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A COMPARATIVE STUDY OF FORECASTING TECHNIQUES
FOR THE US AIR FORCE
MEDICAL MATERIEL MANAGEMENT SYSTEM

BY

PHILIP JOHN VAN ESS
B.S.E., Florida Technological University, 1975

RESEARCH REPORT

Submitted in partial fulfillment of the requirements
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1976

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To my typist-editor, my wife, I express my heartfelt thanks for enduring this trying period.

ABSTRACT

A computer simulation experiment was conducted to evaluate and compare five individual forecasting models across nine different demand patterns. The models were based on the Medical Materiel Management System used by the US Air Force hospitals. Results indicated the best model varied depending on the demand pattern, the safety stock level, the noise level of the demand pattern, and the measure of forecast error. Across all demand patterns, exponential smoothing and 12-month moving average were best for the short term forecast used by the system, regardless of noise level in the demand patterns. Analysis of models within a single demand pattern showed, in most cases, several models as ranking equally well. When overall system requirements were considered, the exponential smoothing method was by far the best choice.

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I. INTRODUCTION

Rising inventory costs in US Air Force hospitals due to inflation and a larger patient load have created a monetary squeeze on hospital supply budgets. A solution to this problem may lie in a more efficient forecasting technique for the Medical Materiel Management System. The purpose of this paper is to evaluate the forecasting model used by the Medical Materiel Management System (MMMS) for US Air Force hospitals, with a view to determining a better forecasting model for use. The MMMS is an integrated system of forecasting and inventory control. It was felt that a review of the forecasting procedure was needed since the present data processing system used was previously done by hand.

The extent of the analysis presented was limited due to many factors. The time constraints imposed restricted the amount of data used in the analysis. Another limitation was encountered because only two years of historical data were available. The data, however, was accurate. The data used was restricted to high dollar value items so that

a substantial number of datum points could be used in the analysis. This also made the resulting computer output data more meaningful and useful. The amount of the data also restricted the forecasting techniques that could be meaningfully applied in the analysis.

The data used in the analysis was highly representative of the medical supplies used in a US Air Force hospital. Surgical, pharmaceutical, and ward supplies were used. Enough raw input data was also available to give an excellent contrast between the various forecasting techniques that were used in the analysis.

The study contained in this paper presents a logical and valuable look at the forecasting technique used in the US Air Force MMMS. Chapter II describes the present system now in use. It cites the various Air Force manuals applicable to the system and presents the guidelines outlined in the manuals. An example is presented to aid in understanding the guidelines of the system.

Chapter III gives a brief description of the forecasting techniques and their variations to be used in the analysis. Each is presented with the mathematical formula used in the computer model.

Chapter IV analyzes the data produced by the computer model of the existing system. All of the forecasting techniques are rated on their ability to give an accurate forecast and still maintain a stable ordering system.

Chapter V summarizes the findings of the analysis and then presents reasons for the findings. Recommendations are made for system review and adoption of various MMMS modifications. Studies have been conducted in the past in other areas to evaluate and compare several forecasting models using various criteria, but no studies were reported in the literature reviewed on a system comparable to the US Air Force's Medical Materiel Management System.

II. DESCRIPTION OF EXISTING SYSTEM

The existing Medical Materiel Management System utilized by the US Air Force Base Medical Supply Officer (BMSO) is governed by Air Force Manual (AFM) 67-1, Volume V and AFM 167-240. These two manuals provide the policies and general guidelines on the medical materiel record account of the operating inventory control. The data processing system utilized adheres to the specific procedures outlined in AFM 171-240. The MMMS is concerned with the inventory levels of medical materiel whose unit price is less than \$100. A few exceptions such as x-ray film are also incorporated into the system.

The BMSO considers all recurring demand items for stockage in the operating inventory. Close coordination between the user and the BMSO is vital to obtain valid and complete information for stockage decisions and subsequent establishment of stock levels. When stockage is appropriate, either a BMSO determined stock level or an economic order quantity (EOQ) stock level will be established.

An inventory control system is usually based on one of two different methods. They are the fixed reorder point method and the fixed review time or cyclic ordering method (Greene, 1974). In the fixed reorder point method the quantity on hand is checked whenever material is removed from the inventory. When it reaches a certain point, a quantity of a fixed size is ordered. In the fixed review time method, the time remains fixed and the order quantity varies. The inventory items are periodically surveyed. At each review point an order is placed which will bring the inventory up to an established level.

The Air Force's MMMS is neither of these two pure forms. It is an integrated inventory control forecasting system. The system's guidelines used are shown in Fig. 1. The following paragraphs explain the various headings.

The EOQ method of requisitioning used provides that those items yielding a low dollar value of annual consumption are requisitioned less frequently. Use of the EOQ reduces the number of requisitions initiated in the course of a year. This enables the BMSO to devote his greatest attention to those items which are responsible for the largest dollar expenditure. The top 25 high dollar value items account for 25 percent of the BMSO's supply budget

If the Annual Consumption is	then the Safety Level is	and the Reorder Point is	EOQ Period Normally, this reorder point will reoccur every	at which time sufficient stocks will be ordered to bring stock on hand up to the Stock Control Level which is
Less than \$ 8.00	1 month of stock	1 months stock + pipeline	12 months	13 months of stock + pipeline
\$ 8.00 -- \$ 47.99	1 month of stock	1 months stock + pipeline	6 months	7 months of stock + pipeline
\$ 48.00 -- \$ 287.99	1 month of stock	1 months stock + pipeline	3 months	4 months of stock + pipeline
\$288.00 -- \$1727.99	1 month of stock	1 months stock + pipeline	1 month	2 months of stock + pipeline
over \$1727.99 (CONUS and overseas)	1 month of stock	1 months stock + pipeline	15 days	45 days of stock + pipeline

Source: AFM 67-1, Vol. V, 2 Oct. 72

Figure 1. Basis for determining Economic Order Quantities

and less than one percent of the total items in the inventory. The normal time between replenishment requisitions (the EOQ period), stock control level, and reorder points is determined on the basis of the dollar value of annual issues (AFM 67-1, Vol. V).

The quantity to be requisitioned is that amount needed to bring stock on hand and on order up to the stock control level also shown in Fig. 1. The stock control level is the planned maximum quantity of an item which may be on hand and on order at any time during the month. The quantity requisitioned is adjusted automatically by the computer program to the intermediate pack or shipping container quantity. It should be noted that an issue is a demand and a requisition received or receipt is a supply. These terms will be used interchangeably throughout the paper.

The MMMS computer program which updates the EOQ once a month uses a 12-month simple moving average to forecast the next reorder point. This means that the reorder point stock level changes whenever the forecast for the next month changes. The current stock level is reviewed by the data processing system once a week. A simplified flow chart of the data processing system is shown in Fig. 2. A

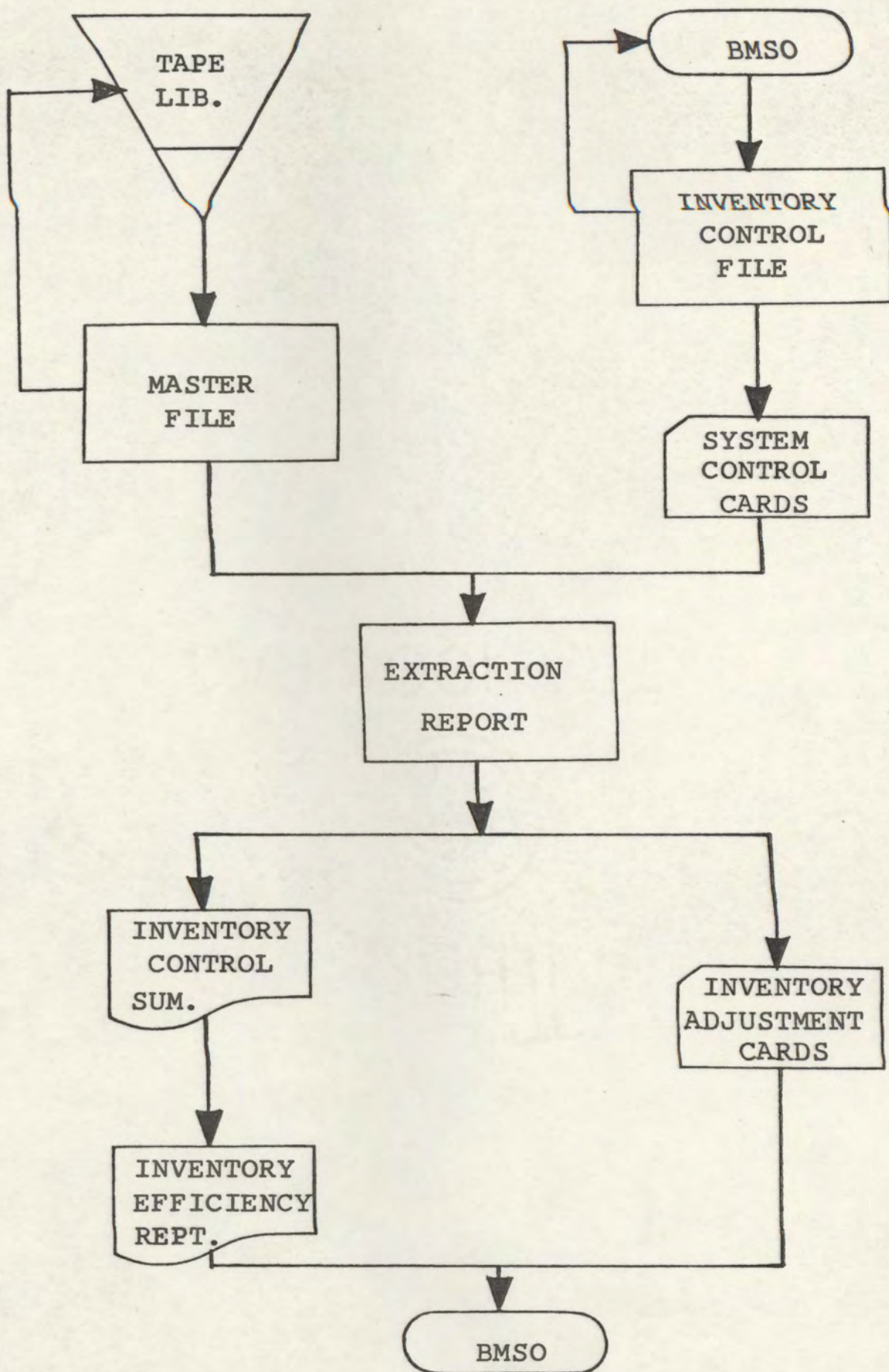


Figure 2. Basic Medical Materiel Management System flowchart.

quantity is requisitioned for an item if the present inventory stock level is less than the monthly forecasted reorder point. The reorder point is some percentage of the stock control level. The percentage used is determined partly by its annual dollar consumption. The example that follows illustrates how the reorder point for each item is obtained.

Variations in stock control levels and EOQ's may be necessary for certain items and under certain conditions. Expiration dated items, programmed population changes on a base, item popularity, and recurring seasonal demand items all provide variations within the stock control system.

To accurately determine the reorder point for any given item, the average pipeline time based on routine requisitions and methods of shipment must be determined. Pipeline time is the number of days between the date a requisition is initiated and the date material is received. Pipeline time length computations are based on normal conditions and methods of transportation. For a new item the computer assigns a 30 day pipeline time. Once six pipeline times are accumulated, the moving average of the last six requisition pipeline time lengths is computed to forecast the next pipeline time used in the computations.

Greene (1974) states that the safety stock quantity is based on the time it takes to obtain materiel in an emergency. AFM 67-1, Vol. V dictates that the safety stock quantity for any item will be a 30 days' supply of that item.

The computational method used to establish the reorder point outlined in AFM 67-1, Vol. V is as follows:

$$\text{Replenishment issues for given number of days} \times \left[\frac{\text{Safety level in days} + \text{Pipeline time in days}}{\text{Number of days during which issues were accumulated}} \right] = \text{Reorder Point}$$

Another way of stating this formulation is:

$$\text{Daily Forecast} \times \left[\text{Safety level in days} + \text{Forecasted Pipeline time in days} \right] = \text{Reorder Point}$$

For example the Patrick AFB hospital used 220 cases of 5% dextrose solution in 1000 cc bottles in the last 12 months. Each case contained six bottles. Thus the reorder point is calculated as follows:

$$1320 \times \frac{30 + 20}{365} = 180 \text{ bottles or } 30 \text{ cases}$$

The stock control level is calculated as follows:

$$\begin{array}{r} \text{Reorder} \\ \text{Point} \end{array} + \begin{array}{r} \text{Amount normally consumed} \\ \text{during EOQ period} \end{array} = \begin{array}{r} \text{Stock} \\ \text{Control} \\ \text{Level} \end{array}$$

The amount normally consumed during an EOQ period is the forecasted moving average multiplied by the length of the EOQ period. Using the dextrose example again, a consideration of the cost per item is necessary to conform to AFM 67-1, Vol. V. The cost of each bottle is \$4.35. Thus the annual dollar consumption is greater than \$1728. This makes the EOQ period 15 days. Therefore the stock control level is:

$$180 + \frac{1320 \times 15}{365} = 234 \text{ bottles or } 39 \text{ cases}$$

The above description of the existing system is the basis used for the comparisons performed in Chapter IV. The computer models used in the analysis adhere to the guidelines of AFM 67-1, Vol. V and use the same methods as just shown to calculate the reorder point and the stock control level.

III. REVIEW OF EXISTING FORECASTING TECHNIQUES

The problem of routine forecasting can be thought of as one of having a sequence of numbers and trying to predict what the next number will be and trying to predict the following one, profiting by our mistakes. The problem of prediction requires a great deal of knowledge about what the numbers represent. Given this, care must be exercised in selecting the forecasting technique to be used in a given system. Since the Medical Materiel Management System under analysis needs a discrete short term forecasting technique, only those techniques suited for discrete short term forecasting were considered for analysis. The limited amount of historical data available also decreased the number of techniques available for analysis. Three techniques with their variations were selected because they conformed to these guidelines. The techniques were moving average, exponential smoothing, and regression analysis.

There are three forecasting variations based on moving average. The first variation is the simple moving average based on a constant process. The second is the moving

average with an adjustment for a linear trend process. The third is a weighted moving average which never was fully explored because of the advent of the exponential smoothing technique.

The moving average forecasting technique comes from applying the least-squares criterion to a data record of a fixed length, where each of the datum points is weighted equally (Johnson and Montgomery, 1974). The following variations were evaluated on their ability to accurately forecast both constant and linear trend processes.

The simple moving average is a forecasting estimate based on the average of the N most recent observations (x_t). At each period the oldest observation is discarded and the newest one added to the observations. This gives:

$$x_{T+1} = \frac{1}{N} \sum_{t=T-N+1}^T x_t = M_T$$

which is the moving average at time T (M_T).

The responsiveness of the moving average method to change is controlled by the choice of the number of observations (N) to be averaged. If N is large, the moving average responds slowly to changes in x_t , and when N is small, it responds more quickly. If the x_t 's are at a constant level and suddenly jump to a new constant level, it

takes N observations for the moving average to give estimates relevant to the new level. With a slow changing process a large value of N would yield good results and for a fast changing process a small value of N would yield the best results (Brown, 1963).

Since the simple moving average will lag behind a trend in a demand, the second variation employing a trend correction factor is often used. The computations minimize the sum of the squares of the errors between the actual observed demand and a straight line. The line's slope is a measure of the magnitude of the trend in the demand (Brown, 1959).

The values of the coefficients a and b are estimated by minimizing the sum of the squares of the errors of the straight line $x_t = a + bt$. The least squares analysis gives

$$a = \frac{T}{N}$$

$$b = \frac{12 S}{N(N^2 - 1)}$$

where T is the total demand for the past N periods and S is a total where the demand in each period is weighted by

the number of periods from the center of the averaging interval (Brown, 1959).

Assuming a trend is in effect, our forecast for x_t one period in advance is

$$x_{t+1} = \frac{T_t}{N} + \frac{6 S_t}{N^2 - 1} \left(\frac{N+2}{N} \right)$$

where

$$S_t = S_{t-1} - T_{t-1} + \left(\frac{N-1}{2} \right) x_t + \left(\frac{N+1}{2} \right) x_{t-N}$$

and

$$T_t = T_{t-1} + x_t - x_{t-N}$$

(Brown, 1959).

The third moving average variation is called the weighted moving average. Instead of weighting all previous datum points equally, an experimentally determined weight is assigned to all past N periods considered in the computations. Due to the emergence of exponential smoothing and adaptive smoothing techniques, this method has never been used extensively. It is mentioned here just for completeness.

|| Exponential Smoothing is the name given by Robert Brown in 1959 to a practical method of smoothing fluctuations in a demand history to get an estimate of future

demand. Brown formulated this rule: "To get a new estimate of the average demand, add to the previous estimate a fraction of the amount by which demand this month exceeds that estimate." This fraction is known as a smoothing constant and is denoted by α ($0 < \alpha < 1$). The above basic rule of exponential smoothing is written as follows:

$$\text{New Average} = \alpha (\text{new demand}) + (1 - \alpha) (\text{old average})$$

or restated

$$S_t(x) = \alpha x_t + (1 - \alpha) S_{t-1}(x)$$

where

t = the number of time periods after the point in time where the estimation process began

x_t = the past time period demand

$S_t(x)$ = the smoothing forecast for the next time period

$S_{t-1}(x)$ = the past time period forecast

(Radhakrishnan and Sullivan, 1972).

Simple Exponential Smoothing is usually applied to a constant process system. If a linear trend process or a

constant process that could develop a trend is to be forecasted, Double Exponential Smoothing is used.

The equation as stated by Brown (1959) is the following:

$$\begin{aligned} \text{New Average} &= \alpha(\text{new demand}) \\ &+ 2(1 - \alpha)(\text{average computed last month}) \\ &- (1 - \alpha)(\text{average computed previous month}) \end{aligned}$$

Stated in mathematical terms this gives:

$$\hat{x}_t = \hat{a}_t + \hat{b}_t$$

where

$$\hat{a}_t = 2 S_t(x) - S_t^{[2]}(x)$$

$$\hat{b}_t = \left(\frac{\alpha}{1 - \alpha} \right) S_t(x) - S_t^{[2]}(x)$$

$$S_t^{[2]}(x) = \alpha S_t(x) + (1 - \alpha) S_{t-1}^{[2]}(x)$$

and $S_t(x)$ is as was previously defined. The notation $S_t^{[2]}(x)$ means double smoothing, not the square of exponential smoothing (Brown, 1963). Therefore the last two computed values of the double smoothed average are stored to compute the new forecast each month.

To evaluate the coefficients in an application of exponential smoothing from one time period to another, it

is necessary to select the value of the smoothing constant, α . The accuracy of the forecasts depends upon the correct choice of the smoothing constant. If the forecasting method is to produce stable estimates and smooth out random fluctuations in the data, a small value of the smoothing constant is required. On the other hand, when a rapid response to a real change in the demand pattern is desired a larger value of the smoothing constant is appropriate. (Radhakrishnan and Sullivan, 1972).

To equate the equivalent N-period moving average technique to the exponential smoothing method, the smoothing constant is selected to give basically the same results. With the smoothing constant

$$\alpha = \frac{2}{N + 1}$$

this similarity is achieved. This cannot be 100 percent correct since exponential smoothing applies a varying weight to all the data whereas the moving average only averages the last N values with an equal weight being applied to those N datum values (Bedworth, 1973). If some basis exists for satisfaction with a moving average method for some N-periods, this method is used to establish the value for α .

Usually the smoothing constant, α , is somewhere between 0.01 and 0.3. A widely used technique is to carry out a sequence of trials on a set of historical data using many different values of the smoothing constant, and select the value of α that optimizes a measure of effectiveness such as the minimum of the sum of the squares of the errors. The selection of the "best" smoothing constant is usually a tradeoff between "effectiveness of smoothing" and "rapid response" (Brown, 1963).

It should be noted that the value of the smoothing constant can be recursively updated from one period to the next. This has been termed "adaptive" or "modified" exponential smoothing. Adaptive control of α was not attempted in this study mainly because a sufficiently large datum base was not available. However, past analysis has shown that adaptive smoothing of a constant process gives results comparable to exponential smoothing (Johnson and Montgomery, 1974).

If the results of a set of trials indicate that the optimum value of α is greater than 0.3, then the validity of the model should be questioned. If the plotted data reveals trends or cyclic patterns that will lead to a large

smoothing constant, a more appropriate model should be chosen to forecast future demands.

If it is possible to take derivatives of the fitting parameters of an equation, then it is possible to fit data with that equation using the least-squares procedure of regression analysis. A first-order polynomial regression analysis was used for the data analysis.

The first-order polynomial that will be used is

$$x_{t+1} = a + bt$$

where

$$a = \sum_{t=1}^N x_t - b \sum_{t=1}^N t$$

$$b = \frac{N \sum_{t=1}^N (t \cdot x_t) - \sum_{t=1}^N x_t \sum_{t=1}^N t}{N \sum_{t=1}^N (t)^2 - \left(\sum_{t=1}^N t \right)^2}$$

(Bedworth, 1973).

As the equations indicate, regression analysis is a continually summing process. This tremendous amount of historical data creates a very constant forecasting process.

IV. ANALYSIS AND COMPARISON OF FORECASTING MODELS

The five forecasting methods explained in Chapter III were applied to a computer model of the Medical Materiel Management System. The five methods were evaluated on their ability to meet four criteria. The criteria were the average of the sum of the squares of the errors, overall stock control level, inventory fluctuation, and stock reliability. The computer model used is a somewhat simplified model due to the nature of the data used.

The data used was obtained from the Patrick AFB Hospital in Florida. Historical data was only available for the past two years. Nine medical supply items were used in the analysis. These items shown in Fig. 3 are a representative cross section of the supply inventory. All of the items are high dollar value items which give them a 15 day EOQ period. The items have been stocked for more than two years. The two years of data for each item used in this analysis are shown in Appendix A. An average pipeline time of 16 days was used since this conforms to available data at Patrick AFB.

ITEMS

Stock Number	Item Identification	Where Used	Items/Unit. Issue
6505000635631	Aspirin Tablets	Pharmacy	1000/Bottle 12 Bottles/Case
650500116400	Dextrose	Surgery/ Wards	1000 cc/Bottle
6505007837218	Diazepam Tablets	Pharmacy	500/BT 12 Bottles/Case
6505008897929	Hydrochlorath Tablets	Pharmacy	1000/BT 12 BT/Case
6505009985872	Cloribrate Capsules	Pharmacy	100/BT 12 BT/Case
6510000744579	Surgical Sponges	Surgery	1200/Pkg
6515L030747	Thermometer Sensor Covers	Wards	1000/Pkg
6525C9650AG	X-ray Film RP 14	X-ray	500/Case
6530001070971	Surgical Pack	Surgery	1/Pkg

Figure 3. Description of the items used in the analysis.

The computer programs that were used are shown in Appendix B. Also shown is one year of the analysis of the data using each forecasting method. The computer programs conform to the guidelines in AFM 67-1, Vol. V. The programs calculate a reorder point and a stock control level each month. These calculations are based on the given safety stock period, the pipeline time, and the forecasted issue. The forecast was given in both a daily and a monthly forecast. A weekly available stock level is also given to more accurately show any stockouts. The sum of the squares of the errors was also tabulated for each item for use in the analysis.

The simple moving average technique and trend adjusted moving average variation were both tested with a period of 6 months and 12 months. The safety stock level was assigned a value of 30 days and also equated to pipeline time to check the stock availability of each item. Eight computer runs were made to produce the eight models used in the analysis.

The exponential smoothing technique and the double exponential smoothing variation used a 12-month moving average for the initial forecast. The safety stock level was equated to 30 days of stock and to pipeline time. The

value of α was varied from 0.1 to 0.32 in increments of 0.02 for each item. This was done in an attempt to determine the "best overall" value for α . Four computer runs were needed to generate the models for the analysis. (Each model had 12 different values for α .)

The regression analysis technique used the first 12 months of data to establish the initial forecast. The safety stock level was equated to both one month and to the pipeline time. Two models were generated for analysis by the computer program.

The "best overall" value of α was determined from the sum of the squares of the errors. The data from both the exponential smoothing and double exponential smoothing computer runs indicated a definite preference for $\alpha = 0.1$. This value was found to be a very good value for the constant demand items. It also produced a stable output for the items that had fluctuations in demand. Most of the time, demand follows a very slowly changing pattern, so that a small smoothing constant is appropriate in smoothing out the random fluctuations to give an accurate estimate of the average.

A comparison of the computed data was made based on an average of the sum of the squares of the errors, stock

control level, inventory level fluctuation, and stock availability. Fig. 4 shows a table with the experimental results outlined. The sum of the squares of the errors for both exponential smoothing variations is shown for $\alpha = 0.1$, the "best overall" value, and for $\alpha = 0.16$. The last value most nearly equates the exponential smoothing method to a 12-month moving average, the present system used to forecast demand.

Four of the 14 computer runs produced comparable "best" results. These were the simple 12-month moving average models and the exponential smoothing models. All of the models had a low level of inventory fluctuation, a low average sum of the squares of the errors, a low to medium stock control level, and an excellent stock availability record. Due to the fact that the pipeline time was almost half of the safety stock level, the models with safety stock level equal to pipeline time had a lower stock control level but still maintained an excellent stock availability record.

The worst models were the 6-month moving average with the trend correction factor. These models had a very high average sum of the squares of the errors, a very poor stock

COMPUTER RUN RESULTS

Method Used	α	N (Month)	Safety Stock Level (Days)	Average of SSE	Stock Avail.	Stock Control Level	Inventory Level Fluctuation
Moving Average		12	30	2659	EXC	Med	Low
		12	16	2659	EXC	Low	Low
		6	30	2656	EXC	Med	Med
		6	16	2656	EXC	Low	Med
Moving Average With Trend		12	30	3718	Good	Med	Med
		12	16	3718	Good	Low	Med
		6	30	87,500	POOR	Med	High
		6	16	87,500	POOR	Low	High
Exponential Smoothing	0.10		30	2807	EXC	Med	Low
	0.16		30	2841	EXC	Med	Low
	0.10		16	2807	EXC	Low	Low
	0.16		16	2841	EXC	Low	Low
Double Exponential Smoothing	0.10		30	2862	EXC	Med	Med
	0.16		30	3110	EXC	Med	Med
	0.10		16	2862	EXC	Low	Med
	0.16		16	3110	EXC	Low	Med
Regression Analysis		12	30	3013	EXC	High	Low
		12	16	3013	EXC	Med	Low

Figure 4. Computer Program Results

availability caused by a dangerously low stock control level, and a highly fluctuating inventory level.

The double exponential smoothing models also had an excessive inventory level fluctuation. This was due to their responsiveness to the demand fluctuations that looked like a trend.

The four "best" forecasting models were evaluated on their applicability to the present system. The four forecasting models contain two different techniques. The 12-month moving average method is the technique presently used by the MMMS. The exponential smoothing method of forecasting is an entirely different technique. For this reason these two techniques will be compared and contrasted in their system applicability.

When making a judgment of the relative merits of each alternative, the following three criteria suggested by Brown (1963), which are usually important, were used:

Accuracy

Simplicity of computation

Flexibility to adjust the rate of response

By using some cost criterion, all of these can be optimized (Bedworth, 1973).

The need for an accurate forecast is of the utmost importance. Both of the selected techniques accomplish this with equal ability. It has been noted, however, that if a forecasting system based on exponential smoothing were actively maintained over a period of several years, the accuracy of its predictions could be steadily improved (Radhakrishnan and Sullivan, 1972). This better accuracy could result in a significant monetary reduction of inventory.

In the inventory control system presented, it is necessary to recompute forecasts for three to six thousand supply items every month. Two-tenths of a second consumed unnecessarily for each of these items amounts to approximately one half hour. One half hour of computer time is expensive. Clearly then, simplicity of computation is important when a large number of different times series forecasts are routinely computed.

In a complete records system like the MMMS, there is one field on the historical data tapes for the issue in each of the past 12 months for every item. The 6-period moving average used to forecast pipeline time requires another six tape fields per item. For a 5000 item supply inventory record, this amounts to 90,000 fields. Each

month in the course of the processing, the information in each field in the input record must be shifted one field. The oldest information is dropped and the issue in the past month entered. Then the 6-period and 12-month moving averages can be computed.

Magnetic tape presents no real problem as far as available space for these datum points is concerned. But the longer the record, the more time (and hence cost) is required for data processing.

For a small hospital like the one at Patrick AFB (30 beds), all of this historical information is contained on one magnetic tape. But given a large medical center like Lackland AFB, Texas, four magnetic tapes are required to store the historical data. Four tapes mean four tape readers. This is expensive equipment.

Exponential smoothing does not require keeping a long historical record. Only one historical datum point per item is needed to calculate the new forecast. This datum point is the old forecast. Given this historical datum off the magnetic tape and the past month's demand loaded into the system from cards, the disc stored computer program can calculate the new forecast. By applying the exponential smoothing technique of forecasting to both the item fore-

cast and to the pipeline forecast, the number of magnetic tape fields can be reduced to one-ninth of its original size. So instead of 90,000 historical datum points the system now has only 10,000. This cuts down on the data processing time required and also can represent a substantial savings on computer peripheral equipment. Cost savings occur not only from reduction of capital equipment costs but also from savings on maintenance costs.

This new forecasting technique could easily be applied to the present system. The first old forecast to be used initially can be the 6-period or 12-month moving average of the present historical data. Given the preceding information, the first forecast of the system could be no worse than the 6-period or 12-month moving average method would have given. Conceivably, it could be better.

The third criteria, flexibility to adjust the rate of response, is an inventory system attribute that is seldom considered but should be. When the current issue is different from what was expected there are two considerations. Is the difference a purely random fluctuation (noise)? If so, the forecast will smooth out the fluctuation. But if this difference signifies a new pattern, then the past data is irrelevant.

The moving average methods currently used in the MMMS provide very little flexibility. Flexibility to adjust the rate of response can only occur if the value of N is changed. It is very difficult in the present system to change the value of N , the number of periods to be used in the computations.

The exponential smoothing method on the other hand can easily be adapted to new trends. Simply change the value of the smoothing constant, α . Most of the time demand follows a very slowly changing pattern, so that a small smoothing constant is appropriate in smoothing out the random fluctuations to give an accurate estimate of the average. Occasionally, the BMSO may predict a change due to the introduction of a new product. When a circumstance such as this arises, the item and its related items could have their smoothing constant values increased up to $\alpha = 0.3$, or even to $\alpha = 0.5$ for a period of three to six months.

The higher α value would make these products very responsive to changes in demand during this period. Then, when the new demand pattern has been established, the smoothing constant can be dropped back to its original value for greater stability and accuracy.

It should be noted that the BMSO does not have to predict the magnitude or direction of the demand change. The BMSO needs only predict a change is imminent. The routine calculations of the computerized system can detect and correct for the actual change that materializes in the demand for each item probably much more accurately than any prediction could.

Figures 5, 6, and 7 graphically compare the actual demand of three medical supply items used in the analysis to the forecasts computed by the 12-month moving average model and the exponential smoothing model with $\alpha = 0.10$. Fig. 5 illustrates a low unit count item. The comparison shows how the exponential smoothing model in October and November adjusted to the higher demands better than the moving average method.

The item shown in Fig. 6 is a medium unit count volume item. The comparison illustrates how the exponential smoothing model, once given a two month settling in period, tracked the upward trend of this item.

The high unit volume item shown in Fig. 7 illustrates how the exponential smoothing model, like the present 12-month moving average model, remains stable even when tremendous monthly fluctuations of an item occur. This

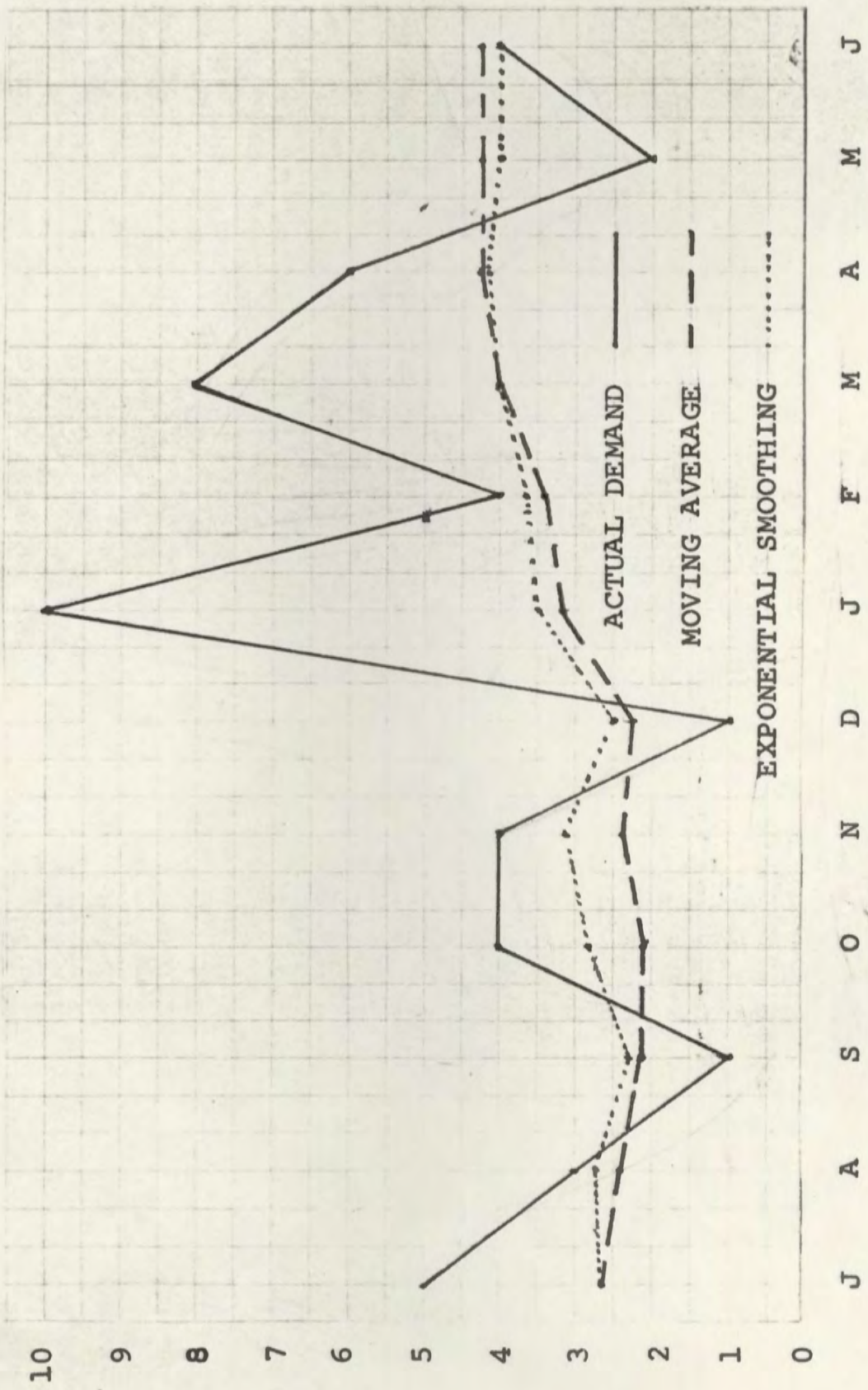


Figure 5. Forecasted demand of thermometer sensor covers compared to actual demand.

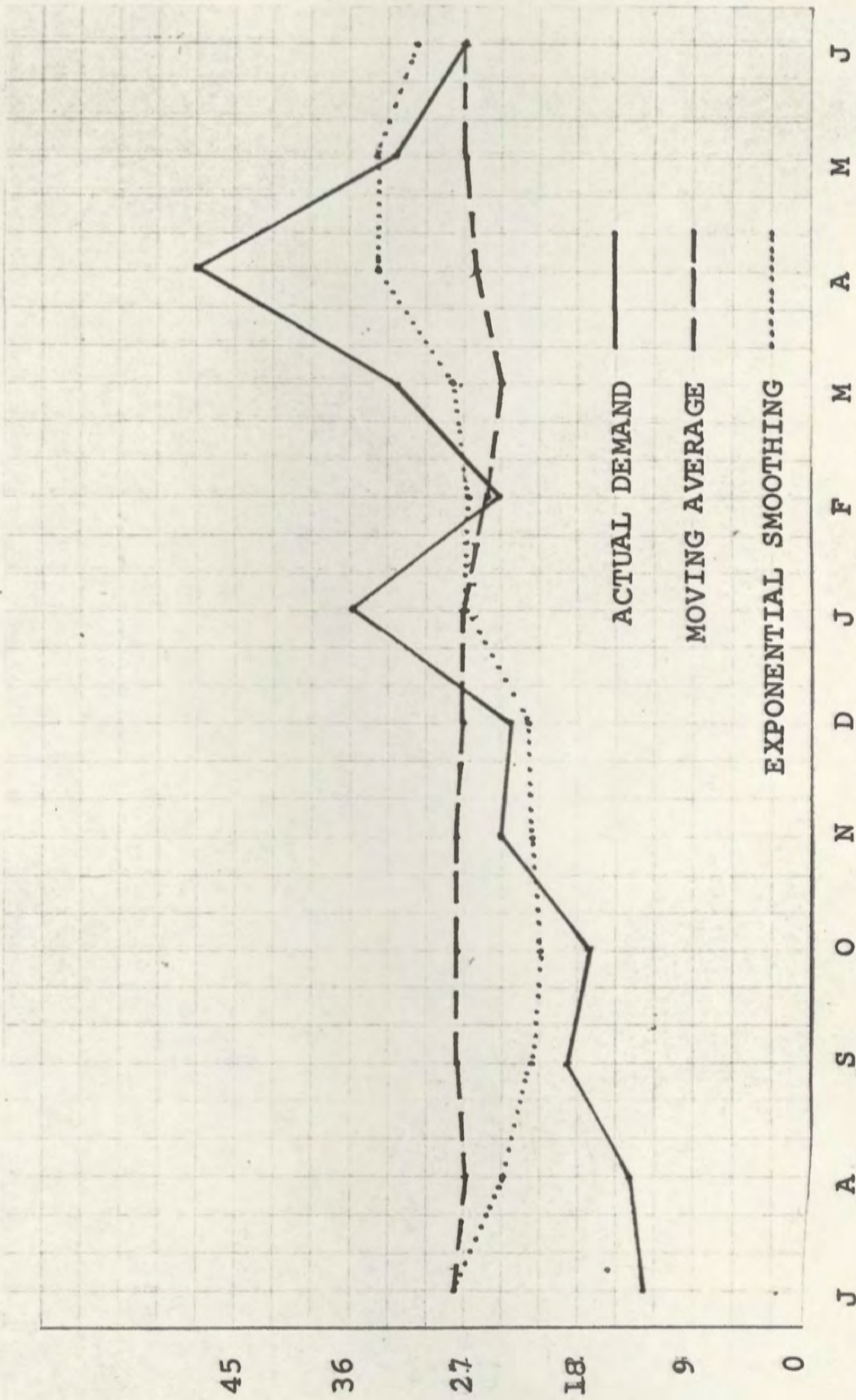


Figure 6. Forecasted demand of dextrose compared to actual demand.

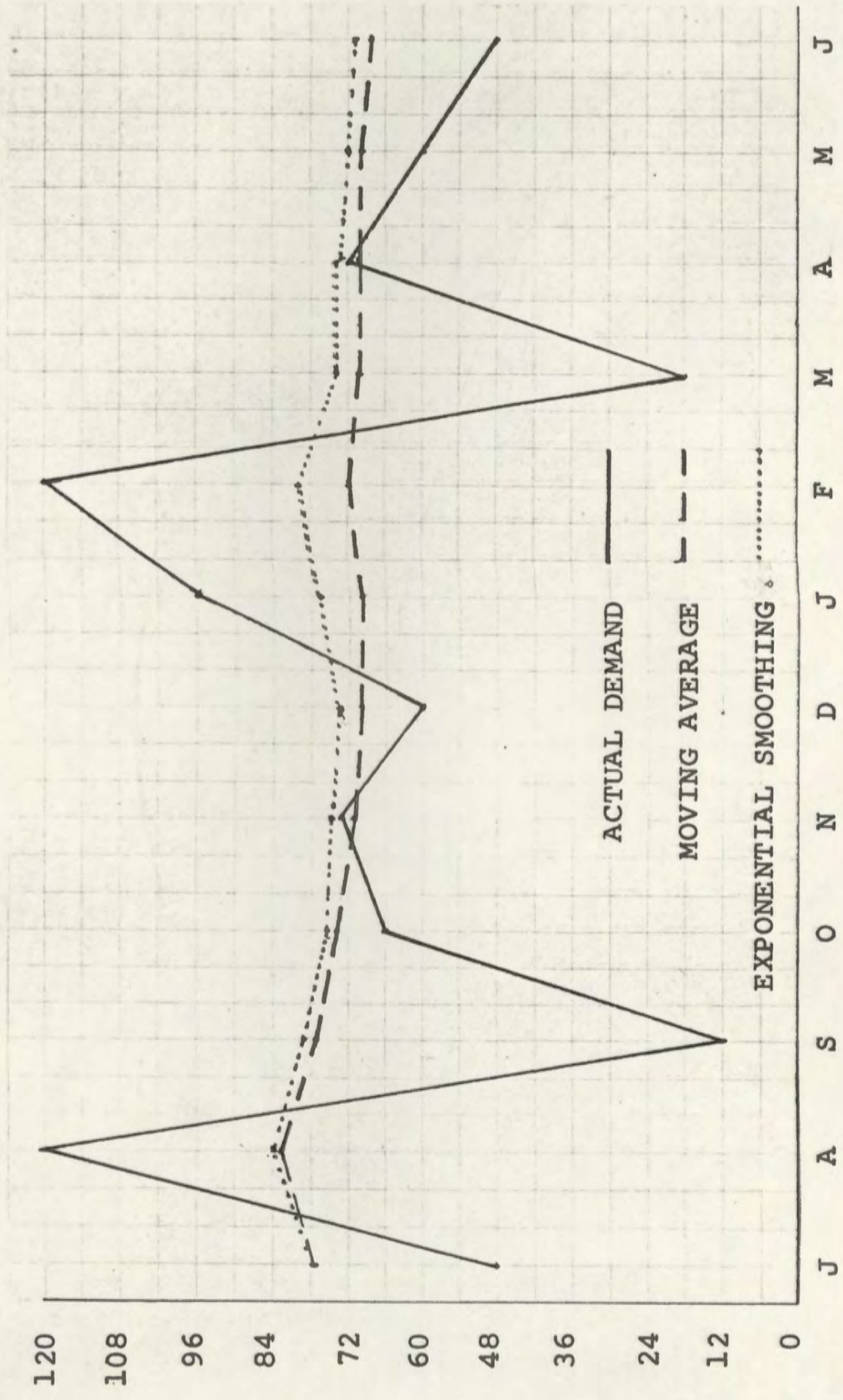


Figure 7. Forecasted demand of cloribrate compared to actual demand.

displays the exponential smoothing model's ability to differentiate between a new trend and noise.

The comparison of the exponential smoothing method to the presently used moving average methods has revealed the following:

1. The exponential smoothing method was as accurate as the moving average method at the time of installation and could be expected to give a better forecast in the future
2. The exponential smoothing method would require one-ninth of the historical data that the present moving average methods employ
3. The exponential smoothing method's flexibility to adjust the rate of response is far superior to the present moving average methods

V. SUMMARY AND RECOMMENDATIONS

This paper has presented the guidelines of the Medical Materiel Management System presently used by the US Air Force BMSO to control the supply inventory. Various manuals were cited which contained the guidelines for different phases of the system. An example was presented illustrating how the reorder point and stock control levels were calculated in the computerized forecasting and inventory management system.

A brief description was given of the forecasting techniques with their variations that were studied in this research report. The formulas shown for the forecasting techniques were the ones used in the computer models.

The computer models were then run adhering to the guidelines outlined. The data produced was then analyzed to evaluate the forecasting models used. The forecasting models were rated on their forecasting accuracy as well as an ability to maintain a stable serviceable stock control level.

Because of the accuracy, simplicity of computation, and flexibility to adjust the rate of response of the exponential smoothing forecasting method, I would recommend it be immediately adopted for use in the Medical Materiel Management System. The initial value of the smoothing constant for forecasting supply demand should be put at 0.10. The pipeline time forecasting portion of the program would initially have $\alpha = 0.29$. This would equate it to a 6-period moving average. After a settling in process this value could be increased or decreased as was deemed necessary.

Another recommendation is to equate the safety stock level in days to pipeline time. The present time of a flat one month's stock is unrealistic. With the exponential smoothing method to forecast pipeline time being highly responsive, any permanent increases or decreases in pipeline time would be adjusted to quickly. The data produced in the analysis showed that no decrease in serviceability occurred when the pipeline time of 16 days was also used for the safety stock level. However, the stock control level was lowered from 10 to 30 percent. Captain Richard Ferguson, USAF, presently assigned to Fort Detrick, Maryland, is presently studying the possibility of equating

pipeline time to safety stock level. His analysis at this point concurs with these findings. This lower level means less money tied up in inventory. Lower levels of physical inventory can also be more accurately counted.

A third recommendation is to rid the Medical Materiel Management System of one of its main problems: tampering. The raw data shown in Appendix A also shows how the present real life system is ordering and receiving stock. Tremendous variations in quantities ordered for these high dollar value items are shown over the course of the past two years. In the three examples shown in Chapter IV, Figures 5, 6, and 7, the plotted values of the 12-month moving average method show how the untampered system would have ordered these supply items. This more smooth ordering method also resulted in a stock control level from 30 to 50 percent less than the present system deems necessary. This is a classic example of creating excessive inventory levels by tampering with an integrated inventory-forecasting system.

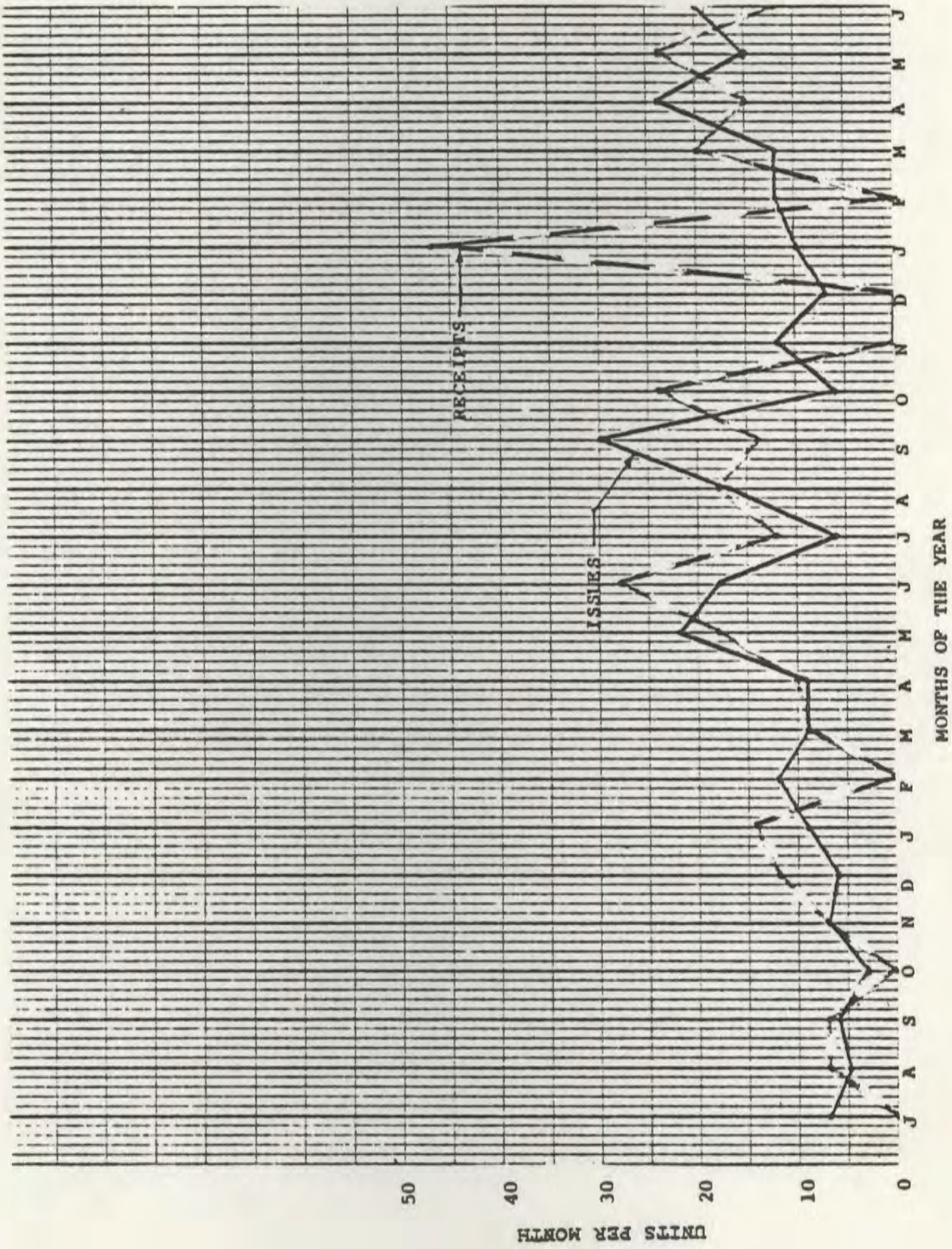
By installing the exponential smoothing forecasting method into the MMMS an accurate stock control level would be immediately calculated. If this system is left untampered with and orders are placed when they are generated

and for the amount computed necessary, the system would settle out within a short time and overall physical inventory cost would decrease substantially.

APPENDIX A
DATA FROM PATRICK AFB

NATURE OF THE DATA

All of the data shown in graphical form in this Appendix was produced at the Patrick AFB Hospital in Florida. The data shown is for nine medical supply items from July 1974 to July 1976. The points on the graphs at each month represent the total issues and receipts during that particular month. A complete description of each item is shown in Fig. 3.



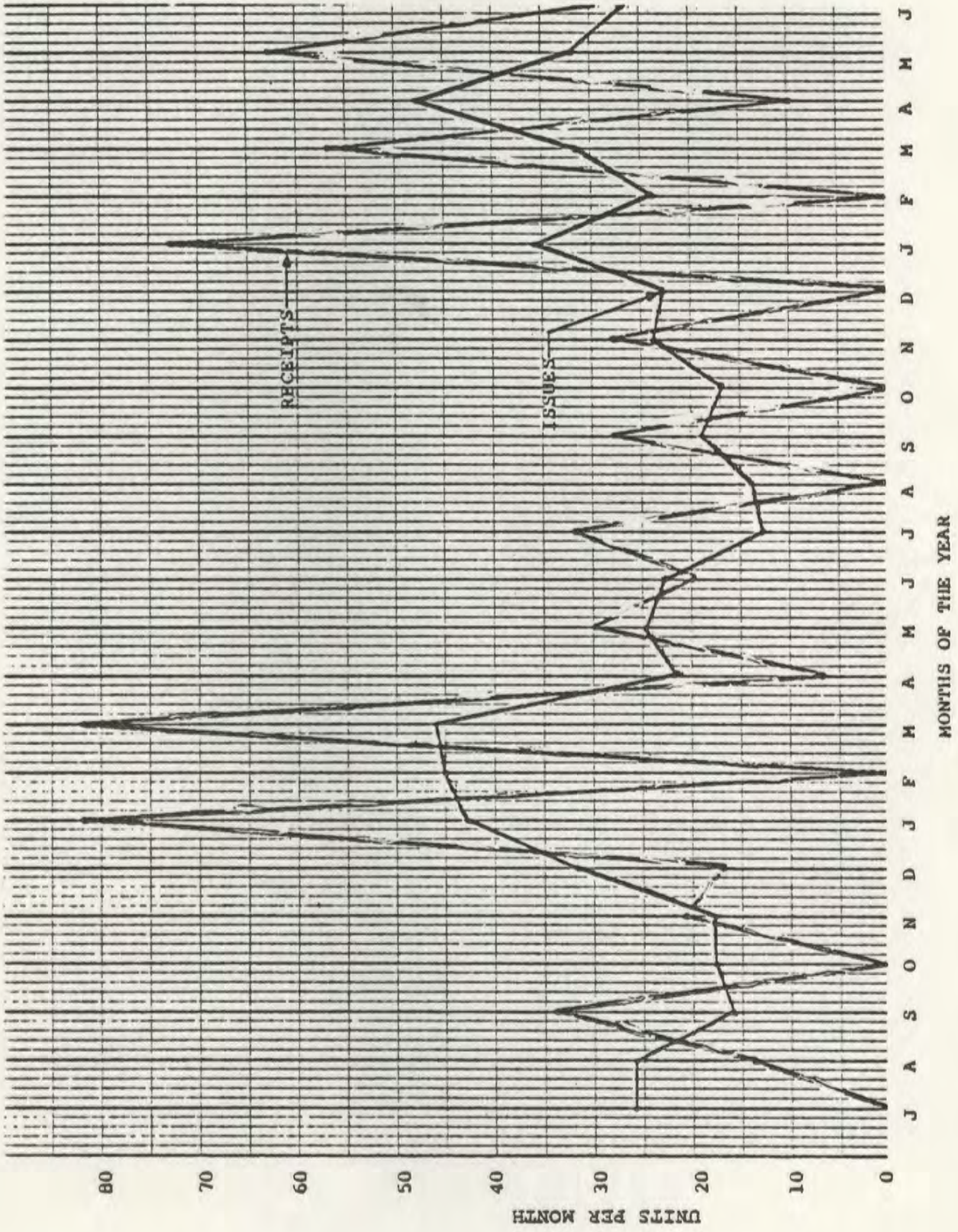


Figure 9. Dextrose: Stock No. 6505001164600

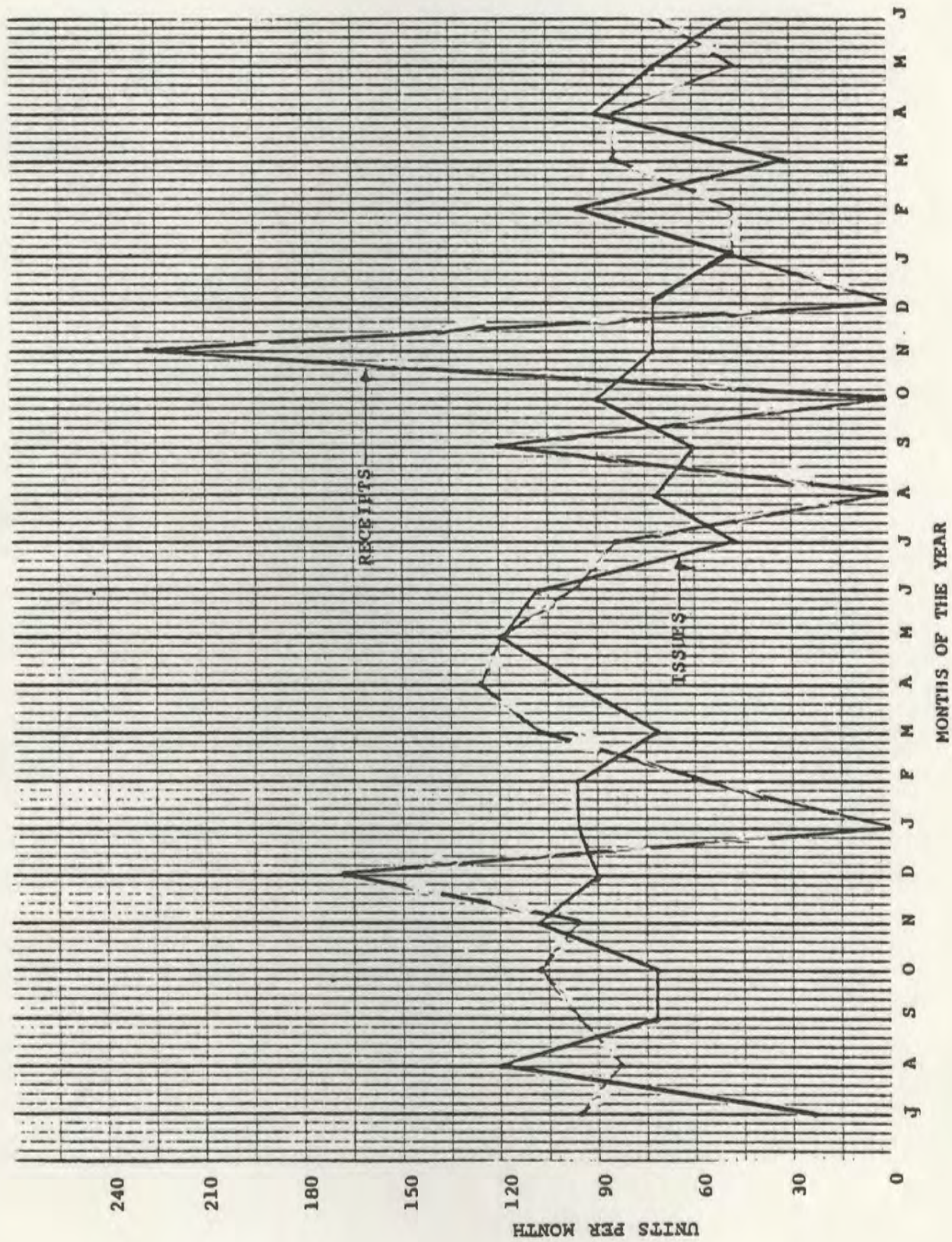


Figure 10. Diazepam: Stock No. 6505007837218

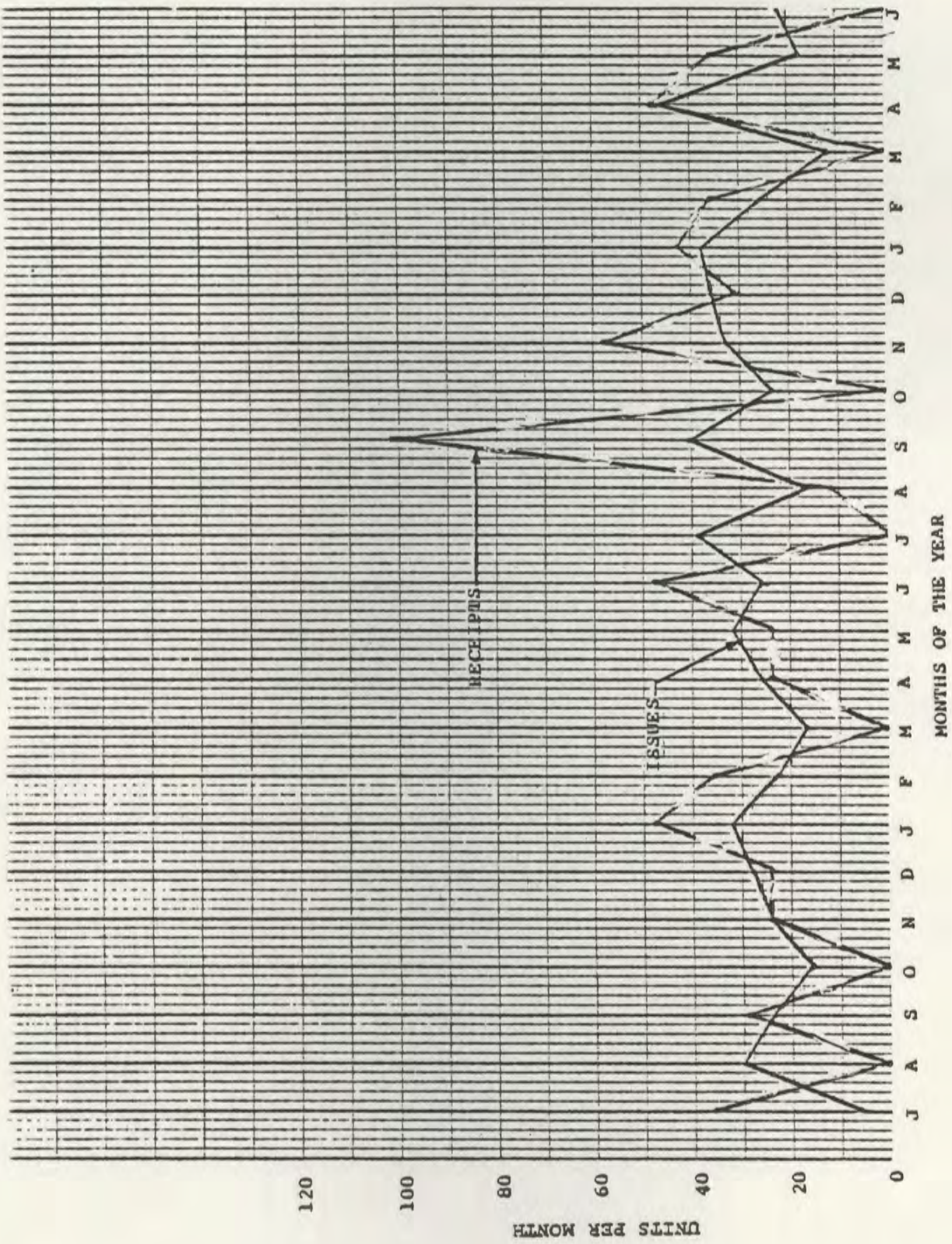


Figure 11. Hydrochloroth Tablets: Stock No. 6505008897929

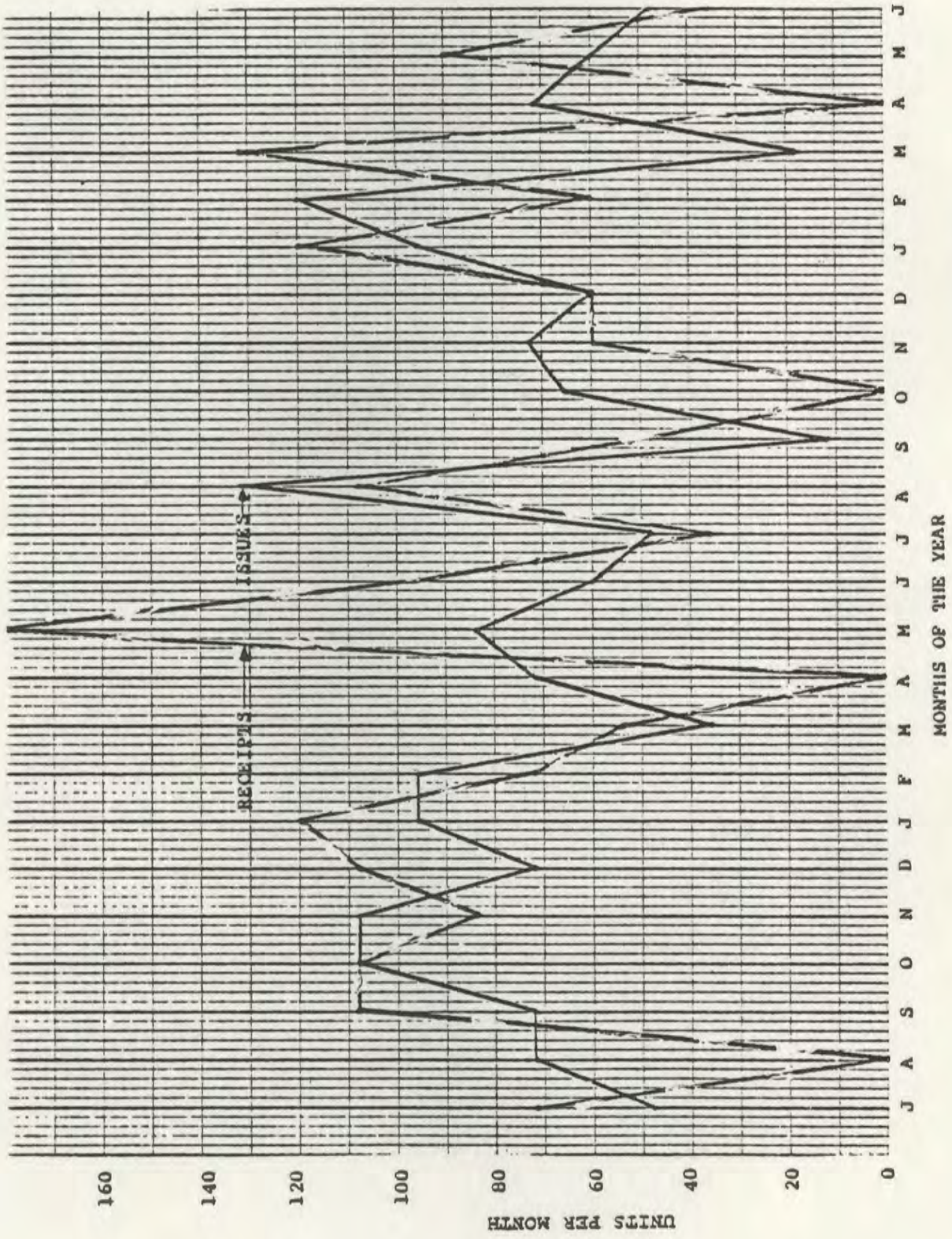


Figure 12. Cloribrate Capsules: Stock No. 6505009985872

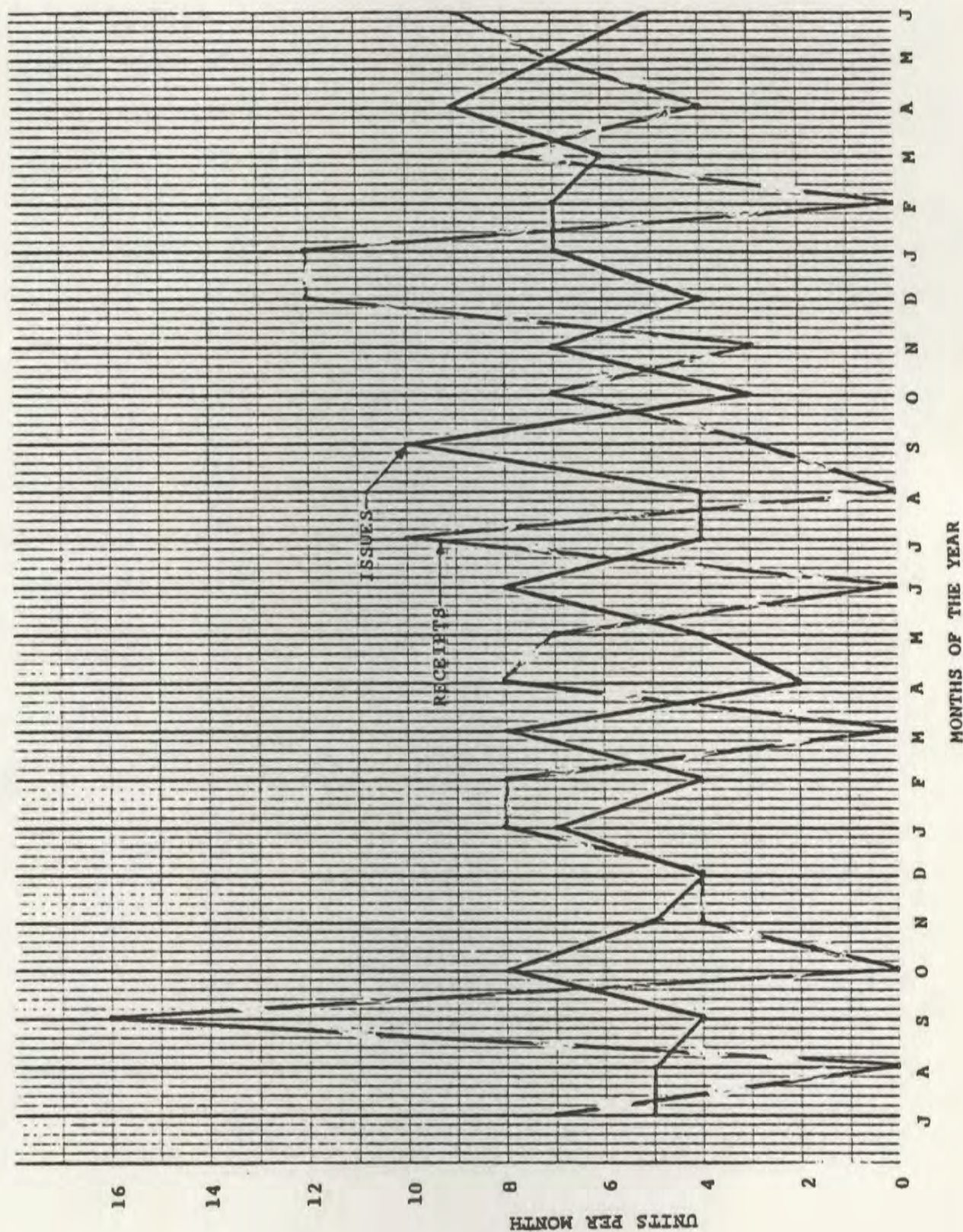


Figure 13. Surgical Sponges: Stock No. 6510000744579

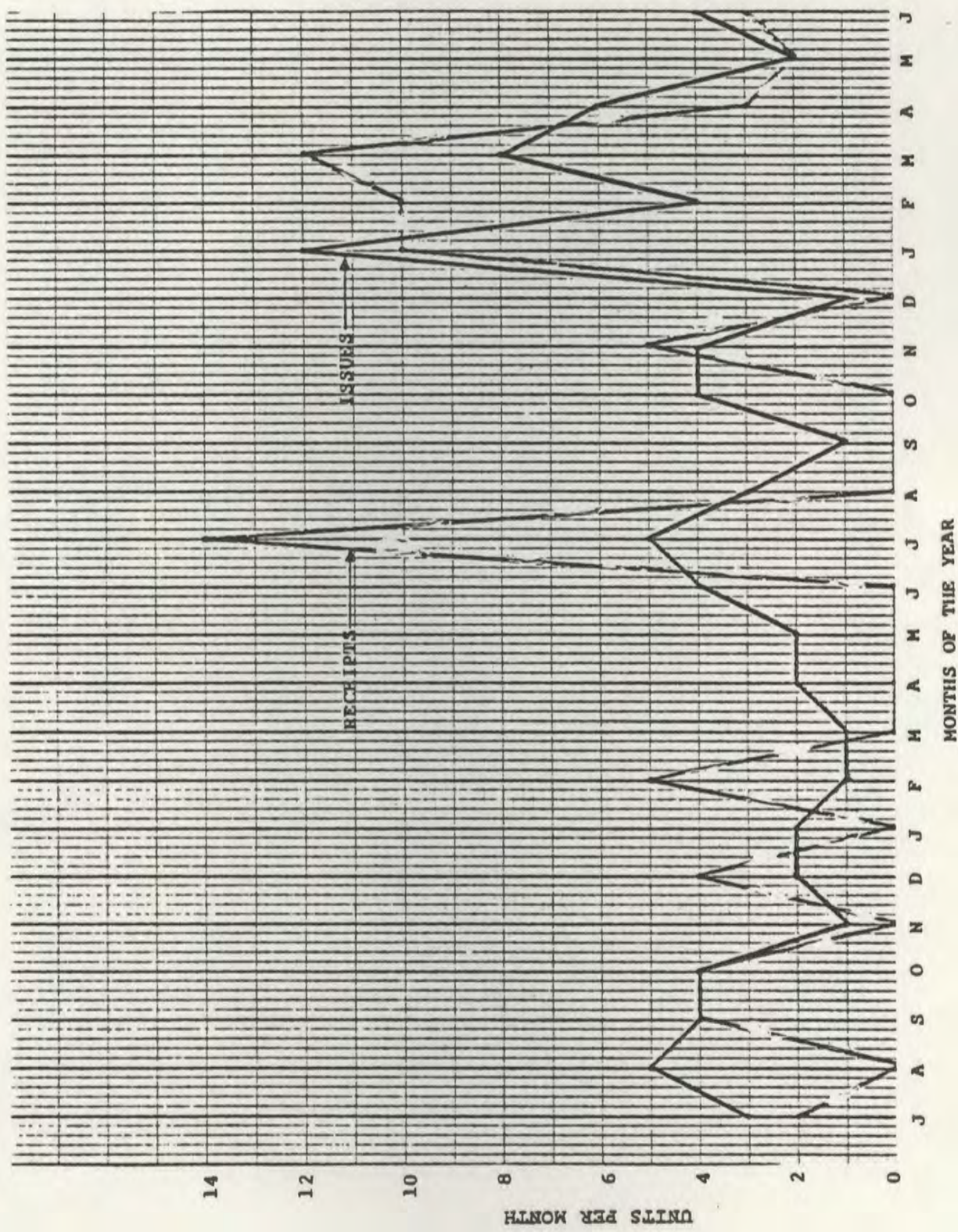


Figure 14. Thermometer Sensor Covers: Stock No. 6515L030747

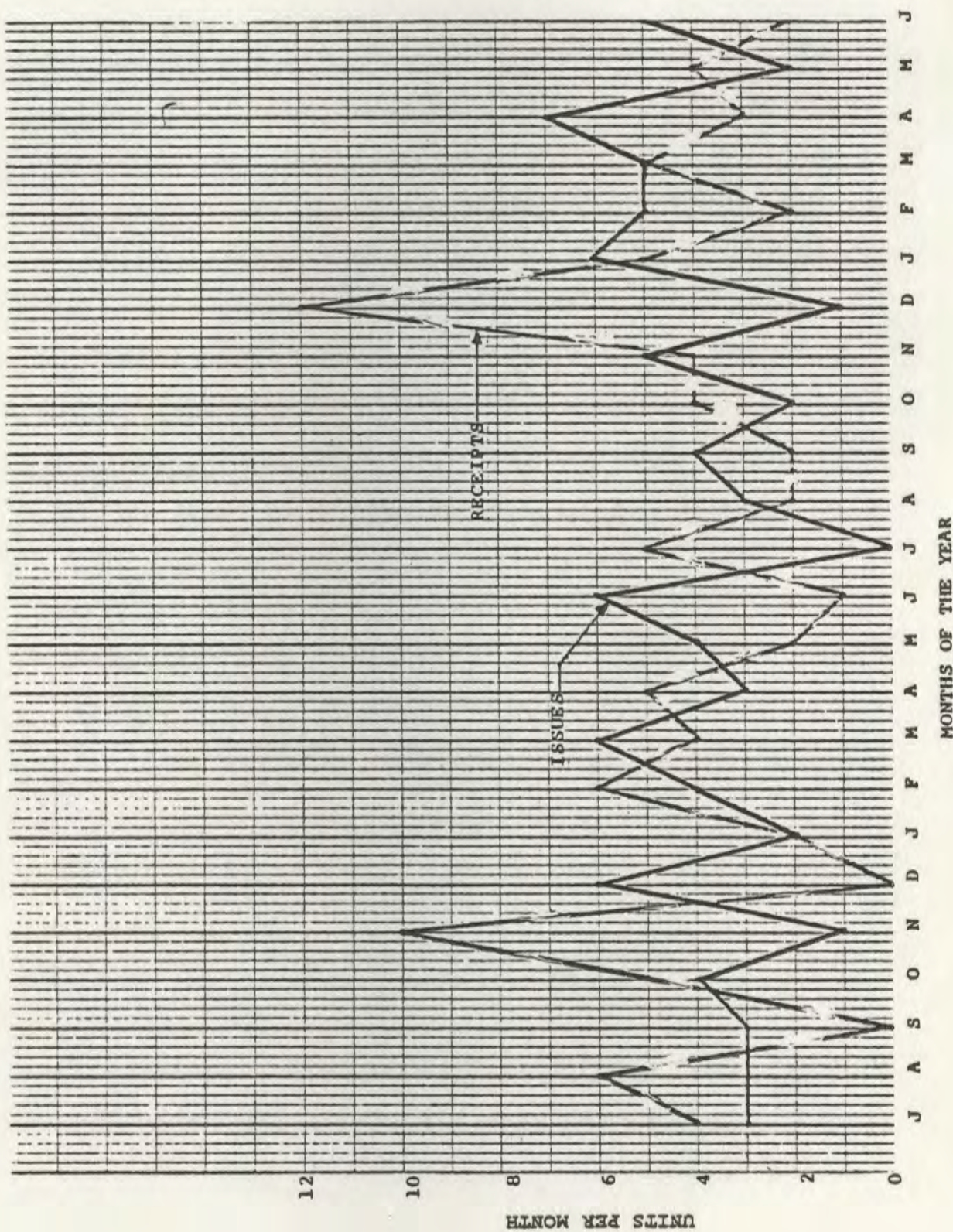


Figure 15. X-ray Film RP14: Stock No. 6525C9650AG

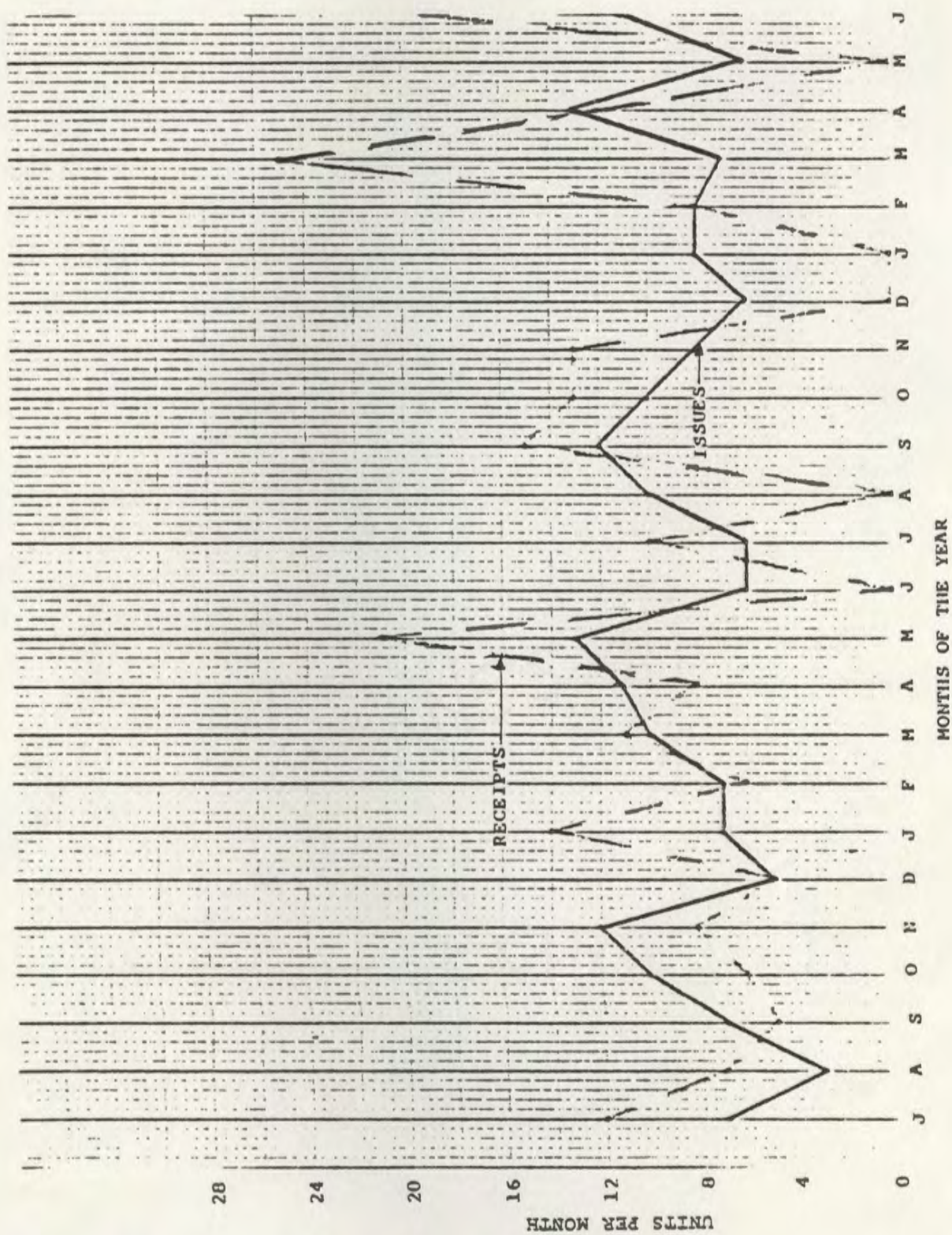


Figure 16. Surgical Package: Stock No. 6530001070971

APPENDIX B
COMPUTER PROGRAMS

PROGRAMS USED IN ANALYSIS

The following five computer programs were used in the production of the test data needed to evaluate the five forecasting methods. Each computer program is followed by a page of the typical output given by each. The exponential smoothing variations' data page was produced with the smoothing constant equal to 0.10. The page of output used the data for the medical supply item dextrose.

AVAILABLE DATA FROM PATRICK AFB FROM JULY 74 TO JUNE 76

FORECAST PER DAY	FORECAST PER MNTH	REORDER POINT	STOCK CONTROL LEVEL	WEEKLY STOCK LEVEL	SUM OF SQUARES OF ERROR
0.929	28.333	43.197	57	57	0.000
0.896	27.333	41.672	55	54 51 48	205.444
0.904	27.583	42.053	56	45 41 51 47	274.888
0.902	27.500	41.926	55	43 39 52 48	386.895
0.918	28.000	42.689	56	44 38 49 43	399.145
0.893	27.250	41.545	55	37 50 45 40	424.145
0.874	26.567	40.656	54	51 42 33 46	500.708
0.817	24.917	37.988	50	37 49 43 37	507.818
0.779	23.750	36.209	48	48 40 32 42	557.992
0.850	25.917	39.512	52	34 38 26 36	1146.055
0.869	26.500	40.402	53	24 40 32 44	1183.062
0.880	26.833	40.910	54	36 45 40 47 41	1183.312

Figure 18. Data produced by moving average model.

AVAILABLE DATA FROM PATRICK AFB FROM JULY 74 TO JUNE 76

FORECAST PER DAY	FORECAST PER MNTH	REORDER POINT	STOCK CONTROL LEVEL	WEEKLY STOCK LEVEL	SUM OF SQUARES OF ERROR
0.955	29.141	44.428	59	59	0.000
0.791	24.127	36.784	49	56 53 50 47	229.250
0.603	18.381	28.023	37	43 39 35 45	255.536
0.408	12.448	18.977	25	41 37 33 29	257.442
0.285	8.689	13.247	18	23 17 19 13	390.901
0.272	8.306	12.663	17	20 15 10 13	595.711
0.506	15.432	23.528	31	4 8 -1 8 2	1362.671
0.650	19.826	30.226	40	25 19 25 17	1436.074
0.917	27.960	42.627	56	32 24 32 20	1584.287
1.142	34.826	53.095	70	44 32 44 36	1985.898
1.194	36.413	55.514	73	62 54 46 64	1993.883
1.166	35.571	54.231	72	58 52 67	2082.479

Figure 20. Data produced by trend corrected moving average model.

AVAILABLE DATA FROM PATRICK AFB FROM JULY 74 TO JUNE 76

26.	26.	16.	18.	18.	32.	43.	45.
46.	22.	25.	23.	13.	14.	19.	17.
24.	23.	36.	24.	32.	48.	32.	27.

FORECAST PER DAY	FORECAST PER MONTH	REORDER POINT	STOCK CONTROL LEVEL	WEEKLY STOCK LEVEL	SUM OF SQUARES OF ERROR
0.929	28.333	43.197	57	57	0.000
				54.	
				51	
0.882	26.900	41.011	54	48	205.444
				45	
				41	
				50	
0.856	26.110	39.807	53	46	267.854
				42	
				38	
				49	
0.826	25.199	38.418	51	45	350.846
				41	
				35	
				45	
0.822	25.079	38.235	51	39	352.283
				33	
				46	
				41	
0.815	24.871	37.918	50	36	356.606
				45	
				37	
				41	
0.852	25.984	39.615	52	32	480.457
				41	
				35	
				46	
0.845	25.786	39.313	52	40	484.393
				34	
				44	
				36	
0.866	26.407	40.260	53	44	523.011
				36	
				40	
				28	
0.937	28.566	43.552	58	41	989.265
				29	
				45	
				37	
0.948	28.910	44.075	58	50	1001.055
				42	
				52	
				46	
0.942	28.719	43.784	58	40	1004.702
				52	

Figure 22. Data produced by exponential smoothing model.

AVAILABLE DATA FROM PATRICK AFB FROM JULY 74 TO JUNE 76

FORECAST PER DAY	FORECAST PER MNTH	REORDER POINT	STOCK CONTROL LEVEL	WEEKLY STOCK LEVEL	SUM OF SQUARES OF ERROR
0.945	28.818	43.936	58	58	0.000
0.848	25.855	39.418	52	55 52 49	219.578
0.798	24.335	37.102	49	46 42 38 48	266.563
0.743	22.652	34.534	46	44 40 36 45	320.371
0.742	22.631	34.503	46	41 35 29 40	322.189
0.735	22.428	34.194	45	34 41 36 31	322.325
0.815	24.870	37.916	50	41 32 26 36	506.515
0.805	24.559	37.442	50	30 44 38 32	507.271
0.849	25.901	39.488	52	42 34 38 26	562.645
0.992	30.249	46.118	61	40 28 44 36	1051.011
1.008	30.749	46.880	62	53 45 55 49	1054.076
0.989	30.166	45.991	61	43 56	1068.130

Figure 24. Data produced by double exponential smoothing model.

```

$JOB
REGRESSION ANALYSIS

FORCST= MONTHLY FORECAST IN UNITS PER DAY.
SL= SAFETY LEVEL IN DAYS (BOTH 30 DAYS AND PIPELINE WERE USED.)
PL= PIPELINE TIME IN DAYS.
REOPT= REORDER POINT ESTABLISHED EACH MONTH.
SCL= STOCK CONTROL LEVEL.
NEWSL= WEEKLY STOCK LEVEL.
N= NUMBER OF MONTHS OF HISTORICAL DATA USED AS FORECAST BASE.
ORDER= AMOUNT ORDERED WHEN INVENTORY<REORDER POINT
ISSUE= WEEKLY ISSUE BASED ON ONE FOURTH OF MONTHLY ISSUE

DIMENSION X(50)
INTEGER T,DP,SCL,ORDER

INITIALIZE NUMERICAL VALUES
M=0
10 ERROR=0.
L=0
SUMXT=0.
SUMT=0.
SUMTXT=0.
SUMTSQ=0.
PL=16.
SL=30.5
1 FORMAT(1X,F7.3,2F10.3,2I7,F11.3)
2 FORMAT(16F5.1)
3 FORMAT(2I2)
4 FORMAT(1X,8(F5.0,2X)/1X,8(F5.0,2X)/1X,8(F5.0,2X)//)
5 FORMAT(1X,'FORECAST FORECAST REORDER STOCK WEEKLY SUM OF',/
1,1X,'PER DAY PER MNTH POINT CONTROL STOCK SQUARES',/,31X,'
2 LEVEL LEVEL OF ERROR',/)
17 6 FORMAT(1H1,'AVAILABLE DATA FROM PATRICK AFB FROM JULY 74 TO JUNE 7
16',/)
18 7 FORMAT(39X,1I3)

READ AND WRITE INPUT VALUES
READ(5,3)N,DP
READ(5,2)(X(T),T=1,16)
READ(5,2)(X(T),T=17,DP)
WRITE(6,6)
WRITE(6,4)(X(T),T=1,DP)
15 WRITE(6,5)

BEGINNING OF THE COMPUTATIONS
T=1
N=T
20 SUMXT=SUMXT+X(T)
SUMTSQ=SUMTSQ+(T*T)
SUMT=SUMT+T
SUMTXT=SUMTXT+(T*X(T))
IF(T.GT.11) GO TO 25
T=T+1
GO TO 20
25 B=(N*SUMTXT-SUMXT*SUMT)/(N*SUMTSQ-(SUMT)**2.)
A=(SUMXT-B*SUMT)/N
FM=A+B*T
FORCST=FM/30.5
REOPT=FORCST*(SL+PL)
SCL=REOPT+(FORCST*15.)*.5
IF(T.GT.12)GO TO 30
NEWSL=SCL
30 WRITE(6,1) FORCST,FM,REOPT,SCL,NEWSL,ERROR
IF(T.GE.DP) GO TO 90

T=T+1
ERROR=ERROR+((FM-X(T))*(FM-X(T)))
J=0
40 ISSUE=X(T)/4.
NEWSL=NEWSL-ISSUE
IF(NEWSL.GT.REOPT) GO TO 70
L=L+1
IF(L.GE.2.) GO TO 60
ORDER=SCL-NEWSL
GO TO 70
60 NEWSL=NEWSL+ORDER
L=0
70 J=J+1

57 IF(J.GE.4.) GO TO 20
58 WRITE(6,7)NEWSL
59 GO TO 40

```

Figure 25. Regression analysis computer program.

AVAILABLE DATA FROM PATRICK AFB FROM JULY 74 TO JUNE 76

26.	26.	16.	18.	18.	32.	43.	45.
46.	22.	25.	23.	13.	14.	19.	17.
24.	23.	36.	24.	32.	48.	32.	27.

FORECAST PER DAY	FORECAST PER MNTH	REORDER POINT	STOCK CONTROL LEVEL	WEEKLY STOCK LEVEL	SUM OF SQUARES OF ERROR
1.075	32.795	49.999	66	66	0.000
				63	
				60	
0.916	27.945	42.605	56	57	391.836
				54	
				51	
				48	
				45	
0.802	24.457	37.287	49	42	586.300
				38	
				48	
				44	
0.752	22.933	34.964	46	40	616.080
				36	
				32	
				42	
0.697	21.272	32.431	43	38	651.283
				32	
				37	
				31	
0.703	21.451	32.704	43	37	658.725
				32	
				38	
				33	
0.702	21.403	32.632	43	28	661.125
				34	
				25	
				34	
0.784	23.905	36.446	48	25	874.183
				37	
				31	
				42	
0.779	23.771	36.242	48	36	874.191
				40	
				32	
				40	
0.822	25.082	38.240	51	32	941.901
				36	
				24	
				39	
0.948	28.917	44.087	58	27	1467.125
				43	
				35	
				50	
0.970	29.587	45.108	60	42	1476.630
				52	
				46	
				40	
0.963	29.377	44.787	59	54	1483.322

Figure 26. Data produced by regression analysis model.

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