performance of the system is evaluated in terms of four measures of eectiveness: blood platelet shortage, outdating, inventory level, and reward gained. While this study discussed some aspects of the ecient dispensation of PLT, it is clear other research should consider (1) The application of ADP was promising in terms of optimizations; however, there is a need for more study which emphasizes policies that cope with dierent demand types such as no substitute demand, new platelets demand, and emergency demand, and (2) Other sources of platelet acquisition, given that the demand for blood platelets is increasing, and perhaps will overcome donor willingness one day.

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