
DECISION SCIENCES INSTITUTE
Ordering Blood Donations Under Uncertain Environment

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ABSTRACT

Blood is important for hospitals but its demand and supply are uncertain due to seasonality, natural disasters, and available donors, and while perishable, it's a natural resource that cannot be manufactured at the time of need. Our study employs an econometric methodology known as ARMA-in-ARMA-out (AIAO) to practically place orders for donations in this uncertain environment. Instead of economic order quantity (EOQ) and inventory policy changes (not allowed here due to governmental regulations), we show that following our methodology could match supply with demand and increase profits for blood centers without relying on practitioner's experience to place orders.

KEYWORDS: Perishable, Wastage, Shortage, Contribution margin, Inventory turnover

INTRODUCTION

Motivation

The incentive behind our study is the need for *practical* methods to (a) match supply and demand for blood and (b) place just-in-time (JIT) orders to reduce wastage and shortage of this product. We allow placing orders 'exactly' equal to computed values without adjusting quantities based on practitioner experience, which we believe could cause unnecessary variability and thereby contribute to product wastages and shortages. We seek 'practical' approaches because although popular in academic research, the Economic Order Quantity (EOQ) model and changes of inventory policies are not appropriate due to the importance of product and governmental regulations (discussed in upcoming sections). Thus, we must match supply and demand of blood and increased profits for our focused blood center via practical approaches.

Choosing order quantities to satisfy demand while reducing surplus inventory is difficult in general, but it's especially challenging when the product is perishable and surplus inventory could result in product wastage. Having higher than desired product wastage could have a negative impact on a blood center's financial standing, raising operational costs. Similarly, governmental regulations imposed on blood centers demand low product wastage (below 6%)

and sufficient inventory to meet demand during emergencies ([Department of Health and Human Services, DHHS, 2011](#)). Therefore, while excess inventory could help blood centers meet demand during emergencies, it is difficult to vent because of the product's rate of perishability. Additionally, recent studies show many doctors prefer using fresh blood (i.e., blood at the beginning of its shelf life) to increase the quality of a patient's care ([Abbasi and Hosseinifard, 2014](#)). Hence, an adequate level of inventory is required as under-stocking is risky, negatively influencing patients' lives, while overstocking causes product wastage.

On the supply side, our investigation points out that for the past several decades, blood centers across the world have decreased operational costs and product wastage by lowering inventory due to limited available blood supply. On the demand side, due to the recent increase in demand and price of blood, hospitals have sought to lower demand by using fewer blood packages during surgeries (we were told that for some surgeries blood transfusion is omitted entirely and the patient is treated with steroids injections to speed up his/her recovery instead). Some hospitals have even turned away patients that required considerable blood transfusions during peak demand months. Other hospitals delay non-life-threatening surgeries during high demand cycles. In 2010, for example, some hospitals delayed non-life-threatening surgeries because the demand for blood was higher than anticipated, while the actual supply was lower than projected for the year ([DHHS, 2011](#)).

Due to a lack of adequate blood supply, hospitals have been encouraging patients to reach out to social media to supply the blood needed for their surgery. Although delayed surgeries are typically not life threatening, they contribute to increased operational costs at hospitals because they are often high profit margin activities. Nevertheless, despite all efforts from the supply and the demand side, the world-wide problems with adequate blood availability exists because there is a constant rate of increased demand and a continuous rate of decreased supply for blood due to the world-wide aging demographic. Thus, given this problem, we are inspired to examine several ordering methods along with their profit margins to determine how well they allow product availability, high profit margins, and low shortage and wastage rates using one large blood center in the eastern region of the U.S.A.

Challenges for using the existing approaches to lower wastage and increase profitability: Matching supply with demand for blood can be a challenging task due to product perishability (approximately 40 days), limited natural supply source (i.e., cannot be manufactured), the dependency of supply on voluntary donations, and the price of the product (price of blood depends on the hospital's geographic location and the blood center's annual demand rate; the price could reach the price of a laptop computer (\$550), a cellphone, or an iPad (\$350)). Hence, any amount of excess inventory that might result in wastage is not desirable, as it increases operational costs and the price of blood. Even though most blood centers (not all) are non-profit organizations, achieving lower wastage can reduce operational costs and increase profit margins, which would be directly passed on to the hospitals via product-pricing; thus, the blood center could continue to operate as a non-profit firm more efficiently. Our interview with one of the large hospitals in the region of study indicated that in February of 2011, the hospital had switched suppliers from the Red Cross to other community blood centers due to the price of blood packages promoted by the Red Cross. Hence, we need to achieve profitability by lowering wastage at the focused blood center.

One problem is that although using the EOQ model is popular in the academic realm to allow profitability, this method is not appropriate for blood because in order to maximize profit, this model results in ample shortages that could put patients' lives at risk. An overview of the literature shows several researchers have focused on the EOQ model (e.g., [Tajbakhsh et al., 2010](#)), which typically optimizes profit. However, when we examined this model using our empirical data obtained from our focused blood center, we discovered that in order to optimize profit, the EOQ model undertakes a 45% service level, which would be intolerable for hospitals. The shortage cost of this model (C_u , cost of under-stocking) is found to be the price (p) less the fixed and variable costs (c). The problem with this is that the shortage costs don't represent the true costs of not having an adequate inventory of blood. The actual shortage costs of blood for hospitals, which cannot be easily quantified, include the costs of human life, delayed or missed surgeries, transferring patients to another hospital, and complications after surgery, among others. Since these costs are not easily quantifiable, the EOQ model cannot be used for this study. Additionally, our interviews with several blood centers and hospital blood bank representatives showed managers had never used the EOQ model for ordering blood or other products, and were hesitant to practice it.

A search of the literature indicates various inventory models have been studied for perishable products such as blood (discussed in literature review). A recent example, [Abbasi and Hosseinifard \(2014\)](#), used mathematical modeling and simulation to modify the First-in-First-out (FIFO) policy for inventory management applied to blood and platelets for hospital blood banks. The authors divided their FIFO policy into two parts to ensure the freshest inventory is always available. The variable "m" was noted as the shelf life of blood and platelets. The shelf life, m, was then partitioned into two variables m1 and m2, which together equaled m (the total shelf life of the product). The FIFO policy was modified and applied to each stage (m1 and m2) independently. Their inspiring work showed their modified FIFO policy outperforms a simple FIFO policy. However, we found most blood centers use a simple (one-stage) FIFO policy and are not open (or not allowed) to easily modify their inventory policies due to the underlying governmental and medical regulations. Thus, we are required to find methods that significantly reduce product wastages and shortages while increasing the profit margins and allowing the simple FIFO policy (as it's currently in place).

Our practical approach

Instead of the EOQ model and changing inventory policies, we applied practical ordering techniques and the lean principle of accounting budgets to inventory holdings to design a JIT ordering technique (reducing wastages and shortages), which results in increasing profit margins without undesirably changing the operational management of blood. The investigated techniques are listed in the 'Research Methodology' sections. Furthermore, we allowed placing the periodic order quantities to follow an 'automatic process'. The automatic process involves placing the order quantities 'exactly' equal to the computed values each period without any adjustments by the practitioner, which could cause unnecessary variability resulting in higher wastage and shortage of product. Subsequently, we compared the above techniques by monitoring their profit margins, wastage rates, and inventory turnover ratios (to allow availability of fresh inventory).

Research contribution

Our study contributes to the existing literature because not only do we allow ordering methodologies that can be easily implemented in practice, but also we use real-life managerial accounting to seek higher profit margins instead of EOQ. This practice is important in cases that EOQ cannot be implemented. To ensure our contribution to the literature, we examined the work of [Schneider and Wallenburg \(2013\)](#), which summarized 212 quantitative and qualitative published scholarly papers over the duration of 50 years. The authors performed a content analysis to divide the articles into several subdivisions based on the investigations' foci: purchasing and supply management (SCM), logistics, operations management, general management, and miscellaneous. According to their analysis, there were several papers focused on relationship management (i.e., they emphasized the importance of relationship among different departments). Although some studies stressed the relationship between the purchasing department and IT/HR divisions as useful to increase profit, *we found that none of the above studies investigated practical ordering methodology and none of them used real-life accounting practices to increase profit margins*. Similarly, even though we follow the path of [Axelsson et al. \(2002\)](#) and apply sophisticated managerial techniques to develop a modern ordering method for blood, our study is different because the above study analyzes inventory units theoretically, while *we allow continuous budgeting, inventory liquidity, and safety inventory in our decision-making*.

LITERATURE REVIEW

In this study, we focus on the lean or Just-in-Time (JIT) ordering technique to reduce the cost of operations inside the blood center. We acknowledge that this methodology has an impact on the cost of logistics, as orders are placed when needed and might not be combined. [Liu et al. \(2013\)](#), for example, studied a two-echelon supply chain to minimize the cost of logistic service integrators where the demand was assumed to be random and following a normal distribution. In contrast, we will not make any assumption about the demand distribution. Instead, we use real-life data to study the demand pattern and use demand forecasts or previous sales to place orders. Furthermore, [Tajbakhsh et al. \(2010\)](#) used a quantitative method to investigate the EOQ model, which allowed the model to incorporate the supplier's reliability. Although effective and popular, our previous investigation showed the EOQ model is not a practical tool for ordering blood (the reason is mentioned in the Introduction section), and therefore is not included in the current study. The following subsections categorize the literature reviews based on their approaches.

Literature Review of Ordering Methods

[Elston and Pickrel \(1963\)](#) examined the ordering policies for Hospital Blood Bank via simulation in order to reduce wastage. The authors discovered that both inventory and ordering policies significantly affected outdate rates and contributed to a high rate of wastage. They did not, however, consider profitability and practical application to determining order quantities.

Somewhat differently, [Gélinas et al. \(1996\)](#) used JIT purchasing and partnership strategies to examine ordering methods. Then, in 2004, [Zhang](#) was among the first to use ARMA (Autoregressive Integrated Moving Average) demand in supply chain for manufacturing ordering

without consideration to coordinate activities, which resulted in meeting demand without increasing inventory levels. Subsequently, [Gaur et al. \(2005\)](#) and [Gilbert and Chatpattananan \(2006\)](#) also used the ARMA demand process to study ordering models that matched demand patterns. Unlike our study, none of the above studies compared several methods to compute order quantities.

Literature Review for Perishable Products

Focusing on perishable goods and order quantity, [Nahmias \(1982\)](#) reviewed relevant literature for determining ordering policies for fixed-life perishable inventory and inventory subject to continuous exponential decay. The author considered both deterministic and stochastic demand for single and multiple products, and discussed both optimal and suboptimal order policies. In an approximation study, [Chiu \(1995\)](#) created a continuous review perishable inventory model to identify a best ordering policy based on approximations to expected wastage, shortages, and inventory levels. This included introducing an ordering policy under a positive order lead-time to minimize the total expected average cost per unit time. In yet another study, [Ravichandran \(1995\)](#) explored the stochastic process associated with the inventory levels of a continuous review perishable inventory system of (S, s) type. The assumption was that the inventory system followed a homogeneous Poisson process and had a positive lead-time, which derived the stationary distribution of the stochastic process and determined the optimal reorder level. Similarly, [Chun \(2003\)](#) determined the optimal product price for perishable commodities based on the demand rate, buyers' preferences, and length of the sales period. Chun also identified the optimal-order quantity that maximized the seller's total expected profit and proposed a multi-period pricing model. Other related research for inventory management includes a study conducted by [Weiss \(1980\)](#), which considered lost-sales and backlogging continuous review of perishable inventory models, and another study by [Adachi et al. \(1999\)](#), which proposed an inventory model for perishable items using the Markov decision process.

Literature Review of Integrating Managerial Accounting Approach in Supply Chain Studies

According to the literature, several scholars have used managerial accounting for supply chain practices. [Buvik \(2000\)](#), for example, used managerial accounting to document the increased volume of orders and its relationship with improved administrative facilitates and the buyer-seller business relationship. [Axelsson et al. \(2002\)](#) highlighted several management accounting tools for supply chain such as target costing, cost tables, quality-function-price trade-offs, activity-based-costing (ABC) method, and balanced scorecard. [Boute et al. \(2014 and 2015\)](#) explored a time-driven ABC method that estimates activity costs by using productivity measures, and discovered that this method could provide managers with relevant information for supply chain design and planning. Finally, using a survey of managerial accounting, [Fayard et al. \(2012\)](#) found that the resources of internal electronic integration, external electronic integration, internal cost management, and absorptive capacity played a significant role to manage inter-organizational costs.

Deviating from the above literature, we apply the lean principle for estimating practical ordering methodologies and integrate managerial accounting to ensure higher profits. The lean precept allows a company to reduce waste by focusing on ordering just the essential material at the

specific time ([Kocakülâh et al., 2008](#)). Other authors such as [Gélinas et al. \(1996\)](#) recognized JIT purchasing would result in lead time reduction, inventory level reduction, waste elimination, and quality improvement, however, the above authors didn't include the lean principle of accounting budgets in their investigation, and they didn't study perishable products or a practical approach to ordering methods. Thus, supplementing the above authors, we construct several ordering models to quantify purchasing blood packages as needed. Subsequently, we compare our ordering methods based on their profit margin gain, wastage reduction, ending/average/days of inventory, inventory turnover, and their essential safety inventory to meet demand each month. It's clear that the ordering methodology with lower essential safety inventory is desired, as it meets demand accurately without requiring having a considerable safety inventory that could result in wastage.

DATA

Monthly demand data for blood was obtained from a large blood center in the eastern region of the U.S.A that satisfies blood demand for approximately 200 hospitals. Due to several proprietary agreements between the authors and the blood center, the name of the center cannot be revealed. The obtained time series data includes monthly blood-demand during seven years (2006 through 2012). The study period contains demand disturbances caused by hurricanes Irene (August, 2011) and Sandy (October, 2012). The above disruptions allow us to determine the ordering methodology that is robust during unforeseen events and in an uncertain environment. In addition, 10 hospitals in the same region were visited, and the blood-banking managers were interviewed to gain insight into practical blood procurement practices, as well as their demand patterns. We visited a variety of hospitals (research, large, and small) and represented the combined-demand for all hospitals as one large order for the blood center (Figure 1). Our study focuses on the blood center and we concentrate on placing orders for blood donation following the JIT ordering technique.

RESEARCH METHODOLOGY

Our interviews with hospital blood banking representatives indicated the most popular ordering method in practice was the Order-up-to-Level (OUL) technique, which was often adjusted using the forecasted values realized by 4-period Moving Average (MA) methods. A similar strategy was used in our focused blood center. Therefore, we examined the OUL and MA methods to place orders, as well as two additional ordering methods: 1) placing order quantities equal to the values of demand forecasts obtained by the Box-Jenkins technique and, 2) placing order quantities following previous shipments (not forecasted values) known as the ARMA-in-ARAM-out (AIAO) approach. The AIAO strategy is similar to the Material Requirements Planning (MRP) strategy, but the order quantities are not computed in the same way. We compared the four above methodologies for determining order quantities. Subsequently, we pursued the approach in determining the order quantity that had the lowest wastage rate without increasing shortage of product, while allowing the highest contribution profit margin. We allowed order quantities to be placed equal to the exact computed values (no quantity adjustment was allowed by the practitioner). We believe that adjusting pre-determined order quantities based on practitioner experience could cause unnecessary variability contributing to product wastages and shortages.

Model Setup

For simplicity, a two-stage supply chain is considered that involves manufacturer (blood bank) and retailer (hospital). Figure 1 below shows that we combined all hospitals' blood-orders into one large order (O_H) because our focused blood center recognizes its monthly demand as one large order. Similarly, combining all hospital orders eliminates variability due to the size of each order. In practice, our interview with hospital representatives in the region of our study indicated that large research hospitals and small non-research hospitals have significantly different demand patterns for blood, and thus, they have different sizes for orders. However, we were told that hospitals that are located in geographic proximity often collaborate to fulfill their regular demand when a shortage occurs and to overcome emergency conditions. Therefore, we combine all hospitals' orders and focus merely on ordering methodology between the blood center and the donors (supplier) during each period.

To simplify our practice, we assumed our focused blood center periodically determines order quantities (number of donations) during the last week of each month for the upcoming period when the actual demand for the upcoming period is not yet known. The assumption of placing orders during the last week of each month for the following month's demand was confirmed by interviewing several purchasing managers at various blood centers, including our focused blood center. We were told that due to some emergencies, several orders might be adjusted during the month; however, since generally orders are placed during the last week of each month for the upcoming period, we ignore these special circumstances. Nevertheless, we will show there is no need to adjust orders often when the pre-determined order quantities are obtained using an accurate ordering methodology. Furthermore, due to the high rate of product perishability, we allow the unused blood (or the surplus inventory) to be discarded each month. Although some hospitals can still use one-month-old blood because the shelf life of blood is approximately 40 days, we decided to discard one-month-old blood in order to be conservative in our calculations and to allow having fresh blood available each month. Our personal interviews with several blood doctors indicated the shelf life of blood varies based on the doctor's preference, hospital, and the type of surgery. For example, for high-risk surgeries (or when the patient is very young), some doctors might request fresh blood (no more than two weeks old), while other doctors might not. Hence, we find it's beneficial to allow one-month-old blood to be discarded to always have fresh inventory available.

Figure 1 below shows the general idea used for our study. When hospitals place orders for blood (O_H), the blood center contacts donors (O_t) using several different methods including inviting donors to the blood center, setting a mobile location in public places, going to the donor's residence to get his/her blood, and so on. These different ways to receive a supply of blood are shown in Figure 1 as method 1, 2 ... n to reaching donors. In Figure 1, O_t represents the blood center's periodic request for donors (supply), and O_H represent the total monthly demand placed by hospitals (demand). O_t (supply) is assumed to be placed at the end of each period for the upcoming period and O_H (demand) is the actual periodic demand as it occurs. Henceforth, for this investigation, we determine O_t in a way to match O_H each period.

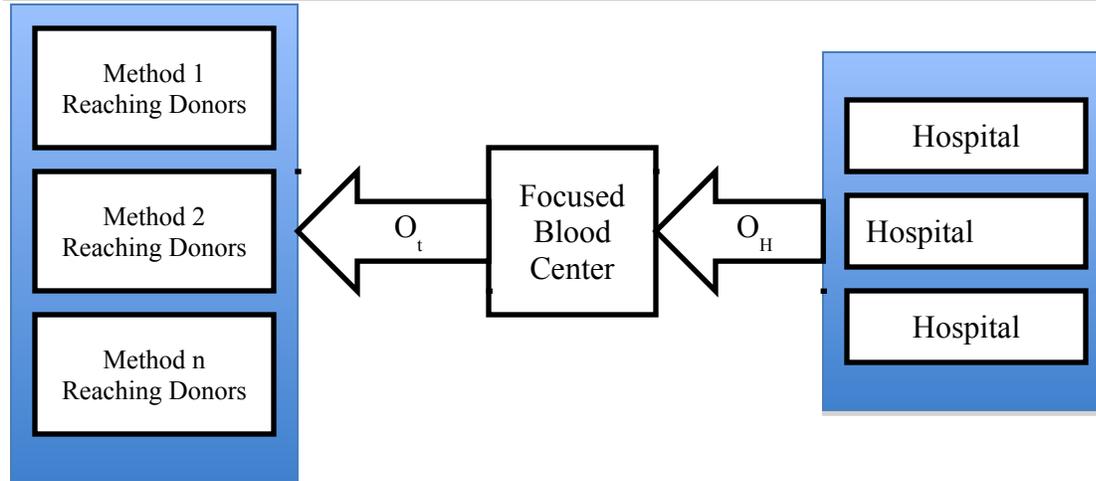


Fig. 1. Supply Chain setting for blood.

To construct orders that match demand pattern, we used the forecasted values of demand and the actual data for previous orders. To construct the contribution margins, we used the actual variable costs and average price for blood in the region of study (\$350/package). Our goal is to reduce product wastage and shortage without compromising the hospital's service level and blood center's profitability.

Performance Evaluation

In the year 2011, the U.S. Department of Health and Human Services (DHHS) set the proposed blood wastage rate to $\leq 6\%$ nationwide (DHHS, 2011). According to the DHHS (2011) annual report, blood waste rate in 2011 was approximately 6.4%, which also included a reduction of 15% from the year 2008 and forward. Therefore, we are interested in the method that determines the order quantities that significantly reduces product wastage, keeps high service levels, has higher profit margins, and is robust enough to be used during uncertain environments such as natural disasters.

Constructing Order Quantity

For each period, we placed order quantities using the following techniques.

First, we placed the order quantities based on the values computed by the Order-up-to-Level (OUL) methodology (95% customer service level), which neither follows demand forecasts closely, nor does it follow previous sales, but we found it to be surprisingly popular in practice.

Second, we placed order quantities equal to the computed demand forecasts using two forecasting methodologies: Moving Average (MA) and Box-Jenkins (BXJ). The MA method was used because we found this technique to be popular in practice for both blood centers and

hospital blood banks. Although the visited operations used the OUL technique for blood ordering, they often adjusted their order quantities based on the computed values of demand forecasts by the MA method. We investigated the BXJ methodology to signify the effect of the forecasting approaches on waste reduction.

Third, we placed order quantities based on previous sales (not demand forecasts) using the ARMA-in-ARMA-out (AIAO) methodology. ARMA stands for Autoregressive Integrated Moving Average. The AIAO's strategy is similar to the MRP strategy, but the computed order quantities are not the same. This methodology can only be applied when the demand follows an ARMA process; thus, we employed this model after examining our demand data and discovering that our demand represented the ARMA process ([Fortsch and Khapalova, 2016](#)). It's worth mentioning that the use of actual data from previous orders to construct upcoming orders has been studied by [Zhang \(2004\)](#), [Gaur et al. \(2005\)](#), and [Gilbert and Chatpattananan \(2006\)](#). The authors proved that once the demand is known to follow an ARMA process, ordering methods using AIAO matched the demand consistently without requiring the practitioner to forecast demand frequently; however, the above authors didn't investigate profitability, and their studies utilized modeling, not real-life data sets. Our study confirms their theoretical models in practical application, as well as allowing us to focus on profitability by using a lean principle of managerial accounting.

To construct the AIAO ordering technique, we follow a methodology suggested by [Gaur et al. \(2005\)](#). These authors mathematically proved that when demand follows ARMA (p, q), the best method to quantify orders should follow ARMA (p, p+q) given in Theorem 1 ([Gaur et al., 2005](#)), where p is the number of autoregressive lags (historical changes in demand) and q is the number of moving average lags (historical changes in moving averages). Examining our demand data shows demand follows ARMA (3, 2) in which the autoregressive lag is 3 (p=3) and the moving average lag is equal to 2 (q=2) ([Fortsch and Khapalova, 2016](#)). Thus, the future orders must follow (3, 5) in which p=3 and q=3+2. In the course of constructing the upcoming order quantities, the autoregressive lag (p) represents the number of previous orders we must consider, and the moving average lag (q) represents the number of moving averages of the previous orders we must include in our calculations when determining the order quantities for each period.

It is worth mentioning ordering methods that use demand forecasts to quantify orders such as MA and BXJ place an emphasis on the blood center's ability to forecast demand accurately. Since we place orders for blood donations (supply) at the last week of each month when the actual demand for the upcoming month is not known, monthly forecasted values are used. Therefore, following these methods, the blood centers are required to forecast the demand periodically. When placing orders, we assumed the safety inventory is 5% in order to stay within the industry standard practice (the 5% safety inventory is the nation-wide average because the safety requirement varies alongside state and regional regulations and blood centers' preferences). Afterward, we analyze the *actual* safety inventory required for each methodology to fulfill monthly demand. The superior ordering methodology would be the one that results in the lowest requirement of *actual* safety inventory and the highest contribution profit margin to meet demand each period. Lowest requirement for safety inventory signifies that orders match demand for blood consistently. The following are the monthly order quantities placed using the forecasting approach:

MA = quantities of orders are based on 4PMA demand forecasts (1)

BXJ = quantities of orders are based on Box_Jenkins forecasts (2)

In the AIAO approach, the monthly order quantities are calculated using the ARMA-in-ARMA-out methodology. This method places emphasis on the accuracy of information about previous actual sales (not demand). The simple logic of this approach is that when demand has a specific pattern such as ARMA, periodic demand forecasting is redundant. [Gaur et al. \(2005\)](#) argue that ARMA models resemble real-life settings and carry all information needed to match orders with demands. Therefore, to determine the order quantities, the historical data from the actual shipments can be used directly by fitting previous orders quantities into the ARMA models.

It is worth mentioning a natural assumption of the AIAO technique is previous sales are equal to actual demand (demand = sales), and the patterns of demand (ARMA) stay the same at least for a while. Another assumption of the AIAO technique is that the decision-maker (procurement manager) does not deviate from the theoretical AIAO model when fulfilling orders so that the quantities of the historical sales would precisely represent the quantities of the historical demands. In other words, the shipped order quantities must match the exact order quantities determined by AIAO (cannot be more or less). This assumption may be somewhat unrealistic because the decision-maker may be forced to deviate from the exact order quantities needed each period due to transportation costs, truck loading constraints, holidays, and discount purchasing ([Cui et al., 2015](#)). When the shipped order quantities are not equal to the actual demand for each period, the historical order quantity's pattern (or ARMA pattern) can significantly be affected, and this could negatively influence calculations for determining future order quantities. In such cases, the AIAO method might not be appropriate because the order received and the shipped quantities don't match. Nevertheless, several researchers have suggested the importance of using the AIAO methodology, including [Zhang \(2004\)](#), [Gilbert and Chatpattananan \(2006\)](#), and [Gaur et al. \(2005\)](#). As with other scholars, we continue forward and use the AIAO method of quantifying orders regardless of its assumptions. Correspondingly, a similar supposition about matching order quantities with demand each period is used for all ordering models in the literature, including the commonly used EOQ model; thus, this assumption is widely popular among scholars.

Following Theorem 1 of the [Gaur et al. \(2005\)](#) technique, we first examined our demand data and found that the autoregressive lag, p , is 3, and the moving average lag, q , is 2. Therefore, orders were quantified using ARMA ($p, p+q$) or ARMA (3, 5). Thus, we needed to consider the changes in quantities for three previous shipments and five previous moving averages. AIAO quantifies orders as the following:

$$O_{t+1} = \mu + \rho_1 O_t + \rho_2 O_{t-1} + \rho_3 O_{t-2} + \lambda_1 \varepsilon_{t-1} + \lambda_2 \varepsilon_{t-2} + \lambda_3 \varepsilon_{t-3} + \lambda_4 \varepsilon_{t-4} + \lambda_5 \varepsilon_{t-5} \quad (3)$$

Where ρ_i is the regression coefficient of changes in past shipments quantities, O_{t-i} is the quantity of the orders shipped, t is time interval such that: t is the current period, $t-1$ is the past

period, $t-2$ is the period before past, etc. λ_i is regression the coefficient of the moving averages for the past shipments, and ε_{t-i} is the value of past period moving averages. Note that ARMA (3, 5) signifies use of the quantities of the three past orders that were shipped, and the five past moving averages of those shipments to quantify the next period's orders (O_{t+1}).

Managerial Accounting Approach

Typically, companies adopt perpetual (continuous inventory) systems to manage their stocks. In a perpetual inventory system, the status of inventory is managed and updated continuously; this is in contrast to a periodic inventory system in which the company determines the quantity of inventory on hand periodically. The difference between the two methods is that the perpetual inventory system provides real time inventory balance information, while the periodic inventory system determines inventory by physical count at the end of each period. The former system, therefore, is more accurate than the latter, and is more appropriate for perishable products.

We compute the cost of goods sold and contribution margins for each ordering method at the end of each period by using the price and cost data obtained from our focused blood center. Furthermore, we compare different ordering methods via contribution margins and inventory turnovers for each ordering technique. Table 1 shows the detailed definitions of the variables used in the study.

Table 1
Definitions of variables

Variable	Definition	Equation
FIFO	Goods are assumed to be used in the order in which they are purchased.	N/A
LIFO	The cost of goods sold or issued comes from the most recent purchase.	N/A
Moving average method	The cost of inventory is averaged of all similar goods available during the period.	N/A
Unadjusted purchase/ Unadjusted order ¹	The predictions of demand using different forecasting techniques.	$UAPUR = Sales + Unadjusted\ Ending\ inventory$
Adjusted purchase	The sum of 75% of the current month demand, 25% of the next month demand, and safety inventory.	$Adjusted\ purchase = 75\% \text{ of the forecasted sales for the current period} + 25\% \text{ of the forecasted sales for the next period} + safety\ inventory$
Safety inventory	Perished or unusable inventory.	$SI = 5\% \text{ of the demand forecast for the current period}$

¹ In this paper, we treat order as purchases. We assume that there is no distinguish between order and purchase.

Unadjusted ending inventory	The ending inventory builds up using different ordering methods.	N/A
Adjusted ending inventory	The demand for the first week of next month plus the safety inventory.	$AEI = 25\% * \text{next period order received} + 25\% * \text{safety inventory of the current period}$
Units-used	The sum of the units-sold plus the perished safety inventory.	$\text{Units-used} = \text{Beginning inventory units} + \text{Units produced} - \text{ending inventory units}$
Units available for sale	The units available for sale are the units-used minus perished safety inventory.	$\text{Units-used} - \text{Safety inventory}$
Cost of goods sold	The costs of sold inventory.	$\text{Cost of goods sold} = \text{Beginning inventory cost} + \text{Cost of goods purchased} - \text{Ending inventory cost}$
Wastage	Perished blood	N/A
Shortage	Unfulfilled orders	N/A
Contribution margin	The dollar amount remained from sales revenue after variable expenses have been deducted.	$\text{Contribution Margin} = \text{Sales revenue} - \text{Cost of goods sold}$
Contribution margin ratio	The value of contribution margin scaled by sales revenue.	$\text{Contribution Margin Ratio} = \text{Contribution Margin} / \text{Sales}$
Inventory turnover	The number of times a company's inventory is replaced over one year.	$\text{Inventory Turnover} = \text{Sales} / [(\text{Beginning Inventory} + \text{Ending Inventory}) / 2]$
Days sales in inventory	The number of days that a company would need to sell its accumulated inventory.	$\text{Days sales in inventory} = 365 / \text{Inventory Turnover}$

Unadjusted/adjusted purchases

In order to analyze the contribution margin for each period as it's done in real-world applications, we define unadjusted purchased quantity as equal to the sum of sales and unadjusted ending inventory. Unadjusted ending inventory is shown in Table 2 ($UAPUR = \text{Sales} + \text{Unadjusted Ending Inventory}$). However, since it would take at least one week to receive orders, blood centers must place orders during the last week of each month and receive at least 1/4 (one week) of them during the same week in order to have enough supplies to start each period. Therefore, at the start of each month, it is reasonable to assume that blood banks must satisfy the remaining three-weeks' demand of the current period in addition to the first-week's demand of each upcoming month. Nevertheless, the demand for blood fluctuates during each period, and an unadjusted purchase that is merely based on one-month's demand is not appropriate. To overcome this problem, we define the current period adjusted purchase quantity ($APUR_t$) as equal to 75% (3 weeks) of the current monthly allowed purchase ($UAPUR_t$), plus 25% (1 week) of the forthcoming monthly allowed purchase ($UAPUR_{t+1}$), plus the current

period of allowed safety inventory (SI_t). This method is in agreement with real-life accounting practices of industries. Moreover, using the adjusted purchasing method ($APUR_t$) allows us to consider monthly fluctuations in demand during ordering. This ensures purchased quantities match demand for each period accurately, and decreases product wastage. Hence, we have the following formula for adjusted purchases made during each period: $APUR_t = 0.75 * UAPUR_t + 0.25 * UAPUR_{t+1} + SI_t$ (Table 2).

We also assume excess inventory *older than one month* is discarded because of the rate of perishability of the product. In order to be consistent with industry standards, we allow a safety inventory of 5% for unadjusted purchase (Table 3).

Table 2

Unadjusted purchase emanand adjusted purchase

Panel A: Unadjusted purchase (UAPUR)	
Unadjusted purchase equal to the predictions of demand using different forecasting techniques. It does not consider safety inventory.	
Unadjusted purchase	$UAPUR = Sales + Unadjusted\ Ending\ inventory$
Unadjusted purchase using order-up-to-level method	$UAPUR_{OUL}_t = \text{Calculated by: norminverse (90\%, mu, std)}$
Unadjusted purchase using moving average method	$UAPUR_{MA}_t = SALES_t + UAEI_{MA}_t$
Unadjusted purchase using Box-Jenkins method	$UAPUR_{BXJ}_t = SALES_t + UAEI_{BXJ}_t$
Unadjusted purchase using ARMA-in-ARMA-out method	$UAPUR_{AIAO}_t = SALES_t + UAEI_{AIAO}_t$
Panel B: Adjusted purchase (APUR)	
Adjusted purchase considers purchase of 75% of the current month demand and 25% of the next month demand and considers safety inventory.	
Adjusted purchase	$Adjusted\ purchase = 75\% \text{ of the forecasted sales for the current period} + 25\% \text{ of the forecasted sales for the next period} + safety\ inventory$
Adjusted purchase using order-up-to-level method	$APUR_{OUL}_t = 0.75 * UAPUR_{OUL}_t + 0.25 * UAPUR_{OUL}_{t+1} + SI_{OUL}_t$
Adjusted purchase using moving average method	$APUR_{MA}_t = 0.75 * UAPUR_{MA}_t + 0.25 * UAPUR_{MA}_{t+1} + SI_{MA}_t$
Adjusted purchase using Box-Jenkins method	$APUR_{BXJ}_t = 0.75 * UAPUR_{BXJ}_t + 0.25 * UAPUR_{BXJ}_{t+1} + SI_{BXJ}_t$
Adjusted purchase using ARMA-in-ARMA-out method	$APUR_{AIAO}_t = 0.75 * UAPUR_{AIAO}_t + 0.25 * UAPUR_{AIAO}_{t+1} + SI_{AIAO}_t$

Table 3

Safety inventory	
Safety inventory	$SI = 5\% \text{ of the demand forecast for the current period is considered to be safety inventory and assumed to be perished at the end of each period.}$
Safety inventory using order-up-to-level method	$SI_{OUL}_t = UAPUR_{OUL}_t * 0.05$
Safety inventory using moving average method	$SI_{MA}_t = UAPUR_{MA}_t * 0.05$
Safety inventory using Box-Jenkins method	$SI_{BXJ}_t = UAPUR_{BXJ}_t * 0.05$
Safety inventory using ARMA-in-ARMA-out method	$SI_{AIAO}_t = UAPUR_{AIAO}_t * 0.05$

 Unadjusted/adjusted Ending Inventory

Table 4 details the method used for estimating excess quantities that have remained in inventory after each period (known as ending inventory). We define adjusted ending inventory (AEI) as the observed remaining quantities at the end of each period. At the end of each period, the observed amount of inventory is one week's worth of safety inventory from the current period, which is 25% (or 1/4) of the total safety inventory for the month, plus one-week's worth of (1/4 of) purchase for the next period (25% of unadjusted purchases). The unadjusted purchase is used for calculating the ending inventory because we are interested in the 'upcoming' period's order quantities, and the adjusted purchase would consider the current period. Thus, if we used the adjusted purchases, we would double count the safety inventory. Simply said, the quantities available to fulfill the demand of the **first week** for each month is the adjusted ending inventory of the prior month. Thus, the adjusted ending inventory quantities are calculated to be: $AEI = 25\% * \text{next period orders received} + 25\% * \text{safety inventory of current period}$. This ending inventory is available to satisfy demand at the start of each new month (Table 4).

Table 4

Unadjusted ending inventory and adjusted ending inventory

Panel A: Unadjusted ending inventory (UAEI)	
Unadjusted ending inventory using order-up-to-level method	$UAEI_{OUL}_t = \text{ending inventory when hospitals order up to a specific level (having 90\% customer service level = 90\% of average demand distribution)}$
Unadjusted ending inventory using moving average method	$UAEI_{MA}_t = \text{ending inventory build up using 4-period moving average to forecast demand.}$
Unadjusted ending inventory using Box-Jenkins method	$UAEI_{BJ}_t = \text{ending inventory build up using Box-Jenkins approach to forecast demand.}$
Unadjusted ending inventory using ARMA-in-ARMA-out method	$UAEI_{AIAO}_t = \text{ending inventory build up using ARMA-in-ARMA-out. This is based on Box Jenkins but it follows the previous shipments (observed sales) instead of forecasted demand (unobserved/estimates of sales) similar to JIT techniques.}$
Panel B: Adjusted ending inventory (AEI)	
Adjusted ending inventory	$AEI = 25\% * \text{next period order received} + 25\% * \text{safety inventory of current period}$
Adjusted ending inventory using order-up-to-level method	$AEI_{OUL}_t = 0.25 * UAPUR_{OUL}_{t+1} + 0.25 * SI_{OUL}_t$
Adjusted ending inventory using moving average method	$AEI_{MA}_t = 0.25 * UAPUR_{MA}_{t+1} + 0.25 * SI_{MA}_t$
Adjusted ending inventory using Box-Jenkins method	$AEI_{BJ}_t = 0.25 * UAPUR_{BJ}_{t+1} + 0.25 * SI_{BJ}_t$
Adjusted ending inventory using ARMA-in-ARMA-out	$AEI_{AIAO}_t = 0.25 * UAPUR_{AIAO}_{t+1} + 0.25 * SI_{AIAO}_t$

method	
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Units-used and Cost of Goods Sold

To estimate the cost of goods sold for each month, we examine the beginning inventory of each period. Theoretically, the quantity of units-used is equal to the quantity of units-sold when there isn't any product wastage. However, in real-life operations, the units-used are different (higher) from the units-sold because the former consists of both sold items and perished products. Therefore, the quantity of the units-used is equal to the sum of the number of the units-sold, plus the number of perished products. Table 5 summarizes the estimates for the cost of goods sold for each ordering method. We can observe that the cost of goods sold for each period ($COGS_t$) is equal to the costs of beginning inventory units (that is the left over inventory from the previous period, $\$AEI_{t-1}$) plus the cost of purchased units in the current period ($\$APUR_t$) subtracted from cost of ending inventory ($\$AEI_t$). The ending inventory is subtracted because some inventory items are not sold and they would have to be subtracted from the cost of goods-available-for-sale (GAS). Thus, for the cost of goods sold each period, we have the following:

$$COGS_t = \$AEI_{t-1} + \$APUR_t - \$AEI_t$$

Table 5
Inventory equation

Panel A: Units-used	
Units-used	<i>Beginning inventory units+Units purchased=Units-used+Ending inventory units</i> \Rightarrow <i>Units-used=Beginning inventory units+Units produced-Ending inventory units</i>
Units-used using order up to level method	$UNITUSED_OUL_t = AEI_OUL_{t-1} + APUR_OUL_t - AEI_OUL_t$
Units-used using moving average method	$UNITUSED_MA_t = AEI_MA_{t-1} + APUR_MA_t - AEI_MA_t$
Units-used using Box-Jenkins method	$UNITUSED_BXJ_t = AEI_BXJ_{t-1} + APUR_BXJ_t - AEI_BXJ_t$
Units-used using ARMA-in-ARMA-out method	$UNITUSED_AIAO_t = AEI_AIAO_{t-1} + APUR_AIAO_t - AEI_AIAO_t$
Panel B: Units available for sale	
Units available for sale	<i>Units-used - safety inventory</i>
Units available for sale using order up to level method	$UNITAVAIL_OUL_t = UNITUSED_OUL_t - SI_OUL_t$
Units available for sale using moving average method	$UNITAVAIL_MA_t = UNITUSED_MA_t - SI_MA_t$
Units available for sale using Box-Jenkins method	$UNITAVAIL_BXJ_t = UNITUSED_BXJ_t - SI_BXJ_t$
Units available for sale using	$UNITAVAIL_AIAO_t = UNITUSED_AIAO_t - SI_AIAO_t$

ARMA-in-ARMA-out method	
Panel C: Cost of goods sold	
Cost of goods sold	<i>Beginning inventory cost+Cost of goods purchased=Cost of goods sold+Ending inventory cost</i> \Rightarrow <i>Cost of goods sold =Beginning inventory cost+Cost of goods purchased-Ending inventory cost</i>
Cost of goods sold using order up to level method	$COGS_{OUL_t} = \$AEI_{OUL_{t-1}} + \$APUR_{OUL_t} - \$AEI_{OUL_t}$
Cost of goods sold using moving average method	$COGS_{MA_t} = \$AEI_{MA_{t-1}} + \$APUR_{MA_t} - \$AEI_{MA_t}$
Cost of goods sold using Box-Jenkins method	$COGS_{BXJ_t} = \$AEI_{BXJ_{t-1}} + \$APUR_{BXJ_t} - \$AEI_{BXJ_t}$
Cost of goods sold using ARMA-in-ARMA-out method	$COGS_{AIAO_t} = \$AEI_{AIAO_{t-1}} + \$APUR_{AIAO_t} - \$AEI_{AIAO_t}$

Contribution Margin

Contribution margin (CM) is the dollar amount gained from sales revenue after variable expenses have been deducted ([Garrison et al., 2014](#)). It is used to cover the organizational fixed expenses and the remaining is profit. It's intuitive that the ordering method with the highest contribution margin would also be the one with the highest net income. We utilize the following equation to estimate the contribution margin:

$$\text{Contribution Margin} = \text{Sales revenue} - \text{Cost of goods sold} \quad (4)$$

Contribution Margin Ratio

Contribution margin ratio (CMR) equals to the value of contribution margin scaled by sales revenue. CMR allows firms to estimate the changes in the contribution margin related to changes in the total sales. For example, a CMR of 35% would mean that for each dollar increase in sales, the contribution margin would be increased by 35 cents (or: $\$1 \text{ sale} * \text{CMR of } 35\%$). The equation is as follows:

$$\text{Contribution Margin Ratio} = \text{Contribution Margin} / \text{Sales}. \quad (5)$$

Inventory Turnover

Inventory turnover (IT) shows how many times a company's inventory is replaced over a period of time. It is an efficiency measure that shows the speed at which a company uses its supply of goods over a given time period. It's intuitive that for perishable products, a high rate of inventory turnover is desirable. The following equation is used for IT:

$$\text{Inventory Turnover} = \text{Cost of Goods Sold} / [(\text{Cost of Beginning Inventory} + \text{Cost of Ending Inventory}) / 2]$$

.(6)

Days Sales in Inventory

The days-sales in inventory (DS) simply measures the number of days a company would need to sell its accumulated inventory, and, therefore, it's called the firm's liquidity measure. The liquidity measure is important for organizations to understand the freshness of their product and the number of days needed for the company's inventory to be converted into cash. The following equation is used to measure the liquidity measure:

$$\text{Days sales in inventory} = 365 / \text{Inventory Turnover} \quad (7)$$

RESULTS

OUL Method

Our results revealed that estimating upcoming order quantities using the popular Order-up-to-Level (OUL), had the lowest contribution profit margin (43.05%) in comparison to all other methods (Table 6). Furthermore, the days of inventory was 1.06 days and the inventory turns was 346 times per year, which were not significantly different for the BXJ and AIAO methods. On the other hand, Table 7 shows this method resulted in the highest product wastage in comparison to all other methods. During several months, the average product waste for the seven-year period of study was 1,668 packages of blood per month, and during a few months the maximum monthly wastage was 5,225 packages of blood. Although this method had the highest product wastage, it still resulted in stock-outs in several months during the period of study. The average monthly stock-outs was 1,074 units. Thus, although popular in practice, this method does not follow demand, and is not suggested for demand patterns that include monthly fluctuations.

Moving Average Method

Estimating the upcoming order quantities by following the 4-period Moving Average (MA) method resulted the highest inventory turnover rate (354 times per year) and the lowest days of inventory on hand (1.03 days; Table 6). Comparably, this method resulted in the lowest product wastage; however, it had the highest stock-outs in comparison to all other techniques. The average stock-outs for the seven-year period of study was 3,306 units during several months, and the maximum shortage during the study period was 6,560 packages of blood for a few months (Table 7). The contribution profit margin was 45.83%, which was lower than the BXJ and AIAO methods due to high rate of stock-outs for this technique.

BXJ and AIAO Methods

Quantifying upcoming orders using Box-Jenkins techniques of demand forecasting was similar to using the AIAO methodology, which follows the previous shipments (observed sales). The contribution margin for both methods was about 46%, and the inventory turns was 344 times per year for BXJ, and 341 times per year for the AIAO technique. Thus, both methodologies were comparable. On the other hand, since the BXJ method follows demand forecasts instead of the

actual (observed) sales, it resulted in product wastage (926 units) during a few months, while the AIAO method did not have any product wastage (Table 7). Even though following the BXJ methodology to quantify upcoming orders had several months that resulted in excess inventory and perished products, during several other months it resulted in shortages of blood. The BXJ technique resulted in average stock-outs of 1,661 units during several months, and the maximum of 4,155 units in a few months during the seven-year study period. The AIAO methodology that had not resulted in any product wastage had the average stock-outs of 1,591 units during several months, and a maximum of 2,235 units.

In conclusion, our results indicate that using the AIAO methodology for quantifying upcoming orders is *slightly* superior for products with monthly fluctuations in demand in comparison to all other techniques studied.

Table 6 Comparison of Inventory Turnover and Profit for different Ordering Methods

Measures	OUL	MA	BXJ	AIAO
CMR	43.05%	45.83%	46.00%	46.02%
Inv_Turns	346/year	354/year	344/year	341/year
Days_Inv	1.06	1.03	1.06	1.07
Demand (solid) Vs. Adjusted Purchases (dotted)				
Demand (solid) Vs. Units-used (dotted)				
Ending Inventories				

Table 7
Comparison of Wastage/Shortage for different Ordering Methods

Measures	OUL	MA	BXJ	AIAO
	Units (Packages of blood)			
Wastage (+) / Shortage (-)	1,668	-3,306	-1,661	-1,591
Max. Wastage	5,225	0	926	0
Max. Shortage	1,074	6,560	4,155	2,235
Wastages (+ numbers) & Shortages (- numbers)				

Table 8
Contribution Margin and Inventory Turnover Analyses

Month 6-91	OUL method	MA method	BXJ method	AIAO method
Sales*: (1)	\$886,577,340	\$885,967,830	\$886,577,340	\$886,577,340
Cost of goods sold: (2)	\$504,869,400	\$479,962,360	\$478,772,360	\$478,577,200
Contribution margin: (3)=(1)-(2)	\$381,707,940	\$406,005,470	\$407,804,980	\$408,000,140
Contribution margin ratio: (4)=(3)/(1)	43.05%	45.83%	46.00%	46.02%
Rank	4	3	2	1
Beginning inventory: (5)	\$1,478,150	\$1,377,170	\$1,360,340	\$1,365,270
Ending inventory: (6)	\$1,441,940	\$1,335,180	\$1,424,600	\$1,440,410
Average inventory: (7)=((5)+(6))/2	\$1,460,045	\$1,356,175	\$1,392,470	\$1,402,840
Inventory turnover: (8)=(2)/(7)	345.790	353.909	343.830	341.15
Rank	2***	1**	3	4
Days sales in inventory: (9)=365/(8)	1.056	1.031	1.062	1.070
Rank	2	1	3	4

*The sales revenue is determined as:

(a) demand < units-used: sales=demand*\$330;

(b) demand > units-used: sales=units-used*\$330.

The units-used is different from units sold because it consists of safety and perished inventories.

**Although MA method results in the freshest inventory, the consequences are many stock-out periods.

***OUL method has the second best for fresh inventory but the contribution margin is the lowest.

CONCLUSION AND MANAGERIAL IMPLICATIONS

In this study, we obtained data from a large blood center located in the eastern region of U.S.A. We investigated a practical technique for determining upcoming order quantities following the JIT principle when the actual demand is not yet known. We analyzed inventory units by allowing continuous budgeting, inventory liquidity, and safety inventory in our decision-making. Due to the importance of the product, the fact that it cannot be manufactured, the dependency of its supply on voluntary donations, and underlying governmental regulations, we sought a practical

ordering methodology that resulted in reducing product shortages and wastages. We quantified and compared upcoming orders using four techniques, which included OUL, MA, BXJ, and AIAO. We analyzed each technique by focusing on the product wastage and shortage, contribution profit margins, and inventory turnovers by real-life lean principles of managerial accounting. Prior literature focused on perishable goods theoretically or by simulation models had suggested the use of EOQ model to increase profit, and changing in inventory policies to reduce wastage. However, our interview with the representatives of several blood centers and hospitals blood banks indicated that not only does the EOQ model not match the real-life application in this industry, but also changing inventory practices might not be practical due to governmental regulations and specific medical applications. Therefore, we used the lean principle of the managerial accounting to determine profits to help us choose the technique with higher profit margins.

Our study is unique in combining real-life data and accounting practices, and a practical ordering methodology to determine order quantities. We recommend that decision-makers allows order quantities for requesting donors to be equal to the computed values determined by the AIAO methodology to avoid the unnecessary variability, which in could result product wastage and stock-outs.

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