FORECASTING THE DEMAND FOR HOSPITAL SUPPLY ITEMS

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TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS iv

LIST OF TABLES v

LIST OF ILLUSTRATIONS vi

ABSTRACT vii

Chapter

I. INTRODUCTION 1

II. EXPERIMENTAL ENVIRONMENT AND DATA COLLECTION 5

III. CORRELATION AND REGRESSION ANALYSIS 9

IV. DEMAND FORECASTING 15

Exponential Smoothing
Base Periods for Seasonal Forecasting
Forecasting by Months
Forecasting by Weeks

V. CONCLUSIONS 28

VI. DISCUSSION OF CONCLUSIONS AND RECOMMENDATIONS 30

APPENDIX 32

BIBLIOGRAPHY 60

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LIST OF TABLES

Table		Page
1.	Results of Correlation Analysis	11
2.	Values Used in Multiple Correlation and Regression Analysis with Time Lag j = 2	33
3.	Observed Glove Demand Data and Demand Ratios Used in Forecasting by Months	47
4.	Results of Exponential Smoothing: Correlation Between Actual and Predicted Demand, and Standard Deviation of Forecast Errors. Monthly, L = 1	48
5.	Results of Exponential Smoothing: Correlation Between Actual and Predicted Demand and Standard Deviation of Forecast Errors. Monthly, B = 2	50
6.	Results of Exponential Smoothing: Correlation Between Actual and Predicted Demand, and Standard Deviation of Forecast Errors. Weekly, B = 3	52
7.	Observed Monthly Demand, Predicted Demand, and Forecast Errors, for Series L = 1, B = 1, α = 0.001	54
8.	Observed Monthly Demand, Predicted Demand, and Forecast Errors for Series L = 1, B = 1, α = 0.001	55
9.	Exponential Smoothing Results--Weekly	56

LIST OF ILLUSTRATIONS

Figure Page

1. Simplified Diagram of Glove Flow in Hospital. 6

2. Average Daily Glove Demand by Weeks, September 1957 - June 1959. 8

3. Scatter Diagram for Census Versus Glove Demand with Least Squares Regression Line 13

4. Total Monthly Glove Demand, March 1957 - June 1959 19

5. Standard Deviation of Forecast Error, Forecasting by Months, L = 1, B = 1, 2, 3 23

6. Standard Deviation of Forecast Error, Forecasting by Months, Base = 1, L = 1, 2 24

7. Standard Deviation of Forecast Error, Forecasting by Weeks, Base = 2, L = 1, 2, 3 26

8. Scatter Diagrams of Glove Demand Versus Operations and Births Respectively, with Least Squares Regression Line 37

9. Average Daily Hospital Census, by Weeks, September 1957 - January 1959 38

10. Average Daily Births, by Weeks, September 1957 - January 1959. 39

11. Average Daily Number of Operations, by Weeks, September 1957 - January 1959 40

12. Average Glove Demand by Day of the Week, September 1957 - June 1959. 41

13. Flow Diagram of IBM 650 Program for Exponential Smoothing Method, by Weeks. 59

ABSTRACT

This thesis is concerned with the development of a practical forecasting model for use by hospital administrators in estimating the future demand for hospital supply items. For the purpose of this study, daily demand data on one specific item, surgical rubber gloves, was collected for a continuous 22-month period at Emory University Hospital, Atlanta, Georgia.

One original goal of this study was to quantify the relationship between the number of rubber gloves used and total hospital census, total number of births, and total number of operations performed. Since the latter variables are readily available to the hospital administration, it was thought that they might be used as indices of future demand for the relevant supply item. Therefore, with the aid of an IBM 650 computer, a linear multiple regression equation was calculated, relating these four variables. This equation was found to be unsatisfactory, however, and a simple regression equation relating weekly glove demand and weekly hospital census was calculated which specifies the relationship between these two variables in a more usable manner. The simple correlation coefficient for this second equation was calculated as 0.80, which was too low for forecasting purposes in conjunction with a forecast of census. The unsatisfactory nature of the statistical results determined in both cases prompted use of a second, more direct method of forecasting.

This method, called exponential smoothing, is described and its application illustrated. Using an IBM 650 computer, the glove demand data was analyzed on a monthly and weekly basis, and forecasts were made for each of the periods in the sample, employing different combinations of the smoothing constant and base series. The predicted and actual results were compared by computing the standard deviation of the forecast errors and selecting as best, those values of the smoothing constant and base series which yielded a minimum standard deviation.

The conclusions of the study are that exponential smoothing is suitable for use in forecasting monthly and weekly glove demand at Emory University Hospital. Specific values of the smoothing constant and base series are suggested for use in the forecasting model, and economic implications of usable forecasts are pointed out.

CHAPTER I

INTRODUCTION

This study is concerned with the development of a practical forecasting model for use by hospital administrators in estimating the future demand for a certain hospital supply item. The need for such a model may be explained by the following remarks.

The ever increasing demand for hospital services and the rise in labor and associated operating costs have created increasing requirements for more efficient use of hospital facilities and personnel. Since illnesses and accidents are largely unpredictable, hospitals must be prepared to provide services for demands which may vary greatly from day to day. This situation results in a varying demand on the medical and nursing staffs. One traditional approach to the problem of allocation of staff time and supplies has been to provide at all times adequate facilities to meet past peak demands, accepting as normal procedure the presence of standby personnel. The justification for this approach lies, of course, in the concept of providing acceptable patient care--the ultimate criterion for judging any measure of hospital performance.

However, when operating costs become so great that they become a matter of concern, the hospital administration seeks means of providing facilities for adequate patient care with less wasteful use of available resources. One of these means has been the introduction of disposable supply items which would require less processing and application times at possibly lower total cost; another means has been to attempt better scheduling of nursing and medical staff time.

The purpose of this study was to develop a method of forecasting the probable future demand for certain supply items. Two of the more obvious benefits of accurate forecasts exist in the form of possible reductions in inventory levels and in better scheduling and utilization of the available labor force. Also, in consideration of disposable supply items, a knowledge of variability of demand would be of use in minimizing the risk of a shortage, by having sufficient stock on hand and yet at the same time preventing unnecessary over-stocking of the relevant item.

A literature search indicated a surprising lack of information on practical ways to forecast demand. Most of the works available which concern forecasting deal with the mechanics of long-range business forecasting rather than with the day-to-day variations in demand for a certain item. One popular method of economic forecasting, based on a theory of cycles, is described by Abramson (4) and Forrester (15). They show how random variations can generate sympathetic oscillations in industrial operations and how these oscillations have predictable cyclic variations. Another method (5) is based on cross correlation with a leading index; i.e., correlating the unknown variable with some known or predictable variable, and using this known variable as an index of future demand for the unknown variable. Another, somewhat more complicated variation of this method is outlined by Cotter (9), in which the "trend line" of past demand for the unknown variable and the "trend line" of the index are utilized. Given a future forecast of the index, the amount of deviation of this forecast from its trend line is determined, and a related degree of deviation of the unknown variable about its trend line is calculated from a known correlation between the two variables.

Two other methods mentioned by various authors attempt to give a prediction of the future level of demand of a variable from an analysis of the variations of its past level of demand. The first of these two methods involves use of probability theory; the distribution of past demand is approximated by a theoretical probability distribution, and the prediction of future demand is based upon the properties of this theoretical distribution. Specific applications of this method in areas of hospital research are described by Balintfy (7), Sonnendeker (16) and others (14),(8). The second of these two methods utilizes some form of moving average to calculate the general long-term trend of past demand, and extrapolates this trend into the future. Moroney (3) treats this method and its associated limitations at some length, as does Hanson (6). Brown (12) treats several variations of the method of moving averages, for applications to inventory control, and was the only source discovered which offered a routine practical method of forecasting day-to-day variation in demand.

The present study describes an attempt to apply a combination of these methods to the problem of forecasting the future level of demand for hospital supply items. One original goal of this study was to quantify the relationship between the number of supply items used and total hospital census, number of births, and number of surgical operations performed. Since the latter variables are readily available to the hospital management, it was thought that they might be used as indices of future demand for the relevant supply items. However, the weakness of the statistical relationships discovered between the variables prompted use of a second method of forecasting. This method, developed by Brown (12), is described in Chapter IV of this study.

The scope of this study was planned to include several hospitals so that conclusions might be drawn regarding the general pattern of demand for hospital supply items and their association with the mentioned hospital variables. However, limitations of time and the unavailability of data narrowed the scope to one hospital and one supply item. Although it was possible to institute a continuing system of data collection (for possible future application of the methodology described in this paper), the statistics and accompanying conclusions herein must be recognized as being restrictive in nature and inadequate for broad generalization.

CHAPTER II

EXPERIMENTAL ENVIRONMENT AND DATA COLLECTION

For the purpose of this study, two of the most important supply items (in terms of comparative usage) were originally selected for investigation; viz, surgical rubber gloves and glass-barreled hypodermic syringes. Because of incomplete and inaccurate data, however, the syringe data was eventually eliminated from the study, and all subsequent work refers to data collected on surgical rubber gloves at Emory University Hospital, Atlanta, Georgia. Data on the daily number of rubber gloves processed by the Central Supply Department were collected for a continuous 22-month period from January 21, 1957, to June 30, 1959.

Figure 1 indicates the typical flow pattern of reprocessed rubber gloves within the hospital system; the numbers given are approximate average daily flow rates. In general, gloves which are used on one day are processed on the evening of the same day or on the following day, the number processed being recorded by central supply personnel. New gloves are introduced into the system as needed, and over a period of time, other things being equal, the total number of gloves introduced into the system will equal the total number discarded during that period. A previous study[1] indicated that each pair of gloves is used approximately five times before being discarded.

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[1]Unpublished research study, "Introductory Cost Determination For Disposable versus Reprocessed Hospital Supplies," Engineering Experiment Station, Georgia Institute of Technology, 1959., Project B-158.

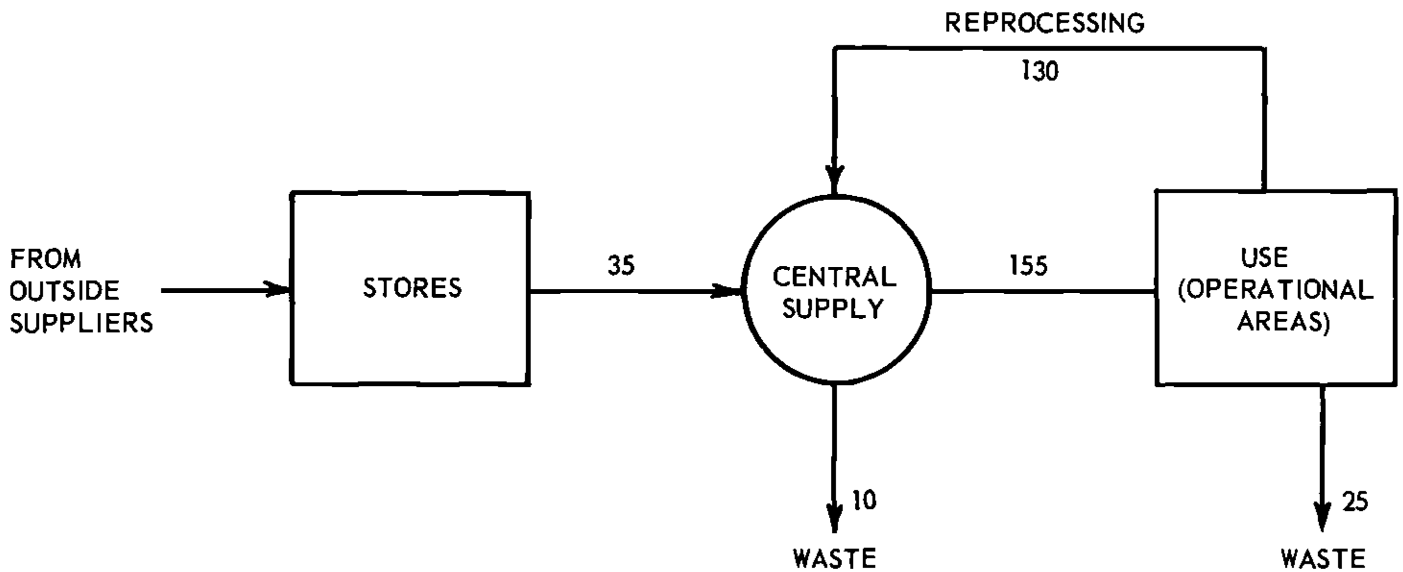

Figure 1. Simplified Diagram of Glove Flow in Hospital.

Slight daily inaccuracies in this representation of demand may arise from the fact that some of the items may have been on the floors (point of use) for more than one day, or because central supply personnel for one reason or another processed more than the actual number used (such cases comprised about 2.5 per cent of the total observations). Over a period of time, however, these daily inaccuracies balance out, since each glove processed is eventually used, and only at the end points of the time interval under observation would there be any expectation of error. Initial analysis of the data indicated that a period of one week would be sufficient to allow these daily inaccuracies to balance out. Accordingly, final analysis of the glove processing data was carried out on a weekly basis. Figure 2 shows the variation in average daily glove demand, by weeks, for the 22-month observation period.

Since the glove processing data can be taken as an index of demand over time, hereafter the data will be referred to as demand data. This should cause no misconceptions if one keeps in mind the differences pointed out above.

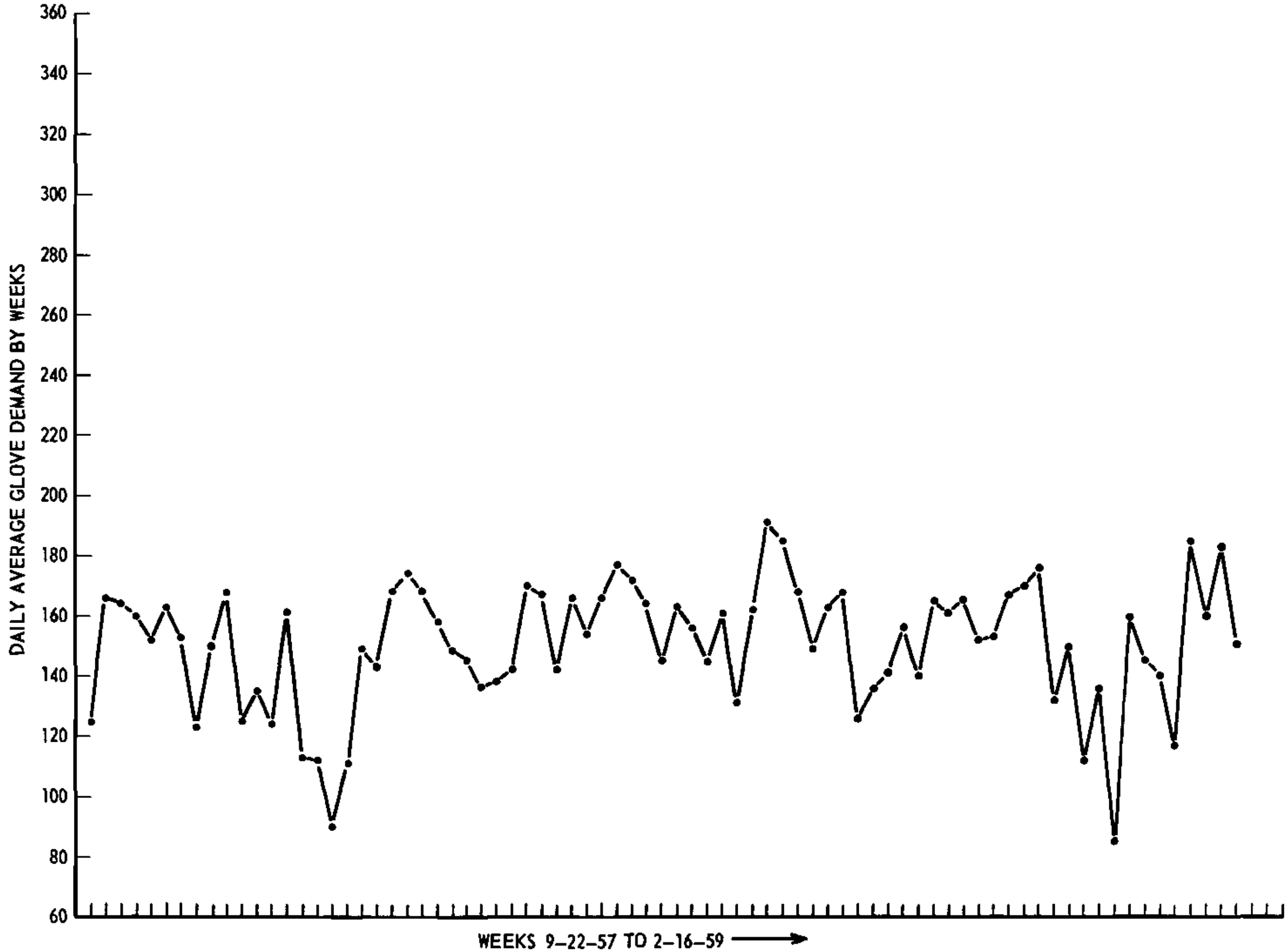

Figure 2. Average Daily Glove Demand by Weeks, September 1957 - June 1959.

CHAPTER III

CORRELATION AND REGRESSION ANALYSIS

In an attempt to quantify the relationship between the supply item demand under investigation and several hospital parameters, the variables were classified in the following manner:

<u>Dependent Variable</u>

Y_i = the number of pairs of gloves demanded during the i^{th} week.

<u>Independent Variables</u>

X_{1ij} = the sum of the daily hospital census figures for the i^{th} week which started j days before the start of the glove demand week. (j = 0, 1, 2, 3),

X_{2ij} and X_{3ij} are defined as above for daily number of births and daily number of operations, respectively.

The proposed multiple regression model, given in equation (1) below, assumes that demand is a linear function of each of the above independent variables.

$$Y_i = \beta_0 + \beta_1 X_{1ij} + \beta_2 X_{2ij} + \beta_3 X_{3ij} + \epsilon_{ij}, \tag{1}$$

where β_i = true regression coefficients for the i^{th} independent variable.

ϵ_{ij} = random error for the i^{th} week and a lag of j days.

An IBM 650 digital computer was used in the analysis, first to obtain weekly sums, Y_i, X_{1ij}, X_{2ij}, X_{3ij}, and then to compute the correlation and regression statistics given in Table 1 below. The standard least squares regression equations were justified since the X_{ij}'s are known without error and there were no reasons to suspect that the ϵ_{ij}'s were correlated with the X_{ij}'s or that the variance was not constant.

The multiple regression equation for the model equation (1) is given as follows:

$$(2) \quad Y_{i(predicted)} = \hat{Y}_i = b_o + b_1 X_{1ij} + b_2 X_{1ij} + b_3 X_{3ij},$$

where $\hat{Y}_i - Y_i = e_{ij}$ = residual for the i^{th} week with a lag of j days.

As can be seen in Table 1, a time lag of two days (j = 2) yielded the highest degree of correlation between the dependent and independent variables. Accordingly, input data from this group was used to obtain the multiple regression equation (3),

$$(3) \quad Y_i = 238 + 0.45\ X_{1i2} - 0.20\ X_{2i2} + 1.33\ X_{3i2}.$$

The multiple correlation coefficient for this model was found to be R = 0.80, as shown in Appendix I.

The standard error of estimate of the regression coefficients and the residuals were found to be the following:

$S_{b_1} = 0.07 \quad (b_1 = 0.45)$,

$S_{b_2} = 2.12 \quad (b_2 = -0.20)$.

Table 1. Results of Correlation Analysis

		j = 0	j = 1	j = 2	j = 3
Mean:					
	$\bar{Y}$	1061.1	1061.1	1060.1	1060.1
	$\bar{X}_1$	1614.4	1609.8	1560.0	1599.0
	$\bar{X}_2$	17.1	17.3	16.8	17.0
	$\bar{X}_3$	91.1	90.0	89.2	90.2
Standard Deviation:					
	σ_y	141.0	141.0	168.0	145.0
	σ_{x1}	178.0	185.3	255.8	215.9
	σ_{x2}	6.2	6.1	5.7	6.3
	σ_{x3}	29.2	29.4	19.2	31.6
Simple Correlation Coefficients:					
	r_{yx_1}	0.49	0.50	0.80	0.47
	r_{yx_2}	-0.001	-0.006	0.22	0.06
	r_{yx_3}	0.50	0.35	0.65	0.32
	$r_{x_1x_2}$	0.22	0.20	0.30	0.28
	$r_{x_1x_3}$	0.50	0.60	0.72	0.37
	$r_{x_2x_3}$	-0.09	0.25	0.12	0.31
Partial Correlation Coefficients:					
	r'_{yx_1}			0.60	
	r'_{yx_2}			-0.001	
	r'_{yx_3}			0.17	

$S_{b_3} = 0.90 \qquad (b_3 = 1.33),$

S_e = Standard error of estimate = 103.

On the basis of the above results and principally because of the high standard error of the regression coefficients b_2 and b_3, it was concluded that equation (3) is not suitable for predicting glove demand. Since the simple correlation coefficient $(j = 2)\, r_{YX_1} = 0.80$, was of the same magnitude as the multiple correlation coefficient $R = 0.80$, this suggested the possibility of developing a model using X_1 only. Such a model would have the form

$$(4) \quad Y_i = \beta_0 + \beta_1 X_{1ij} + \epsilon_{ij}.$$

This was evaluated for $j = 2$ only; i.e.,

$$(5) \quad Y_i = b_0 + b_1 X_{1i} + e_i,$$

and the final regression equation using Y_i and X_{1i} only, was calculated to be:

$$(6) \quad Y_i = 242 + 0.52\, X_{1i},$$

$$S_{b1} = 0.092, \ (b_1 = 0.52),$$

$$S_e = 103.$$

Figure 3 shows the scatter diagram for census versus glove demand with this least squares regression line together with 95 per cent confidence intervals for predicted values of Y_i. These confidence intervals were calculated from the relation,

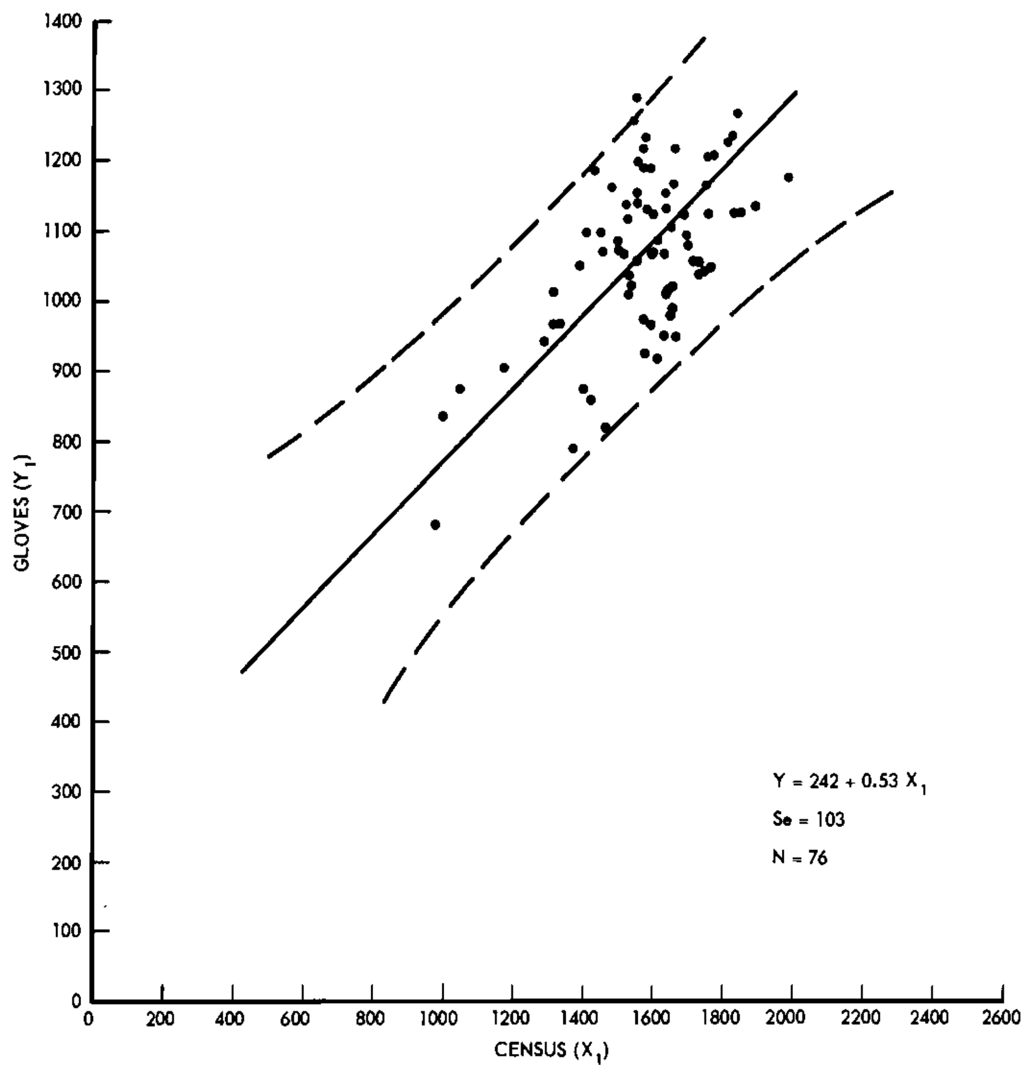

Figure 3. Scatter Diagram for Census Versus Glove Demand with Least Squares Regression Line.

$$\hat{Y} \pm t_{.05}\, s_e \sqrt{1 + \frac{1}{n} + \frac{(X - \bar{X})^2}{\Sigma\,(X - \bar{X})^2}}$$

where $t_{.05}$ is read from Students "t" table with n-2 = 74 degrees of freedom, at the .05 probability level.

In order to ascertain the individual influence of each of the other variables, scatter diagrams for glove demand versus births and operations were plotted and are shown in Appendix I.

If high correlations had been obtained in this study, efforts would then have been directed toward finding some method to forecast the independent variables involved in the prediction equation. Although the statistical correlations discovered in the course of this analysis are interesting per se, they were not of sufficient strength to warrant further work in this direction. For this reason attention was focused on predicting the future glove demand directly. This approach is described in the next chapter.

CHAPTER IV

DEMAND FORECASTING

Exponential Smoothing.--"Exponential Smoothing" is the name given by one author[1] for this description of a practical method of smoothing out the fluctuations in a demand history to get a stable estimate of the expected rate of demand. This method has a stable response to changes, and the rate of response can be controlled by the selection of the appropriate "smoothing constant."

Exponential smoothing is similar to a moving average, but does not require keeping extensive records of past demand data. At the end of each new month (or week) the demand for this month (called the new demand) is compared with an old average demand (computed up to this month) and the old average adjusted accordingly. If the new demand is higher than the old average, the estimate of the new average should be higher, and vice versa. In addition, if the difference between the old average and the new demand is small, the adjustment should be small and vice versa.

Brown[2] has 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 differs from that estimate. The fraction used

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[1] Brown, R. G., Statistical Forecasting For Inventory Control, McGraw-Hill Book Company, New York, 1959.

[2] Brown, op. cit., p. 46.

is called a smoothing constant. Denoting this constant by α, $(0 < \alpha < 1)$, the above rule can be written as follows:

new estimate = old estimate + α (new demand − old estimate),

or restated,

(7) new estimate = α (new demand) + $(1 - \alpha)$ (old estimate)

where α = smoothing constant.

Substituting a new expression for the old estimate,

new estimate = α (new demand) + $(1 - \alpha)$ [α(previous demand) + $(1 - \alpha)$ (previous old estimate)]

this process could be continued.

In general, if we let

D_0 = new demand,

D_1 = demand last month,

D_2 = demand 2 months ago,

$\vdots$

D_k = demand k months ago,

then

(8) $$\text{new estimate} = \sum_{i=o}^{k} \alpha (1 - \alpha)^i D_i + (1 - \alpha)^k \text{(estimate made k months ago)}.$$

Clearly, when k is large, the last term in equation (8) can be neglected, and so the starting estimate, made k months ago, is unimportant.

The new estimate is merely a linear combination of the demand experienced during the past k months. Since the sum of the coefficients in this linear function is equal to unity as shown below, it can be referred to as a weighted average, with the magnitude of the weights steadily decreasing as i increases.

$$\alpha + \alpha(1-\alpha) + \alpha(1-\alpha)^2 + \alpha(1-\alpha)^3 + \ldots = \frac{\alpha}{1-(1-\alpha)} = 1.$$

Thus, equation (7) can be restated as follows:

(9) new average = α (new demand) + $(1-\alpha)$ (old average)

This estimate of the average will lag behind actual demand with a systematic lag, where the magnitude of the lag is given as $\frac{1-\alpha}{\alpha}$ times the rate of growth in demand[3]. If this rate of growth, or trend, can be estimated, adjustments can be made to eliminate the lag, as described below.

The current trend is defined as the new average minus the old average and the average trend can be estimated by the exponential smoothing method as described above. In terms of equation (9) the new trend can be written as follows:

(10) new trend = α (current trend) + $(1-\alpha)$ (old trend).

Now, knowing the trend, the magnitude of the lag can be computed and an expected demand, corrected for lag can be written as

(11) expected demand = new average + $\frac{1-\alpha}{\alpha}$ (new trend).

When the equation is expressed in this form, only the previously calculated values of the average and trend are necessary to compute an expected demand for the period under consideration.

Equations (9), (10), and (11) were used to estimate the most probable level of glove demand in the future. Obviously, one estimate

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[3]Brown, _op. cit._, p. 48.

which could be used is to assume that demand in some month in the near future will be the same as the current expected demand. Then the total demand during a lead time of L periods would be equal to L times the expected demand.

Base Periods for Seasonal Forecasting.--Some of the most common methods of forecasting when there is a seasonal pattern of demand depend on a comparison between the observed demand in a period this year and that in a corresponding period during the previous year, or between the average of the demand in the corresponding periods in several previous years.[4] This standard of comparison is called a "base series" and the criterion for its selection is the closeness with which its pattern follows the pattern of demand of the item being forecast.

Since the monthly glove demand data appeared to be cyclical with an annual low caused by the Christmas holidays (see Figure 4), it was decided to attempt to forecast demand by using as a standard of comparison for months in 1958-59 the demand for appropriate months during 1957-58. First, an attempt was made to forecast monthly demand, varying the value of the base series in an attempt to find the optimum base. The base was taken first as the average of the surrounding quarter (previous year) then as the average of a two-month period (same month and following month in previous year) and last simply as the demand during the same month of the previous year. Next an attempt was made to forecast weekly demand, taking as the value of the base series the average of the three surrounding weeks in the previous year.

[4] Brown, Op. Cit. p. 129

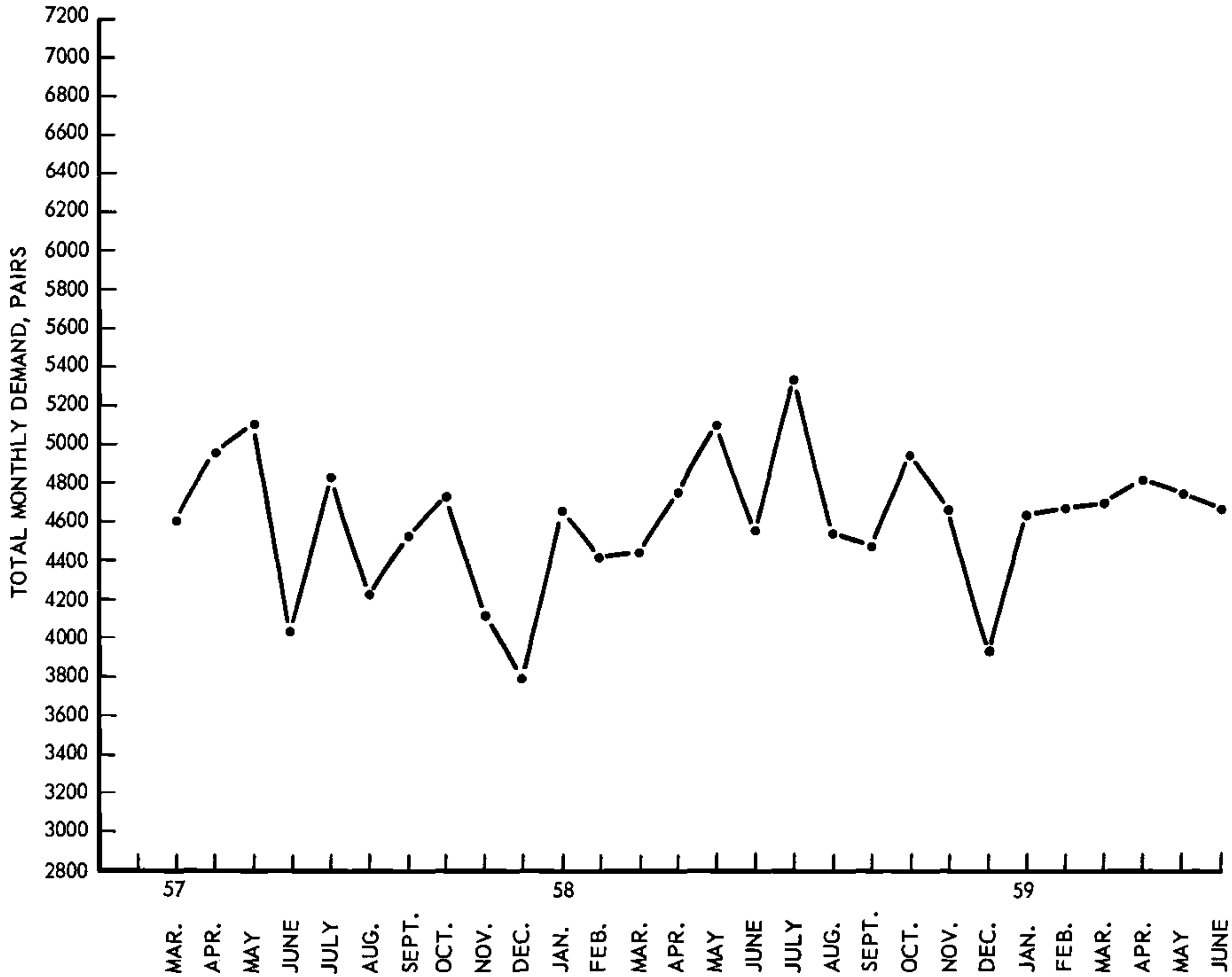

Figure 4. Total Monthly Glove Demand, March 1957 - June 1959.

In all cases the base series was utilized to compute a demand ratio by dividing the current demand by the value of the base series, and the method of exponential smoothing described above was used to smooth this ratio instead of the actual demand. The average, the trend, and the expected value of the demand ratio were calculated as described earlier. Obviously, for any current month, the actual demand is equal to the demand ratio times the value of the base series for that month.

Forecasting by Months.--The following illustrative calculations are carried out for a lead time of one month (forecasting one month in advance) using as a base series the demand for the same month in the previous year. The value of the smoothing constant used in this example is 0.50.

Taking the forecast for April, 1958 as an example,

$$\text{demand ratio for March} = \frac{\text{demand in March 1958}}{\text{demand in March 1957}} = \frac{4412}{4602} = 0.958.$$

The initial value of the average ratio was arbitrarily taken as 1.0; thereafter it was computed as follows:

$$\underline{\text{average ratio}} = (1 - \alpha)\ (\text{average ratio for previous month}) + \alpha\ (\text{demand ratio for current month}),$$

$$= (1 - 0.5)(1.0) + (0.5)(0.958) = 0.979,$$

$$\underline{\text{change}} = (\text{average ratio current month}) - (\text{average ratio last month}),$$

$$= 0.979 - 1.000 = -0.021.$$

Trend: Initial value taken as 0; thereafter,

$$\text{trend} = (1 - \alpha)\ (\text{trend last month}) + \alpha\ (\text{change}).$$

$$\text{Expected ratio} = \text{average ratio} + \frac{1-\alpha}{\alpha}\ (\text{trend}),$$

$$= 0.979 + \frac{1 - 0.5}{0.5}\ (-\ 0.010)$$

$$= 0.969.$$

This is the expected ratio for March. The forecast for April (lead time equal one month) was computed from this expected ratio and from the value of the base series for April, as follows:

$$\text{Forecast for April} = \begin{bmatrix}\text{expected ratio} \\ \text{for March}\end{bmatrix} \times \begin{bmatrix}\text{value of base} \\ \text{series for April}\end{bmatrix},$$

$$= 0.969 \times 4967 = 4813.2.$$

$$\text{Forecast error} = \text{predicted demand} - \text{actual demand},$$

$$= 4757.0 - 4813.2 = -56.2\ .$$

This same procedure with a base series of one month (B = 1) was then carried out to obtain a forecast for each of the remaining sixteen months. The smoothing constant was varied from 0.001 to 0.009 in increments of 0.002, from 0.01 to 0.09 in increments of 0.01 and from 0.1 to 0.9 in increments of 0.1, for lead times of one and two months. Computations also were made for the same ranges of the smoothing constant and lead time using a base series of two and three months as described above. The magnitude of the task involved necessitated use of an IBM 650 digital computer to perform the computations (see Appendix II for program flow chart).

After the predicted values and forecast error between predicted and actual values were obtained from the computer, the machine was again utilized to determine (1) correlation between predicted and actual values and (2) standard deviation of the forecast error. Figure 5 shows the results of trying different values of the base series in an attempt to find the most accurate base for a lead time of one month. For the range of smoothing constant values used (0.1 – 0.9) a base of one month (demand in same month of previous year) gave consistently best results. Table 7 lists the results of these computations.

Since the smallest standard deviation of forecast errors in this series was obtained using a base of one month, a new series of calculations for this base was undertaken in an attempt to find the best value of the smoothing constant for use in forecasting. The character of the curves in Figure 5 suggested that smaller values of the smoothing constant might give better results. Accordingly, the smoothing constant was varied from 0.001 — 0.09, and the results are shown in Figure 6.

Figure 6 indicates the errors to be expected in forecasting demand for the next month and also the second month hence, using a sequence of smoothing constants and the actual demand data shown in Table 3. It can be seen that the smaller the smoothing constant, the smaller is the standard deviation of forecast errors for either lead time. Note that $\alpha = 0.001$, the smallest value tried, gives the most accurate results for both cases. Note also the rather peculiar nature of these two curves; for values of the smoothing constant less than about 0.023, the standard deviation of forecast errors is less for a lead time of two

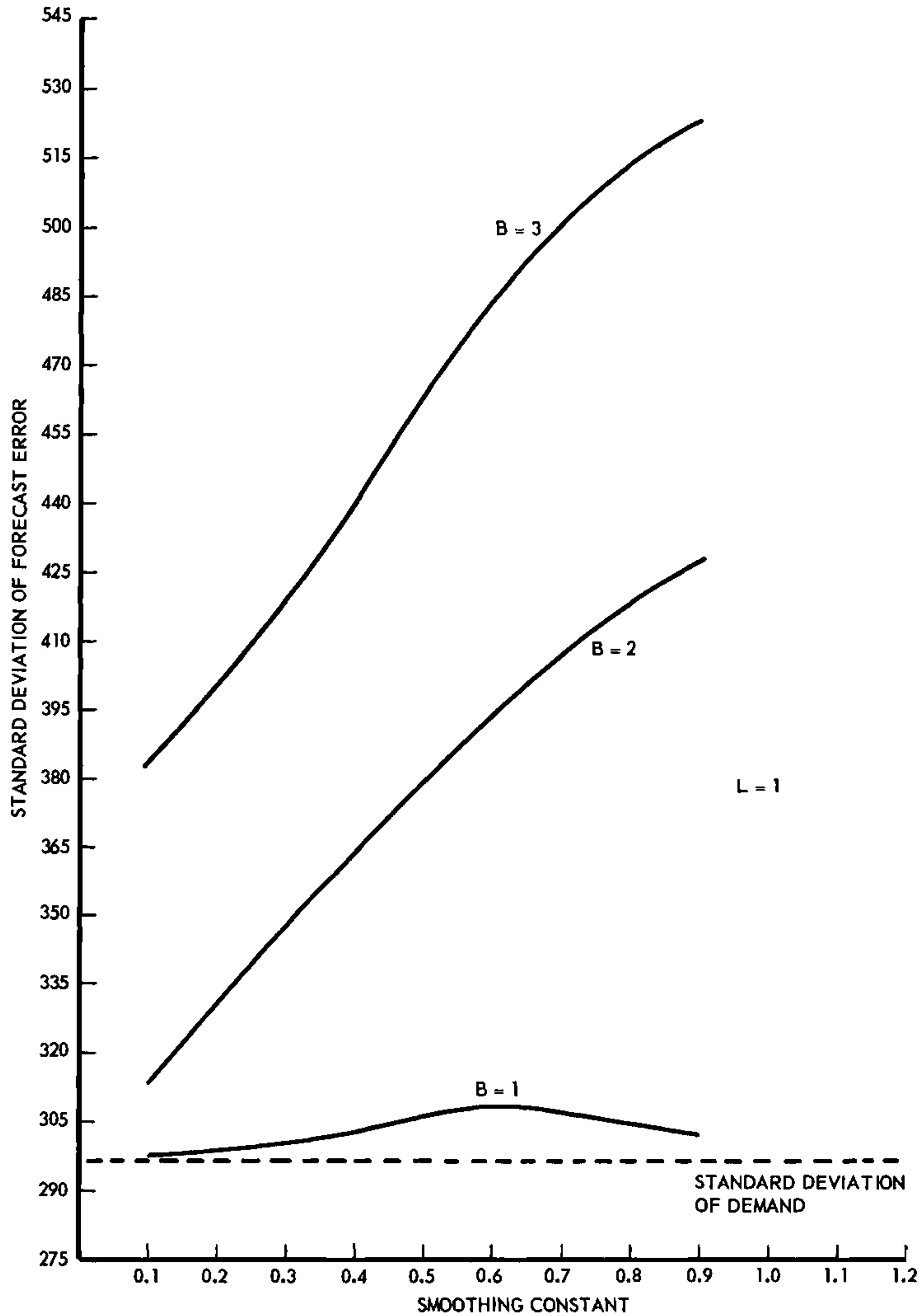

Figure 5. Standard Deviation of Forecast Error, Forecasting by Months, L = 1, B = 1, 2, 3.

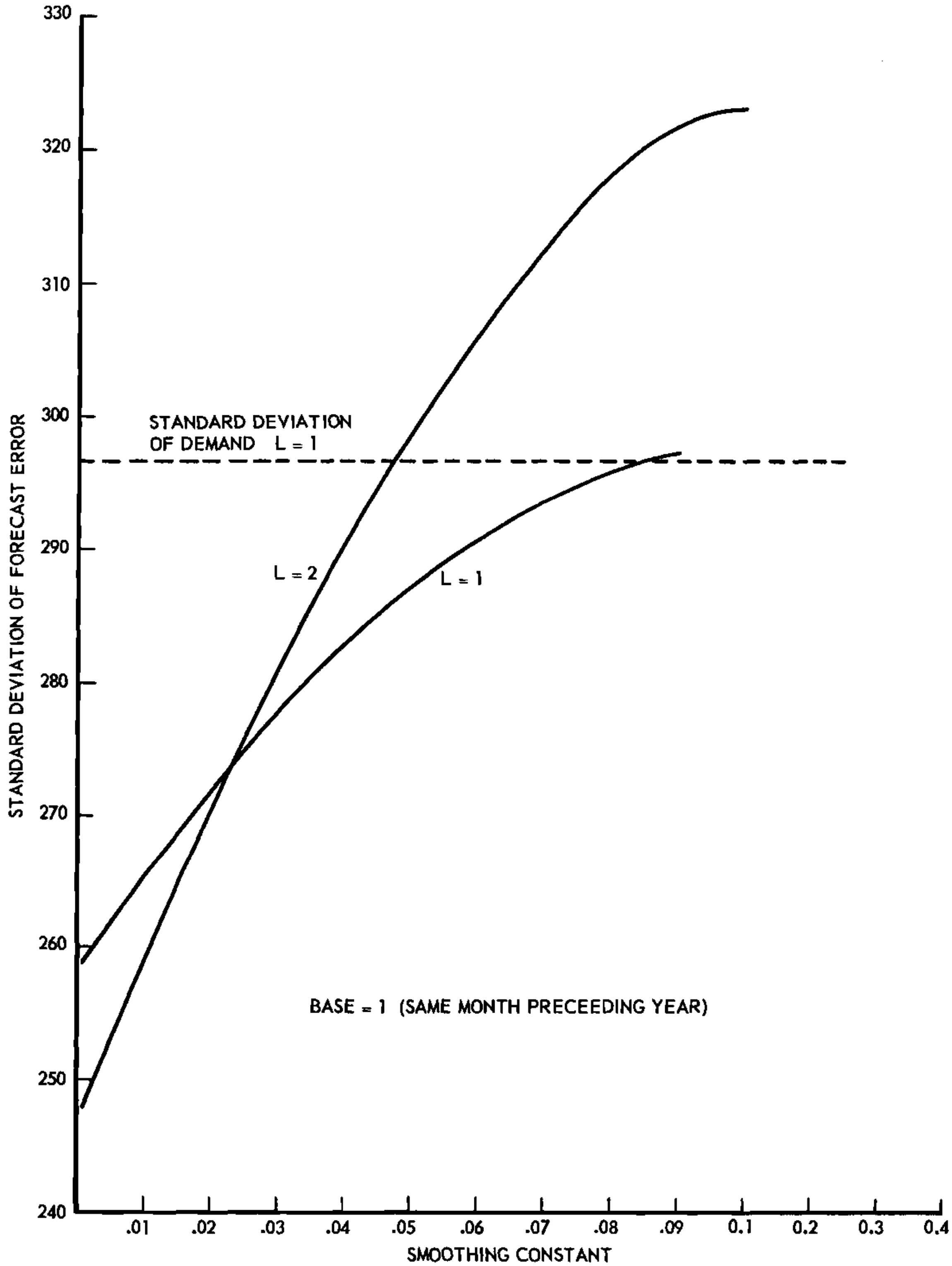

Figure 6. Standard Deviation of Forecast Error, Forecasting by Months, Base = 1, L = 1, 2.

months than for a lead time of one month. The minimum standard deviation computed occurs for a lead time of two months, in contrast to what might be expected. Table 7 gives the actual and predicted values for the series L = 1, B = 1, α = 0.001; Table 8 gives corresponding values for the series L = 2, B = 1, α = 0.001.

Assuming the forecast errors to be normally distributed and neglecting error in the estimate of the standard deviation of this distribution of forecast errors, an approximate 97.5 per cent upper confidence limit for individual future forecasts may be set as being equal to the forecast value plus two times the standard deviation of forecast error for the particular smoothing constant being used.

For example, using a smoothing constant of 0.001, and L = 1 or 2,

$$\text{(12)} \quad \text{maximum expected demand} = \text{forecast} + 2S_e, \\ \approx \text{forecast} + 500.$$

Forecasting by Weeks.--In exactly the same method as described previously, a forecast was made for each of the weeks from January 20, 1958 - January 19, 1959 (current year), utilizing weekly demand figures from the period January 21, 1957 - January 20, 1958 (previous year) to compute the base series (the value of the base series was taken as the average of the three surrounding weeks in the "previous year"). The smoothing constant was varied from 0.01 - 0.9 and the lead time from one to three weeks. The standard deviation of forecast error and the correlation between predicted and actual values were obtained as before; Table 9 lists the data used in these calculations and Figure 7 gives the results in graphic form.

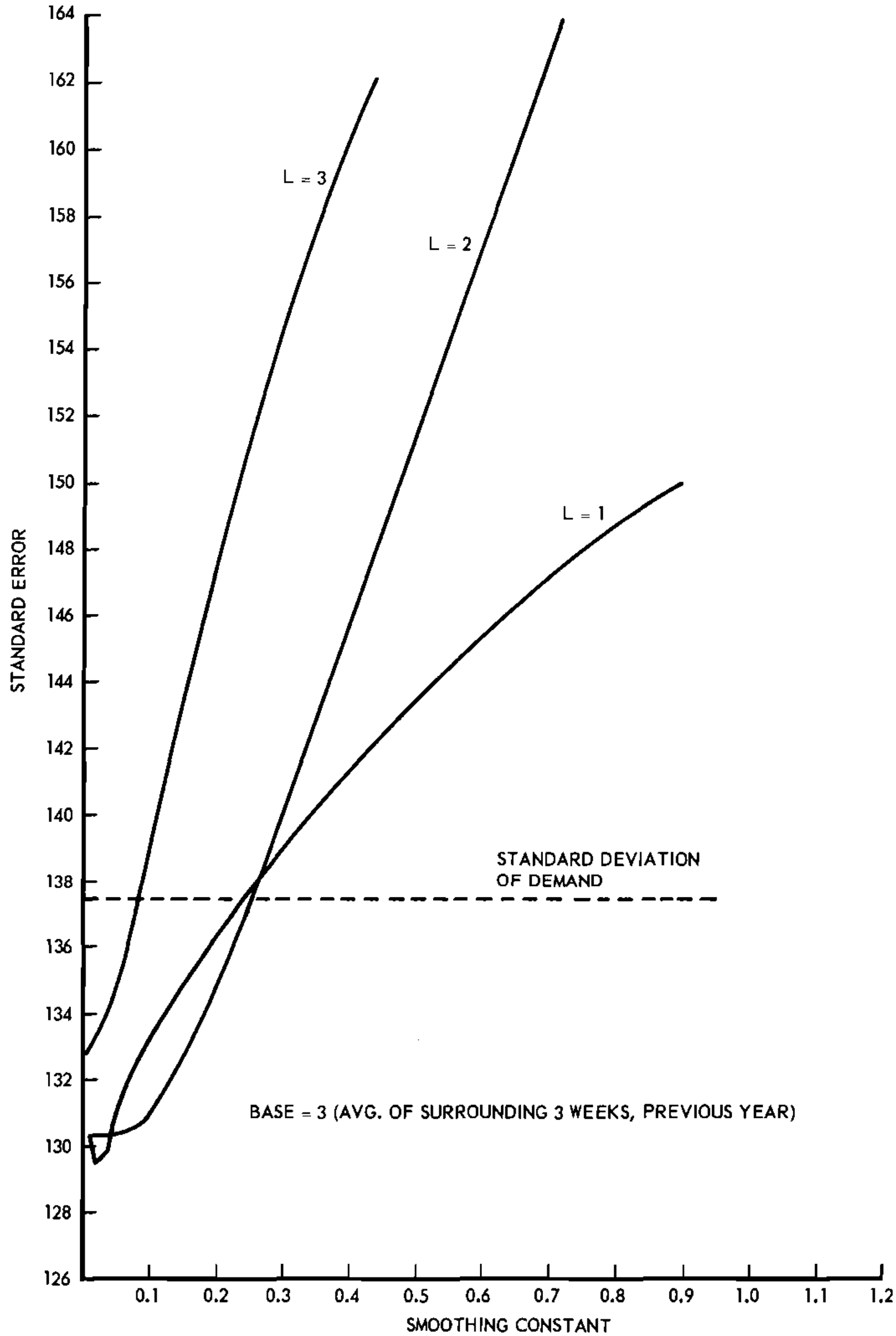

Figure 7. Standard Deviation of Forecast Error, Forecasting by Weeks, Base = 3, L = 1, 2, 3.

Note that for this series a smoothing constant value of 0.02 gave best results as evidenced by the lowest point on the curve. Also note that the minimum standard deviation occurs for a lead time of one week.

Table 9 also gives the predicted values and forecast error for the series which gave best results ($L = 1$, $B = 3$, $\alpha = 0.02$). For this value of the smoothing constant; i.e., 0.02, and $L = 1$ or 2, Equation (13) below gives an approximate 97.5 per cent upper confidence limit for individual future forecasts.

$$\text{(13)} \quad \text{Maximum expected demand} = \text{forecast} + 2S_e,$$
$$\approx \text{forecast} + 260.$$

CHAPTER V

CONCLUSIONS

The results of this study were obtained using data on the number of surgical rubber gloves processed daily by the Central Supply Department of Emory University Hospital, Atlanta, Georgia, during a 22-month period from September 1957, through June 1959.

With these restrictions in mind, the conclusions of this study are as follows:

1. The calculated multiple regression Equation (3) relating weekly glove demand to weekly census, weekly number of births and weekly number of operations was found to be unsuitable for forecasting glove demand.

2. The simple linear regression Equation (6) relating weekly glove demand with weekly hospital census quantifies the relationship between these variables. However, before weekly glove demand can be forecast, total weekly census must be estimated. The magnitude of the standard error of estimate associated with Equation (6) raises doubts as to the practicability of this procedure.

3. Using the method of exponential smoothing, glove demand can be forecast monthly and weekly. Only the values of the average ratio (Equation 9) and the trend (Equation 10) are necessary for calculating an expected ratio (Equation 11) for the current month or week. This expected ratio is then used with the appropriate value of the base series in making the forecast, as explained in Chapter IV. The initial value of the trend and the average ratio should be taken as 0 and 1.0

respectively. For weekly forecasts, a smoothing constant of 0.02 and a base of three weeks should give best results. For monthly forecasts, a smoothing constant of 0.001 and a base of one month appear best. Equations (12) and (13) can be used to calculate the maximum expected demand for any particular case with 97.5 per cent confidence that this estimated demand will not be exceeded.

4. These figures apply for the hospital environment studied in this study. If there is any indication that the state of the system is changing (i.e., significant changes in hospital bed capacity, changes in inventory policy, and/or new sources of glove demand), tests should be made with higher values of the smoothing constant to increase the speed of response of the model, keeping in mind that the model will then also be more responsive to purely random variations.

CHAPTER VI

DISCUSSION OF CONCLUSIONS AND RECOMMENDATIONS

It is felt that the unsatisfactory results obtained in the regression analysis part of this study are due more to selection and definition of the independent variables than to any inherent limitations in the proposed linear form of the multiple regression model, although no tests were made to support this assumption. Future investigations might check this assumption, and also incorporate other variables in the model, such as: major operations (as opposed to total number of operations); census, classified by medical service, such as pediatrics, obstetrics, medical and surgical; number of available students and/or interns; number of patients cared for in Gynecology and Cancer Clinics; and work load in Pathology Department.

Some of the limitations of the results obtained in this study with exponential smoothing should be mentioned. First, for inventory control purposes, glove demand can be forecast up to two months in advance with an accuracy indicated by Equation (12). It should be noted that this forecast yields an estimate of the total number of gloves to be used, inclusive of all sizes. Since some gloves are used moré frequently than others, a more specific estimate of the demand for each size could be obtained by examining the relative proportion of use by size and making corresponding allowances.

Second, for scheduling the Central Supply work force, maximum glove demand can be forecast up to two weeks in advance with an accuracy indicated by Equation (13). Since examination of the 22-month sample indicated that there is some variation in glove demand by day of the week (see Figure 12, Appendix), an estimate of the relative proportion of the weekly glove demand to be allocated to each day could be obtained. If inventory levels and other limitations in Central Supply permit, this would facilitate the establishment of certain weekly periods for glove processing, instead of handling the work on a day-to-day basis as is presently being done.

Finally, whether forecasting weekly or monthly, knowledge of future glove demand can be useful in economic comparisons of reprocessed and disposable gloves. Knowing the standard time for processing one pair of gloves, an estimate of the expected labor cost can be made. The total costs associated with using these gloves in the hospital can then be obtained readily.

APPENDIX

Table 2. Values Used in Multiple Correlation and Regression Analysis with Time Lag j = 2

Observed Input Values				Predicted Values	Residual Values = $\hat{Y}_i - Y_i$
Y_i	X_{1i2}	X_{2i2}	X_{3i2}	$\hat{Y}_i$	e_{12}
1059	1726	22	82	1128	69
1206	1750	20	101	1164	−42
1205	1766	12	93	1161	−44
1065	1517	13	81	1032	−33
1038	1728	14	93	1144	106
1162	1746	17	86	1143	−19
1092	1692	11	92	1126	−34
1040	1741	8	83	1137	97
1224	1806	12	96	1183	−41
1064	1595	18	82	1069	5
949	1623	13	81	1080	131
1130	1580	13	93	1077	−53
1037	1527	14	79	1034	−3
1184	1426	13	85	996	−188
1177	1980	12	72	1230	53
948	1660	24	74	1088	140
1122	1750	16	98	1161	39
1125	1825	20	99	1196	71
1122	1594	21	88	1076	−46

Table 2. Values Used in Multiple Correlation and Regression Analysis with Time Lag j = 2 (continued)

Observed Input Values				Predicted Values	Residual Values = $\hat{Y}_i - Y_i$
Y_i	X_{1i2}	X_{2i2}	X_{3i2}	$\hat{Y}_i$	e_{i2}
1067	1599	19	85	1075	8
1139	1551	32	72	1035	−104
1086	1451	25	67	984	−84
832	995	15	42	744	−88
1135	1520	20	82	1035	−100
1067	1627	26	86	1089	22
1054	1710	18	84	1124	70
1078	1698	14	85	1120	42
1010	1633	25	77	1079	69
856	1422	13	64	967	111
922	1576	28	90	1071	149
815	1461	24	86	1013	198
1121	1683	16	104	1138	17
903	1172	23	59	847	−56
915	1609	19	74	1065	150
1095	1446	11	81	1000	−95
1070	1499	16	85	1029	−41
1266	1837	26	112	1218	−48

Table 2. Values Used in Multiple Correlation and Regression Analysis with Time Lag j = 2 (continued)

Observed Input Values				Predicted Values	Residual Values = $\hat{Y}_i - Y_i$
Y_i	X_{1i2}	X_{2i2}	X_{3i2}	$\hat{Y}_i$	e_{i2}
1236	1822	22	110	1209	-27
1188	1591	13	129	1130	-58
1125	1848	23	97	1204	79
1048	1761	14	92	1158	110
988	1658	16	108	1132	144
1199	1550	11	94	1065	-134
1214	1659	12	89	1107	-107
1130	1637	13	68	1070	-60
1105	1642	12	97	1110	5
1014	1639	11	122	1142	128
1116	1525	15	77	1031	-85
1094	1402	9	78	976	-118
1049	1384	14	81	972	-77
1086	1612	7	106	1109	23
874	1044	18	46	771	-103
1165	1655	16	112	1136	-29
1151	1631	20	99	1108	-43
1007	1535	13	83	1043	36

Table 2. Values Used in Multiple Correlation and Regression Analysis with Time Lag j = 2 (continued)

Observed Input Values				Predicted Values	Residual Values = $\hat{Y}_i - Y_i$
Y_i	X_{1i2}	X_{2i2}	X_{3i2}	$\hat{Y}_i$	e_{i2}
1253	1540	23	90	1055	−198
1217	1562	16	93	1069	−148
1082	1495	10	90	1034	−48
962	1311	9	66	919	−43
963	1331	18	90	960	−3
789	1373	10	87	975	186
940	1283	22	83	929	−11
679	976	15	44	738	−59
1011	1309	12	57	906	−105
1021	1535	24	105	1072	51
972	1568	18	102	1083	111
1188	1567	17	79	1052	−136
1053	1547	10	105	1078	25
1152	1542	13	95	1062	−90
1289	1545	10	91	1058	−231
1231	1576	20	87	1067	−164
1020	1654	16	134	1165	145
1135	1883	25	89	1209	74
962	1586	8	97	1085	123
978	1644	17	79	1087	109

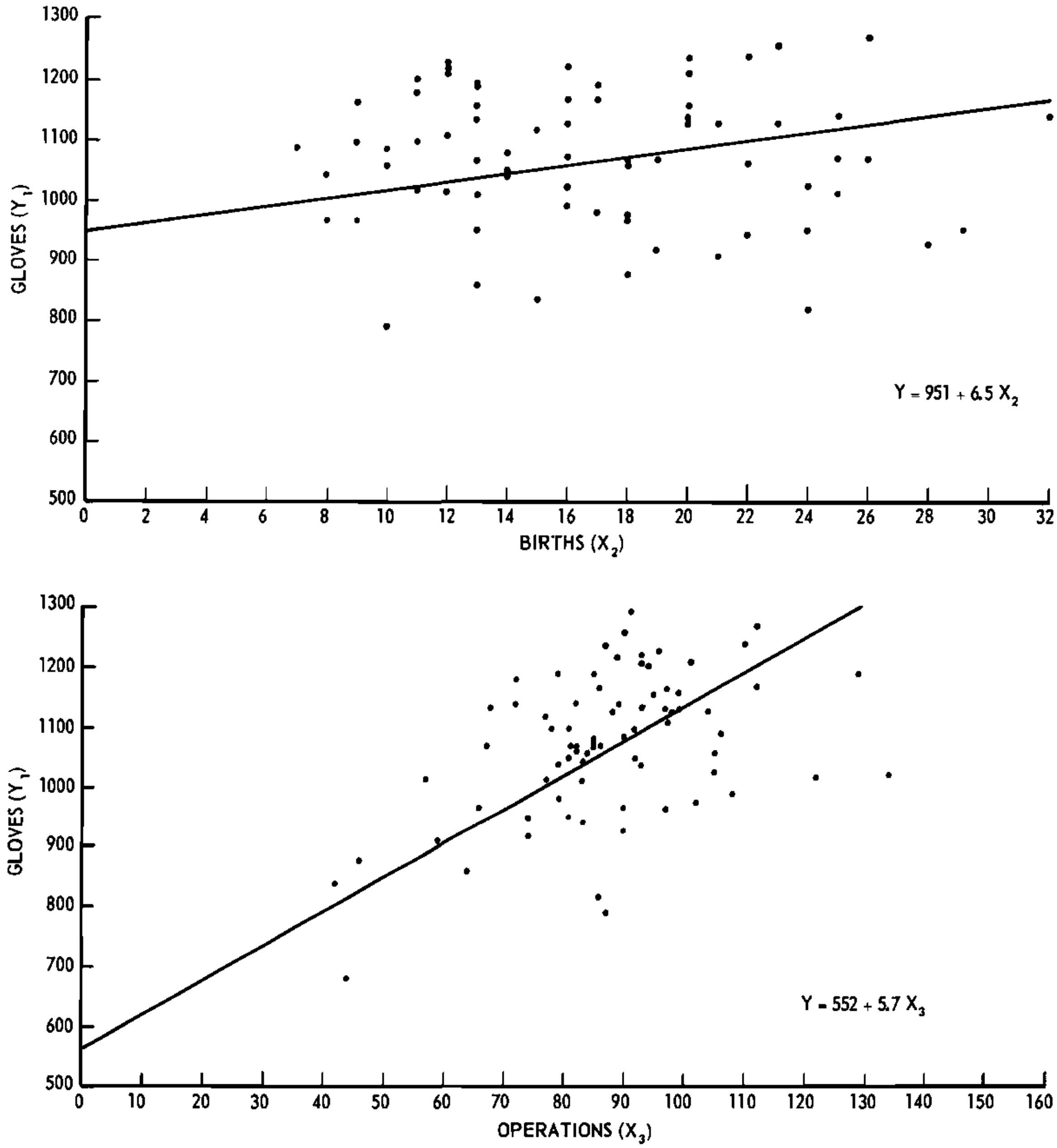

Figure 8. Scatter Diagrams of Glove Demand Versus Operations and Births Respectively, with Least Squares Regression Line.

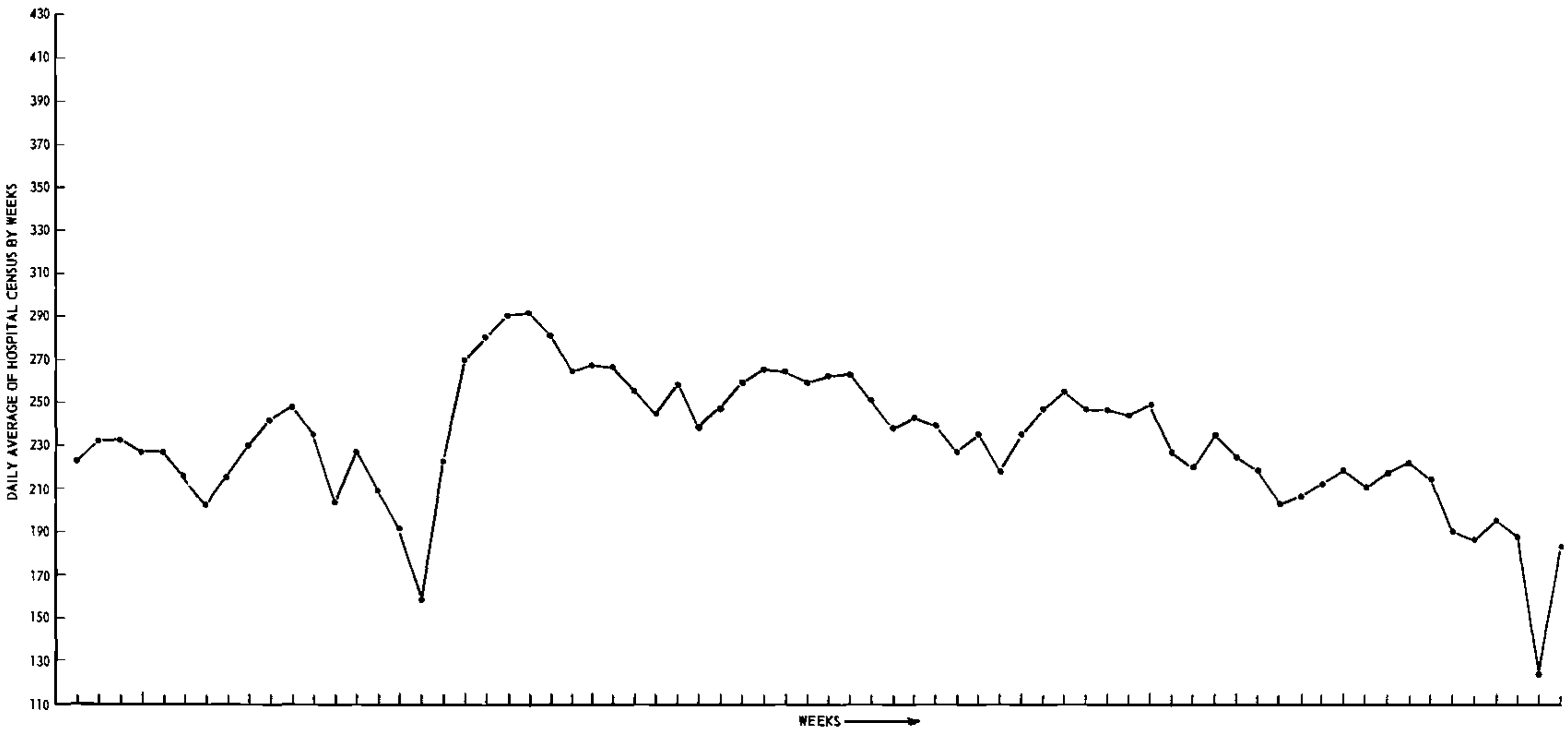

Figure 9. Average Daily Hospital Census, by Weeks, September 1957 - January 1959.

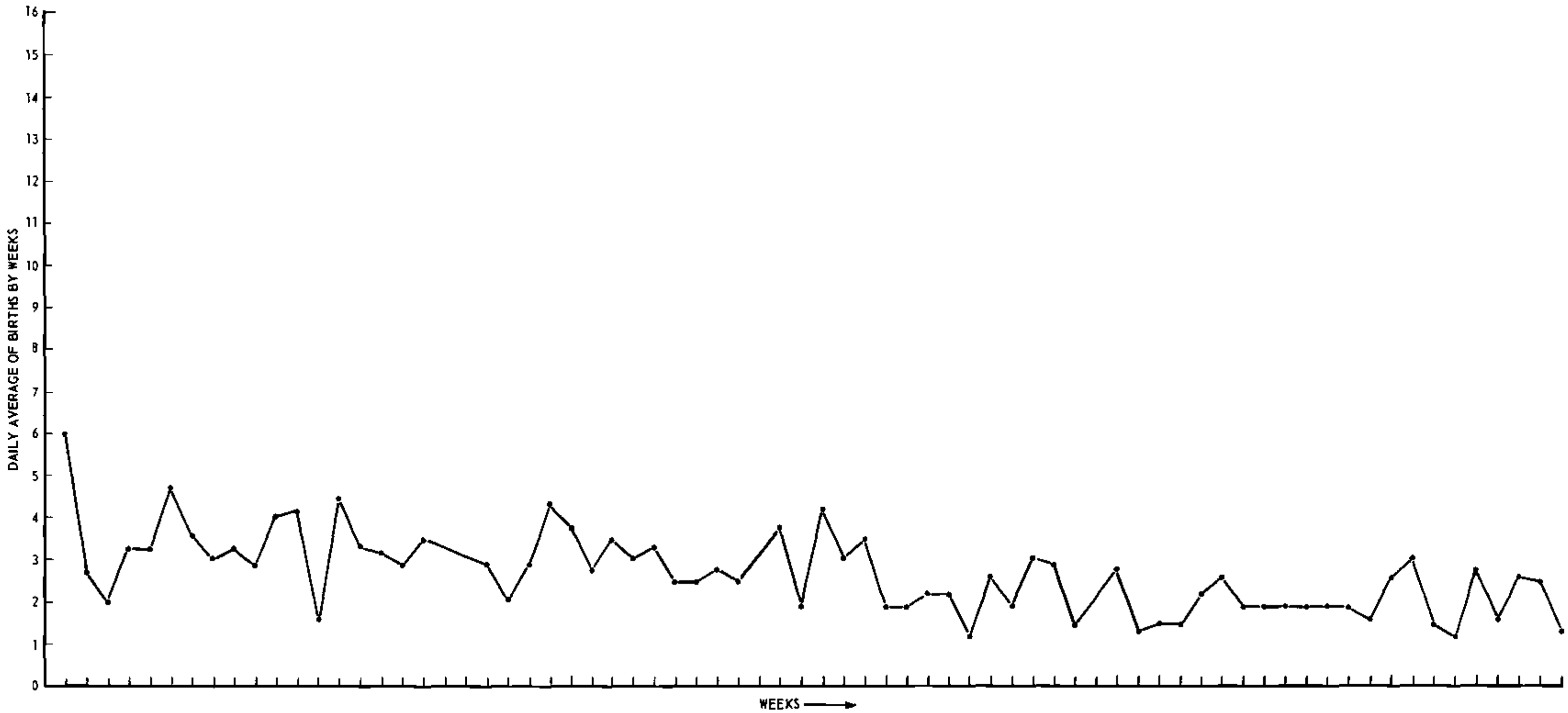

Figure 10. Average Daily Births, by Weeks, September 1957 - January 1959.

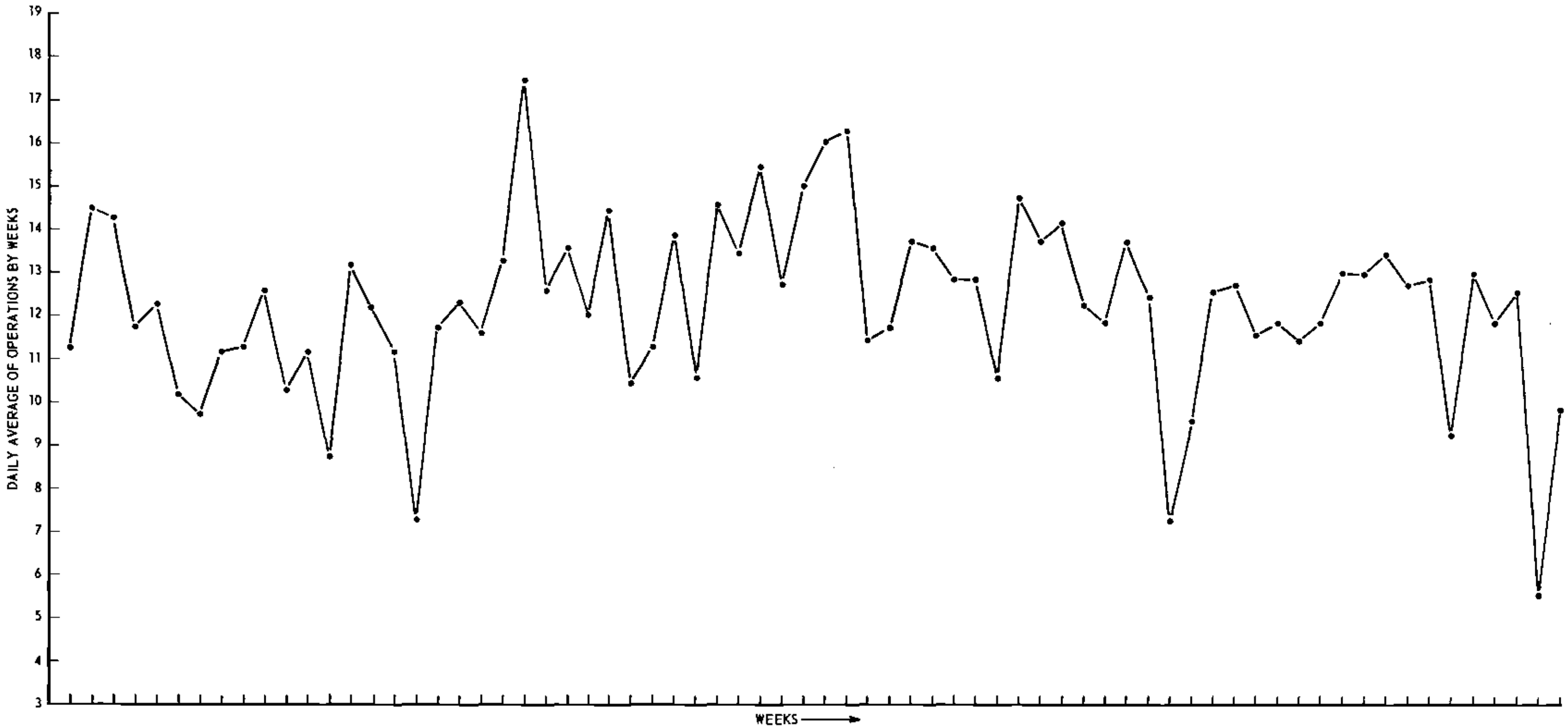

Figure 11. Average Daily Number of Operations, by Weeks, September 1957 - January 1959.

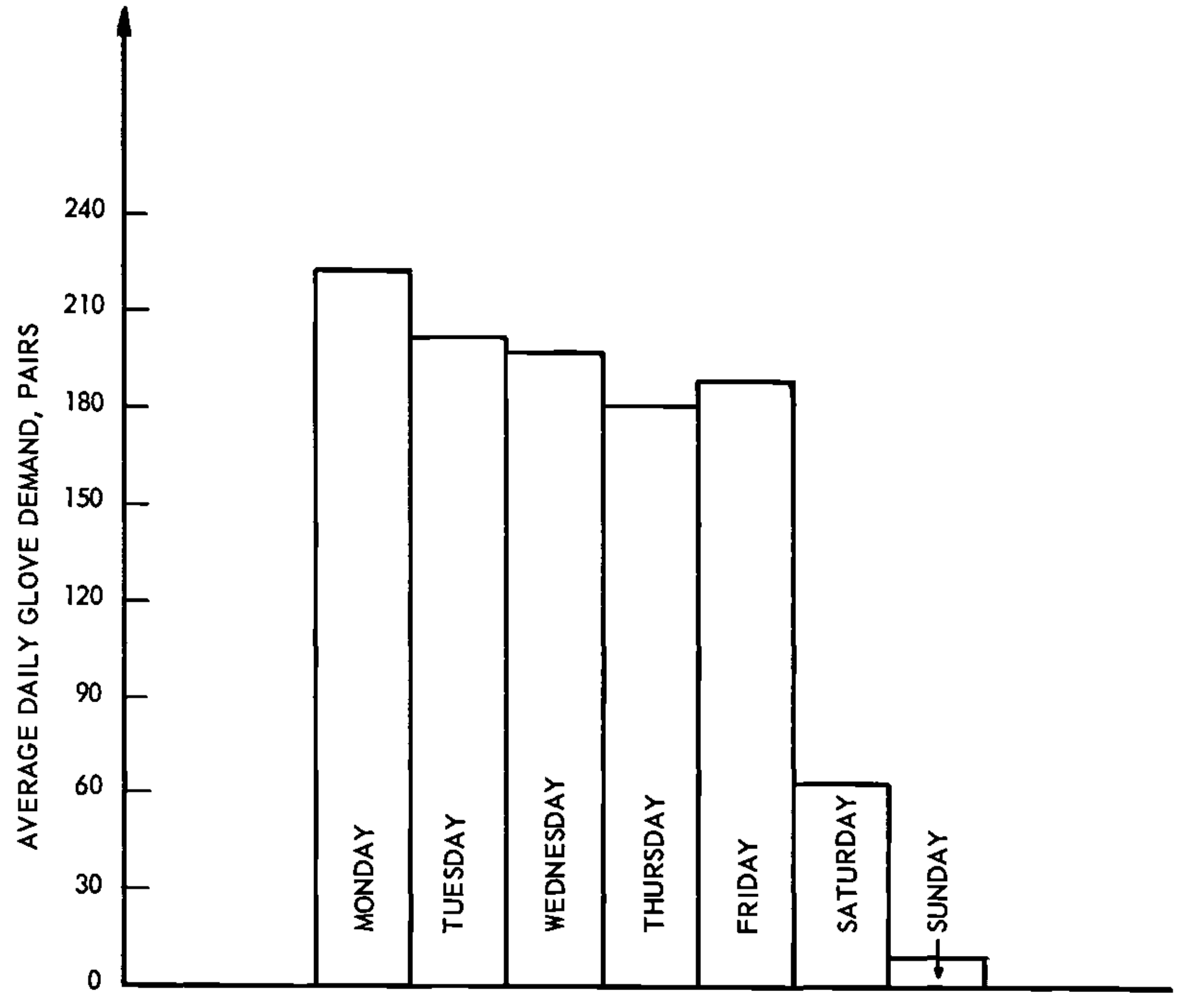

Figure 12. Average Glove Demand by Day of the Week, September 1957 - June 1959.

SAMPLE CALCULATIONS

The matrix of simple correlation coefficients for the regression model Equation (3) is defined below as A.

$$A = \begin{bmatrix} r_{YY} & r_{YX_1} & r_{YX_2} & r_{YX_3} \\ r_{X_1Y} & r_{X_1X_1} & r_{X_1X_2} & r_{X_1X_3} \\ r_{X_2Y} & r_{X_2X_1} & r_{X_2X_2} & r_{X_2X_3} \\ r_{X_3Y} & r_{X_3X_1} & r_{X_3X_2} & r_{X_3X_3} \end{bmatrix}$$

For the sample data analyzed in this study, this A matrix is as follows:

$$A = \begin{bmatrix} 1.0000 & 0.7968 & 0.2196 & 0.6485 \\ 0.7968 & 1.0000 & 0.2951 & 0.7233 \\ 0.2196 & 0.2951 & 1.0000 & 0.1149 \\ 0.6485 & 0.7233 & 0.1149 & 1.0000 \end{bmatrix}$$

The inverse of this matrix is as follows:

$$A = \begin{bmatrix} 2.8233 & -1.9416 & 0.0019 & -0.4266 \\ -1.9416 & 3.6541 & -0.4994 & -1.3266 \\ 0.0019 & -0.4994 & 1.1204 & 0.2313 \\ -0.4266 & -1.3266 & 0.2312 & 2.2097 \end{bmatrix}$$

Now let

$$(a_{ij}) = (r_{ij})^{-1},$$

where $(r_{ij})^{-1} = A^{-1}$ is the inverse of the matrix of simple correlation coefficients. The elements a_{ij}, of this inverse matrix, are used in computing the following statistics.

Multiple Regression Coefficients

$b_i = -\frac{a_{1j}}{a_{11}} \frac{\sigma_1}{\sigma_j}$ $(j = 2, 3, 4)$, where σ_j = standard deviation of the j^{th} variable, and σ_1 = standard deviation of the dependent variable, Y_i.

$$b_2 = \frac{1.9416}{2.8233} \times \frac{168.7}{255.8} = 0.4535,$$

$$b_3 = \frac{-0.00189}{2.8233} \times \frac{168.7}{5.7} = -0.0198,$$

$$b_4 = \frac{0.4266}{2.8233} \times \frac{168.7}{19.2} = 1.3263.$$

Multiple Correlation Coefficient

$$R' = \sqrt{1 - \frac{1}{a_{11}}},$$

$$R' = \sqrt{1 - \frac{1}{2.8233}} = 0.804, \text{ unadjusted and}$$

$R^2 = 1 - (1 - R^2)\ [(N - 1/N - n)]$, where N = sample size and n = number of parameters fitted in the regression model; i.e., b_1, b_2, b_3, and b_4.

$R^2 = 1 - (0.3536)(75/72) = 0.63191$

$R = 0.795$, adjusted.

Standard Error of Estimate

Biased standard error $= S'_e = \dfrac{\sigma_1}{\sqrt{a_{11}}}$,

$$S'_e = \frac{168.7}{\sqrt{2.8233}} = 100.43 .$$

Unbiased standard error $= S_e = \sqrt{N/N - n} \quad S'_e$

$$= \sqrt{76/72} \quad (100.43) = 103.14 .$$

Unbiased Standard Error of Multiple Regression Coefficients

$$S_{b_j} = \frac{b_j}{r_{1j}} \sqrt{\frac{1 - r_{1j}^2}{N - n}}$$

for $j = 2, 3, 4$

where r_{1j} = partial correlation coefficient between the first variable and the j^{th} variable

and b_j = regression coefficients

$$S_{b_2} = \frac{0.4535}{0.6044} \sqrt{\frac{1 - (0.6044)^2}{72}} = 0.0704 ,$$

$$S_{b_3} = \frac{-0.0198}{-0.0011} \sqrt{\frac{1 - (0.0011)^2}{72}} = 2.12 ,$$

$$S_{b_4} = \frac{1.326}{0.1707} \sqrt{\frac{1 - (0.1707)^2}{72}} = 0.901 .$$

Simple Regression Coefficients

$b'_{yx} = r_{yx} \dfrac{\sigma_y}{\sigma_x}$, where r_{yx} = simple correlation coefficient between y and x

σ = Standard Deviation

$$b'_{yx_1} = 0.797 \times \frac{168.7}{255.8} = 0.53,$$

$$b'_{yx_2} = 0.220 \times \frac{168.7}{5.7} = 6.5,$$

$$b'_{yx_3} = 0.648 \times \frac{168.7}{19.2} = 5.7.$$

Standard Error of Estimate, Simple Regression

$$\text{Total S.S.} = nS_y^2 = 76 \times 168.0^2 = 2,145,024,$$

$$\text{S.S. for regression of Y on } X_1 = \left[\frac{\Sigma(X-\bar{X})(Y-\bar{Y})}{\Sigma(X-\bar{X})^2}\right]^2$$

$$= n\,r^2 S_y^2$$

$$= 76(.797)^2(168)^2$$

$$= \underline{1,360,322}\ ,$$

$$\text{S.S. for deviations} = 2,145,024 - 1,360,322 = 784,702.$$

$$\frac{\text{S.S. for deviations}}{\text{Degrees of Freedom}} = S_e^2 = \frac{784,702}{74} = 10,605,$$

$$S_e = 103.$$

95 Per Cent Confidence Limits, Simple Regression

$$\text{95\% Confidence Interval} = \hat{Y} \pm t_{.05}\, S_e \sqrt{1 + 1/n + (X-\bar{X})^2/\Sigma(X-\bar{X})^2}$$

From Student's "t" tables, $t_{.05} = 2.00$ (d.f. = 74)

$$Y = \hat{Y} \pm (2.00)(103)\sqrt{1 + 1/76 + \frac{(X - 1560)^2}{4,980,000}}$$

X	95% Confidence Limits
800	$\hat{Y} \pm 222$
1000	$\hat{Y} \pm 214$
1200	$\hat{Y} \pm 210$
1500	$\hat{Y} \pm 207$
1800	$\hat{Y} \pm 209$
2000	$\hat{Y} \pm 211$

Table 3. Observed Glove Demand Data and Demand Ratios Used in Forecasting by Months

Month	Demand for Month in Current Year	Demand for Same Month in 1957-58 (Base)	Demand Ratio
<u>1958</u>			
February	4406	6083	0.724
March	4412	4602	0.958
April	4757	4967	0.957
May	5103	5100	1.000
June	4579	4094	1.113
July	5363	4815	1.114
August	4565	4216	1.082
September	4480	4526	0.989
October	4964	4728	1.048
November	4660	4107	1.134
December	3962	3797	1.043
<u>1959</u>			
January	4645	4674	0.993
February	4689	4406	1.064
March	4700	4412	1.065
April	4822	4757	1.013
May	4749	5103	0.930
June	4674	4579	1.020

Table 4. Results of Exponential Smoothing: Correlation Between Actual and Predicted Demand, and Standard Deviation of Forecast Errors

Monthly, L = 1

For explanation of symbols see next page.

	α	$\overline{X}_p$	r_{AP}	$\overline{X}_z$	σ_z
<u>Base = 1</u>					
$\overline{X}_A$ = 4714.1	0.1	4694.6	0.616	19.5	298.6
σ_A = 296.7	0.2	4723.5	0.591	-9.4	299.6
	0.3	4722.1	0.585	-8.0	300.2
	0.4				
	0.5	4710.3	0.577	3.7	307.1
	0.6	4705.9	0.576	8.2	308.5
	0.7	4702.5	0.577	11.5	307.5
	0.8	4700.2	0.582	13.9	304.8
	0.9	4698.9	0.587	15.2	301.8
<u>Base = 2</u>					
$\overline{X}_A$ = 4714.1	0.1	4644.1	0.382	70.0	313.3
σ_A = 296.7	0.2	4677.3	0.279	36.8	333.9
	0.3	4682.7	0.234	31.3	347.1
	0.4	4681.0	0.215	33.1	362.0
	0.5	4678.4	0.205	35.7	377.9
	0.6	4676.1	0.198	37.9	393.8
	0.7	4674.4	0.196	39.7	408.5

Table 4. Results of Exponential Smoothing: Correlation Between Actual and Predicted Demand, and Standard Deviation of Forecast Errors (continued)

Monthly, L = 1

	α	$\bar{X}_p$	r_{AP}	$\bar{X}_z$	σ_z
	0.8	4673.3	0.198	40.7	420.6
	0.9	4672.8	0.203	41.2	428.6
Base = 3					
$\bar{X}_A$ = 4714.1	0.1	4671.0	-0.323	43.1	384.1
σ_A = 296.7	0.2	4699.0	-0.221	14.4	402.6
	0.3	4700.5	-0.307	13.5	419.9
	0.4	4696.7	-0.319	17.3	440.9
	0.5	4693.7	-0.312	20.4	462.9
	0.6	4691.6	-0.302	22.5	483.5
	0.7	4690.3	-0.292	23.7	501.5
	0.8	4689.6	-0.279	24.5	515.4
	0.9	4689.3	-0.265	24.8	524.1

α = Smoothing constant ($0 < \alpha < 1$).

$\bar{X}_A$ = Average observed monthly demand.

σ_A = Standard deviation of observed monthly demand.

$\bar{X}_p$ = Average predicted monthly demand.

r_{AP} = Correlation between observed and predicted demands.

$\bar{X}_z$ = Average of forecast errors.

σ_z = Standard deviation of forecast error.

Table 5. Results of Exponential Smoothing: Correlation Between Actual and Predicted Demand and Standard Deviation of Forecast Error

Monthly, Base = 1

	$\overline{X}_A$	σ_A	$\overline{X}_p$	σ_P	r_{AP}	$\overline{X}_Z$	σ_Z
L = 1							
0.001	4714.1	296.7	4554.6	371.1	0.721	159.5	258.9
0.003	4714.1	296.7	4559.5	371.2	0.718	154.6	260.3
0.005	4714.1	296.7	4564.3	371.3	0.714	149.7	261.7
0.01	4714.1	296.7	4575.9	371.7	0.707	138.2	265.2
0.02	4714.1	296.7	4597.1	372.3	0.692	117.1	271.7
0.03	4714.1	296.7	4615.7	372.8	0.678	98.4	277.6
0.04	4714.1	296.7	4632.1	373.1	0.665	82.0	282.7
0.05	4714.1	296.7	4646.5	373.1	0.654	67.6	287.0
0.06	4714.1	296.7	4659.1	372.7	0.644	55.0	290.6
0.07	4714.1	296.7	4670.0	372.1	0.636	44.1	293.5
0.08	4714.1	296.7	4679.5	371.1	0.628	34.6	295.7
0.09	4714.1	296.7	4687.6	370.0	0.622	26.5	297.4
L = 2							
0.001	4711.1	306.9	4524.8	367.1	0.743	186.3	247.9
0.003	4711.1	306.9	4529.5	368.1	0.738	181.5	250.4
0.005	4711.1	306.9	4534.1	369.0	0.734	176.9	252.9
0.01	4711.1	306.9	4545.2	371.4	0.724	165.9	258.9
0.02	4711.1	306.9	--	--	--	--	--

Table 5. Results of Exponential Smoothing: Correlation Between Actual and Predicted Demand and Standard Deviation of Forecast Error (continued)

Monthly, Base = 1

	$\overline{X}_A$	σ_A	$\overline{X}_p$	σ_P	r_{AP}	$\overline{X}_Z$	σ_Z
0.03	4711.1	306.9	4584.2	380.6	0.686	126.9	280.8
0.04	4711.1	306.9	4600.7	384.6	0.669	110.4	290.3
0.05	4711.1	306.9	4615.4	388.2	0.653	95.6	298.7
0.06	4711.1	306.9	4628.6	391.2	0.640	82.5	306.1
0.07	4711.1	306.9	4640.3	393.8	0.627	70.8	312.6
0.08	4711.1	306.9	4650.7	396.0	0.616	60.4	318.2
0.09	4711.1	306.9	4659.8	397.7	0.606	51.3	323.2

Table 6. Results of Exponential Smoothing: Correlation Between Actual and Predicted Demand, and Standard Deviation of Forecast Errors

Weekly, Base = 3

	$\bar{X}_A$	σ_A	$\bar{X}_P$	σ_P	r_{AP}	$\bar{X}_Z$	σ_Z
L = 1							
0.01	1073.9	137.5	1044.4	106.6	0.457	32.80	130.2
0.02	1073.9	137.5	1051.2	102.2	0.450	26.00	129.5
0.03	1073.9	137.5	1056.9	99.7	0.443	20.40	129.6
0.04	1073.9	137.5	1061.4	98.6	0.436	15.80	129.8
0.10	1073.9	137.5	1068.1	102.4	0.414	5.83	133.2
0.20	1073.9	137.5	1070.2	109.9	0.412	3.68	136.1
0.30	1073.9	137.5	1070.4	118.9	0.420	3.52	138.9
0.40	1073.9	137.5	1070.0	126.7	0.430	3.88	141.4
0.50	1073.9	137.5	1069.5	132.5	0.437	4.38	143.4
0.60	1073.9	137.5	1069.0	136.8	0.440	4.88	145.2
0.70	1073.9	137.5	1068.6	140.2	0.440	5.34	147.0
0.80	1073.9	137.5	1068.2	143.0	0.438	5.75	148.7
0.90	1073.9	137.5	1067.9	145.0	0.437	6.04	150.0
L = 2							
0.01	1074.1	136.1	1039.6	106.0	0.451	34.20	130.3
0.03	1074.1	136.1	1052.1	99.9	0.436	21.70	130.0
0.04	1074.1	136.1	1056.6	99.2	0.429	17.20	130.4
0.10	1074.1	136.1	1071.7	98.8	0.410	0.88	130.9

Table 6. Results of Exponential Smoothing: Correlation Between Actual and Predicted Demand, and Standard Deviation of Forecast Errors (continued)

Weekly, Base = 3

	$\bar{X}_A$	σ_A	$\bar{X}_P$	σ_P	r_{AP}	$\bar{X}_Z$	σ_Z
0.20	1074.1	136.1	1074.0	105.1	0.400	0.07	134.6
0.30	1074.1	136.1	1074.6	113.2	0.381	-0.58	140.0
0.40	1074.1	136.1	1074.9	120.1	0.359	-0.84	145.7
0.50	1074.1	136.1	1075.0	125.7	0.333	-0.98	151.4
0.60	1074.1	136.1	1075.1	130.6	0.306	-1.04	157.2
0.70	1074.1	136.1	1075.1	135.2	0.281	-1.04	162.7
0.80	1074.1	136.1	1075.1	139.4	0.261	-1.01	167.5
0.90	1074.1	136.1	1075.0	142.7	0.247	-0.97	171.1
<u>L = 3</u>							
0.10	1071.3	138.0	1064.2	104.2	0.368	8.90	139.1
0.20	1071.3	138.0	1064.6	112.8	0.327	6.70	146.9
0.30	1071.3	138.0	1064.9	123.2	0.308	6.40	154.1
0.40	1071.3	138.0	1064.9	133.5	0.299	6.40	160.7
0.50	1071.3	138.0	1064.8	142.1	0.293	6.50	166.5
0.60	1071.3	138.0	1064.7	148.8	0.287	6.60	171.5
0.70	1071.3	138.0	1064.6	154.1	0.280	6.70	175.7
0.80	1071.3	138.0	1064.4	158.1	0.274	6.80	179.1
0.90	1071.3	138.0	1064.3	160.8	0.269	7.00	181.6

Table 7. Observed Monthly Demand, Predicted Demand, and Forecast Errors for Series
$L = 1, B = 1, \alpha = 0.001$

Month	Actual Demand	Predicted Demand	Forecast Error
1958			
April	4757	4966.5	-209.5
May	5103	5099.1	3.8
June	4579	4093.3	485.6
July	5363	4815.3	547.6
August	4565	4217.3	347.7
September	4480	4528.0	-48.0
October	4964	4730.0	234.0
November	4660	4109.2	550.8
December	3962	3800.1	161.9
1959			
January	4645	4678.0	-33.0
February	4689	4409.9	279.1
March	4700	4416.4	283.6
April	4822	4762.4	59.6
May	4749	5108.9	-359.9
June	4674	4583.7	90.3

Time Span of Forecast: 1 month
Base Period: Same Month of Previous Year
Smoothing Constant: 0.001
Correlation Coefficient of Actual and Predicted: 0.721
Standard Deviation of Error: 258.9

Table 8. Observed Monthly Demand, Predicted Demand, and Forecast Errors for Series
L = 1, B = 1, $\alpha = 0.001$

Month	Actual Demand	Predicted Demand	Forecast Error
1958			
May	5103	5099.6	3.4
June	4579	4093.3	485.6
July	5363	4814.2	548.8
August	4565	4216.3	348.7
September	4480	4527.4	-47.4
October	4964	4730.2	233.8
November	4660	4108.8	551.2
December	3962	3799.1	162.9
1959			
January	4645	4677.8	-32.8
February	4689	4409.9	279.1
March	4700	4415.9	284.1
April	4822	4761.8	60.2
May	4749	5108.8	-359.8
June	4674	4584.3	89.7

Time Span of Forecast: 2 months
Base Period: Same month of previous year
Smoothing Constant: 0.001
Correlation Coefficient of Actual and Predicted: 0.743
Standard Deviation of Error: 247.9

Table 9. Exponential Smoothing Results--Weekly

Time Span of Forecast: 1 week
Base Period: 3 weeks
Smoothing Constant: 0.02
Correlation Coefficient of Actual and Predicted: 0.457
Standard Deviation of Forecast Error: 130.2

Week Beginning	Actual Demand	Predicted Demand	Forecast Error
2-3-58	1176.0	1176.3	-0.3
2-10-58	1103.0	1193.4	-90.4
2-17-58	1034.0	1185.5	-151.5
2-24-58	1013.0	1171.6	-158.6
3- 3-58	952.0	1067.3	-115.3
3-10-58	966.0	1052.4	-86.4
3-17-58	994.0	1032.5	-38.5
3-24-58	1187.0	1051.7	135.3
3-31-58	1169.0	1044.4	124.6
4- 7-58	994.0	1103.2	-109.2
4-14-58	1163.0	1121.8	41.2
4-21-58	1076.0	1191.0	-115.0
4-28-58	1168.0	1211.2	-43.2
5- 5-58	1237.0	1203.1	33.9
5-12-58	1206.0	1061.8	144.2
5-19-58	1148.0	994.6	153.4
5-26-58	1012.0	995.0	17.0

Table 9. Exponential Smoothing Results--Weekly (continued)

Week Beginning	Actual Demand	Predicted Demand	Forecast Error
6- 2-58	1144.0	1039.0	105.0
6- 9-58	1093.0	1046.1	46.9
6-16-58	1017.0	1021.3	-4.3
6-23-58	1129.0	929.2	199.8
6-30-58	920.0	939.2	-19.2
7- 7-58	1132.0	995.9	136.1
7-14-58	1338.0	1151.9	186.1
7-21-58	1293.0	1119.7	173.3
7-28-58	1347.0	1125.0	222.0
8- 4-58	893.0	1077.2	-184.2
8-11-58	1143.0	1034.7	108.3
8-18-58	1176.0	953.6	222.4
8-25-58	882.0	909.3	-27.3
9- 1-58	955.0	1007.4	-52.4
9- 8-58	989.0	1104.7	-115.7
9-15-58	1091.0	1186.1	-95.1
9-22-58	980.0	1149.0	-169.0
9-29-58	1154.0	1138.5	15.5
10- 6-58	1126.0	1120.9	5.1
10-13-58	1153.0	1051.9	101.1
10-20-58	1067.0	1026.9	40.1

Table 9. Exponential Smoothing Results--Weekly (continued)

Week Beginning	Actual Demand	Predicted Demand	Forecast Error
10-27-58	1074.0	1066.0	8.0
11- 3-58	1169.0	1069.4	99.6
11-10-58	1192.0	1034.9	157.1
11-17-58	1233.0	933.8	299.2
11-24-58	921.0	1035.3	-114.3
12- 1-58	1049.0	978.5	70.5
12- 8-58	787.0	952.1	-165.1
12-15-58	950.0	771.6	178.4
12-22-58	592.0	774.0	-182.0
12-29-58	1122.0	859.1	262.9

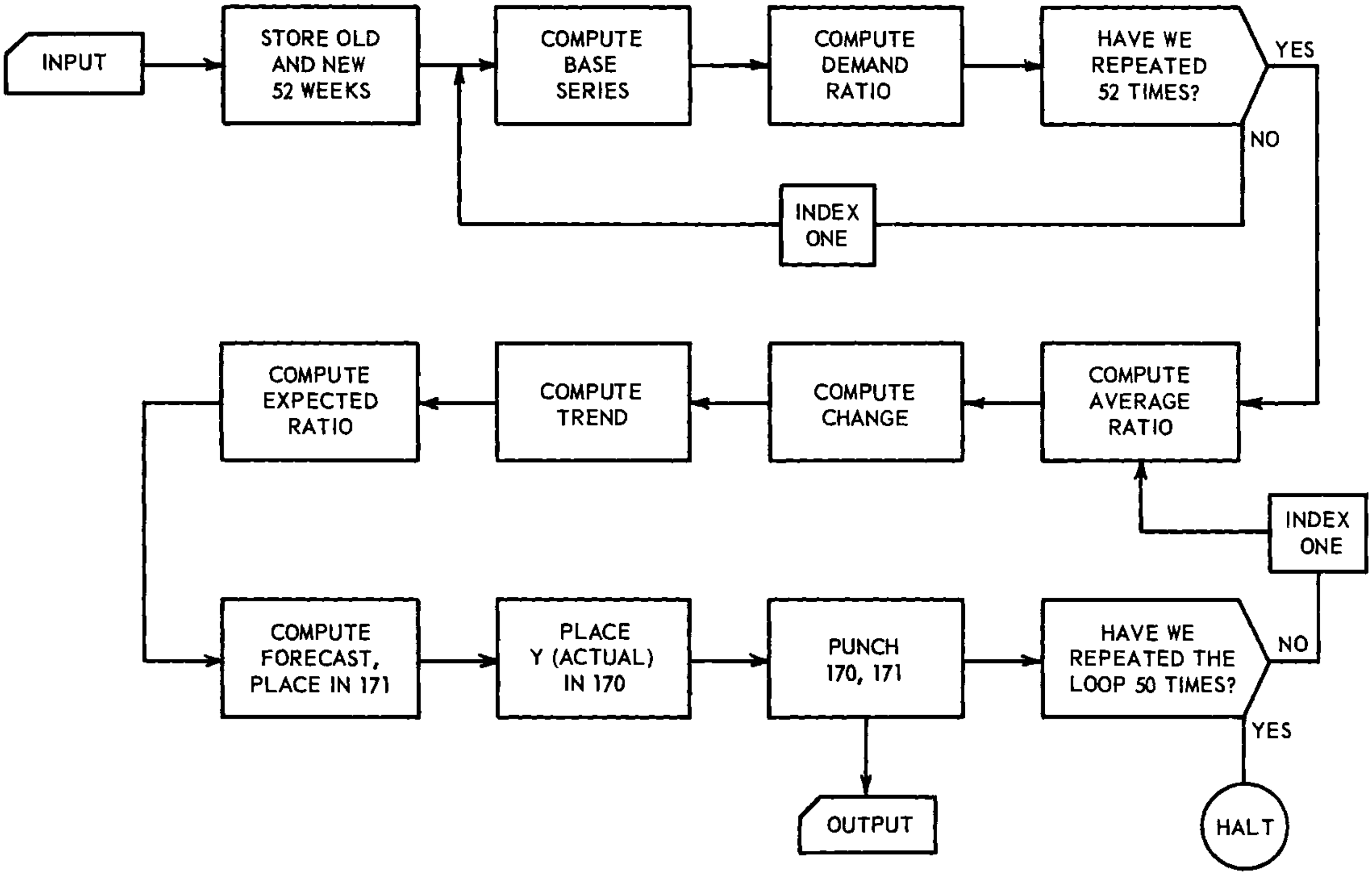

Figure 13. Flow Diagram of IBM 650 Program for Exponential Smoothing Method, by Weeks.

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