Blood Supply Chain Model in Health Care: Models and Analysis

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***Abstract*—Supply chain management of blood supply is one of medical issues that needs special attention. One of general problem in the production of blood donors is total number of demands that not equal to production quantities that available in inventory system of blood donation. One of the constraints on the supply chain issues for the blood supply where blood is a perishable product. This research is modeling the supply chain distribution so that model can be used to minimize the operational costs of hospital of blood availability due to the level demand and the type of blood group.**

Keywords—Supply chain, health service, blood banking, inventory management

I. Introduction

Blood banking is an important main part of the health service systems and its application have a major impact on the success of the medical treatment procedures. There is no alternative to meet the demand for blood in medical procedures at there is no substitute for human blood which voluntarily supplied by donors. Therefore, blood should be considered as a scarce resource allover the world.

In highly competitive market, manufactures faces the problem of supply chain production. Consumers' demand for new products as well as the still-critical economic situation require that companies, as well as organizations, be more innovative while also becoming more cost-effective in the procurement and production of their products and services as well as in their delivery. However, despite numerous significant achievements, the discipline of supply chain management (SCM) is still incapable of satisfactorily addressing many practical, real-world challenges [1].

Supply chain for time-sensitive products, in particular, for perishable products, pose specific and unique challenges. By definition, a perishable product has a limited lifetime during which it can be used, after which it should be discarded [2]. Examples of perishable goods include food and food products, medicines and vaccines, etc. (see [3], [4], [5], [6]). In basic inventory system, it is assumed that suplly of product can be always sufficient for any demand rate in the future. However, perishable feature of any product, influences an inventory system depends on durability of the product. For general example, including perishable

This paper unfolds as follows. Section II we review some background information on the study area and outline that adopted the inventory management. Finally, conclusion and future research are provided in the last section.

II. Blood Supply Chain Management

Over the last fifty years, a somewhat large body of research has been completed regarding blood inventory management as well as supply chain analysis at a regional level. The studies primarily implement simulation, regression and markov chain analysis to examine various policies at a blood bank.

A. Simulation and Regression Analysis

Statistical methods was used to analyze the effects on a single hospital of altering the age composition and the size of blood supply [7]. They also analyzed the effect of issuing policies, specifically LIFO and FIFO policies, on expected shortages and outdates, concluding that the first-in-first-out policy reduces both shortages and outdates and used the negative binomial distribution to model the demand. Using the simulation, they determine an optimal inventory level based on all significant variables and they also analyze various ordering policies, issuing policies, and crossmatching policies while viewing the supply of blood from a regional perspective [8]. They additionally examined the sensitivity of different variables to the total costs and the optimal inventory using outdate costs of $25 and shortage costs of $55.

B. Markov chain analysis

Markov chain analysis has also been applied to this perishable product inventory management problem. They [8] used an absorbing state Markov chain to see how inventory levels and average age of transfused blood is affected by various issuing policies. Their model requires the transition probabilities that a unit of blood will be transfused given its age. The analysis take into account the effects of crossmatching in another model, but neither model is truly dependable as their fixed transition probabilities in reality. Thus, the model is lack and not reliable. It also specifically studied the crossmatch demand process by [8]

C. Dynamic Programming

Fries and Nahmias have each applied dynamic programming to the perishable inventory management problem, both publishing work in 1975 but this studies do not pertain to blood specifically. Their analysis has many valuable conclusions regarding perishable inventory in general: increasing current inventory.

D. Queue Theory

[9] for example, was successfully combined the used of Markov chain with statistical analysis. The model was formulated to determine total of demand rates and the use of any available blood product with the aim of the model as the inventory management system of blood products.

In the US, for example, the regional divisions of the American Red Cross oversee the entire operation of their corresponding regions. Other suppliers of blood are hospitals that typically the larger ones with blood collection programs, which however, account that less than 5% of the market share [10]. Since 1960, the Red Cross has been reimbursed by the hospitals for the costs associated with providing blood to hospital patients. The Red Cross (RC) does not charge for the blood itself; the collection of blood by trained staff, the processing and testing of each unit of blood in state-of-the-art laboratories, and the labeling, storage, and distribution of blood components. Figure 1 shows a network topology of a regionalized blood banking systems as for the American Red Cross in the US as below.

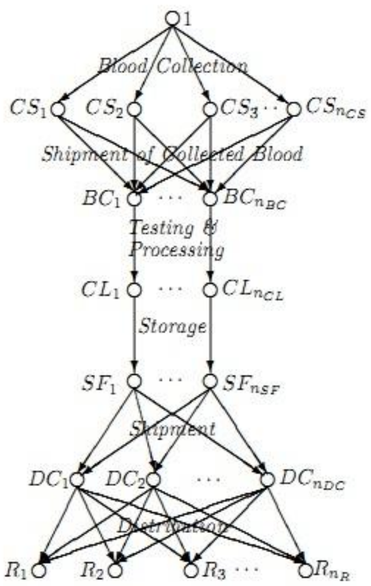

Fig. 1 A network topology of blood banking systems.

In the network, the top level represents the ARC regional division where each node denotes a component or facility in the system. A path connecting the origin node to a destination node, corresponding to a demand point, consists of a sequence of directed links which correspond to supply chain network activities that ensure that the blood is collected, processed, and ultimately, distributed to the demand point. Studied on this network used a single-period type, where the time horizon spans the various activities of procurements, processing and distribution [11].

One potential solution to this problem is to use distributed simulation. This is a technique where models are implemented over many computers in a parallel or distributed fashion with the goals of reducing the execution time of a single formulation run, sharing the memory needs of a simulation across several computers and the linking of simulation sited in different locations (see [12] and [13]). The use of ARIMA method was used to determine the demand rates of blood transfusion [14]. Three time-series method is used into the model: ARIMA, exponential smoothing model and single-artificial intelligence basic method. The result showed the best blood transfusion series is ARIMA $(0,1,1)(0,1,1)_{12}$.

III. OUR MODELS

This paper developed a model of blood supply chain with the objective function is to determine the necessary operational costs in blood inventory system. Perishable product availability can be determined by define a regulation of storage product based on the demand average rates. Thus, this paper was developed a EMQ (Economic Manufacturing Quantity) model in determining availability for chain model supply of blood products. In some literatures that have examined the related issues, there are four aspects of requirements that need to be considered in determining the supply chain model:

- demand of product inventory rule that focused on time and quantities that has been studied by [14];
- policy rules to regular the feasible product to be used by using the FIFO (First In First Out) rule and it has been proved that the rules is optimal for a perishable product with the number of random supply and demand rates are uncertain by [15];
- ineligibility rules for the use of a product that has been described by [16] that extended the demand rates is stochastic;
- price determination rules, the price expressed as a decision variables and the expected demand rates (see [17], [18], [19])

In this paper, we focus on inventory system of Indonesian Red Cross (PMI) – blood banks in Indonesia in determine the demand rates of blood supply for any hospital where the hospital as blood bank of supply chain model. Furthermore, for any perishable product such as blood product, where the demand rates is higher than the availability of blood product, the important things that must be considered in this supply chain model is the provider of blood supply that oversees the demand rates compared with the number of patients. The PMI collects raw blood material supply from any volunteer, then it have tested and processed to be ready-for-use blood supply. Those raw material then grouping based on Rh blood groups where red blood cells have a resistance to over 35 days where only 65% of the units of cross-matched blood can be transfused while the remaining 35% is returned to the blood bank for a given to the other patients.

A. The Model

For the model, we use some mathematical notation as below.

- P_r : blood test process
- O_d : demand rates in a hospital as blood bank
- H_1 : total of health centers
- H_2 : total of hospital
- H_3 : total of international hospital
- S_H : total of inventory blood of each hospital
- S_{PMI} : total of inventory blood in PMI blood bank
- T : total number of blood transfusion that been used
- O_H : hospital demand rates of blood supply
- I_{PMI} : rates of needs blood donors
- d : total of days
- i : index of hospital H_i (i = 1, 2, 3)
- UO_H : total of uncovered hospital demand of blood
- UP_H : total of uncovered patient demand of blood
- B_{UO} : compensation cost of uncovered hospital demand
- B_{UP} : compensation cost of uncovered patient demand
- B_{Pe} : compensation cost of damaged blood product
- S_{PMIm}: total of available blood supply in PMI per week
- P_e : total of damaged blood product
- P_{PMI} : total income of PMI
- I_{PMI} : unit of blood product that distributed to the hospital H_i
- B_{Tr} : distribution cost of blood supply
- K_{PMI} : total profit of PMI
- w : total weeks per month

Assume that collecting the blood products or blood donors is on Monday morning, then the raw blood material product is ready to distribute to blood bank or transfuse to patient based on demand rates on Tuesday after the blood products has been completed tested. Mathematically, blood supply structure for each hospital is due to unit of transfusion (T) and hospital demand rates that formulated as

$$S_H(i,d) = S_H(i,d-1) + I_{PMI}(i,d-1) - T(i,d-1) \quad (3.1)$$

If 65% $O_D(i,d) < S_H(i,d) + I_{PMI}(i,d)$, then $T(i,d) = 0.65{*}O_D(i,d)$ and $T(i,d) = S_H(i,d) + I_{PMI}(i,d)$, otherwise. Thus,

$$S_{PMI}(d') = S_{PMI}(d) - \sum_{i=1}^{3} I_{PMI}(i,d) \quad (3.2)$$

Assume that the PMI doing the calculation of blood supply calculation after the decision-making process on total hospital demand rates that has been distributed as many as three times. Thus, Eq. (3.3) is formulated to calculate inventory rates of PMI that formulated as

$$S_{PMI}(d') = S_{PMI}(d) - \sum_{i=1}^{3} I_{PMI}(i,d) \quad (3.3)$$

with $S_{PMI}(d) \geq 0$. Total of uncovered hospital demand of blood supply is the main purpose that need to be concerned in a blood supply chain model. For this main purpose, we then formulated a formula in determine the operational cost

$$UO_H(i,d) = O_H(i,d) - I_{PMI}(i,d) \quad (3.4)$$

with $O_H(i,d) > I_{PMI}(i,d)$ and

$$UP_H(i,d) = 0.65{*}O_D(i,d) - T(i,d) \quad (3.5)$$

With $0.65{*}O_D(i,d) > T(i,d)$. The other purpose that need to be concerned is that we propose a model to a perishable product, thus we need to calculate the damaged blood supply inventory so that the blood supply availability is stable. If the PMI's inventory increased, then the total of damaged blood product will be decreased. Thus, the total of damaged blood product or out of date is formulated by

$$P_e(d) = 50\%{*}[S_{PMI_m}(m) - S_{PMI_m}(m-1)] \quad (3.6)$$

with the total of compensation cost of damaged blood product (both damaged or out of date) is

$$S_{PMI}(d) = S_{PMI}(d-1) - \sum_{i=1}^{3} P_e(i,d-1) + P_r(d) \quad (3.7)$$

Thus, we can formulate the total profit of PMI is

$$\sum_{i=1}^{28} K_{PMI}(d) = \sum_{d=1}^{28} \left[\begin{array}{l} (P_{PMI}(d) - B_{Tr}(d)) - \sum_{i=1}^{3} (BU_O(i,d) + B_{UP}(i,d) \\ + B_{Pe}(i,d) + C_{Tr}(i,d)) \end{array} \right]$$

$$\sum_{i=1}^{28} K_{PMI}(d) = \sum_{d=1}^{28} \left[\begin{array}{l} (P_{PMI}(d) - B_{Tr}(d)) - \sum_{i=1}^{3} (BU_O(i,d) + B_{UP}(i,d) \\ + B_{Pe}(i,d) + C_{Tr}(i,d)) \end{array} \right] \quad (3.8)$$

IV. COMPUTATIONAL RESULTS

This paper examines the blood supply chain model as one of a perishable product that is easily damaged by high demand and tend by uncertainty conditions. The model can be used as an optimal method to determine the demand rates of blood supply in an emergency at several locations of some particular area. Analysis of this paper is using a multiple attributes which is based on the type or blood type, location, and blood substitutes in helps the making decisions process that affect the supply chain model of the process distribution of blood products. Thus, this model can be used as a reference for hospital or blood donation centers in the provision of blood products supply chain.

V. CONCLUSIONS AND FUTURE RESEARCH

This research introduced a new alternative scheme of 2-stage DEA model to obtain super efficiency score of evaluated DMU in a data set. 2-stage DEA model then was formulated into linear program for an based on a new scheme that showed in Fig. 2. This model was extended of CCR model by considering input-output oriented in a data set. The basic idea of this model based on input-output oriented on Stage 1 and output oriented on Stage 2, so that super efficiency score obtained from model (2.34). Testing our models with data sets taken from previous studies [9], shows that results obtained are comparable to those reported in literature as given in Table 2. In future research, we will extend a new alternative scheme of 2-stage DEA model by considering input and output interval in a data set.

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