1971

An investigation into the development of a predictive model of operating variation

Ted M. Upton
Lehigh University

AN INVESTIGATION INTO THE
DEVELOPMENT OF A PREDICTIVE
MODEL OF OPERATING VARIATION

by

Ted M. Upton

ABSTRACT

The subject considered in this thesis is the development of a predictive model of Operating Variation. A general discussion of Operating Variation and its elements is given along with suggestions for exercising control on the elements.

Several models of Operating Variation are developed each with a varying degree of information required for its application. The employment of a model consists of a two-phase procedure consisting of (a) predict the end-of-month values of the independent variables from their weekly observations and (b) from these end-of-month estimates predict the monthly Operating Variation. In addition, the most significant elements of Operating Variation are determined.

AN INVESTIGATION INTO THE DEVELOPMENT OF A PREDICTIVE MODEL OF OPERATING VARIATION

by

Ted M. Upton

A Thesis

Presented to the Graduate Committee

of Lehigh University

in Candidacy for the Degree of

Master of Science

in Industrial Engineering

Lehigh University

1971

CERTIFICATE OF APPROVAL

This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science.

5/17/71
Date

[signature]
Professor in Charge

[signature]
Chairman of the Department
of Industrial Engineering

ACKNOWLEDGEMENTS

The author expresses his appreciation to Professor A. F. Gould for his advice and guidance during the development and preparation of this thesis.

Mr. R. P. Thayer and Mr. D. C. Snyder of the Western Electric Engineering Research Center Staff deserve special thanks for their encouragement and technical assistance. A special thanks to Mr. P. M. Hamm of Western Electric's Allentown Works for his much needed consultation and responsible criticism. The author also extends thanks to the Western Electric Company, Inc. whose sponsorship has made this thesis possible.

My deepest thanks to my wife, Roberta, and my two children, Timmy and Tommy for their patience, encouragement, and understanding during the course of this effort.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The subject considered in this thesis is the development of a predictive model of Operating Variation. A general discussion of Operating Variation and its elements is given along with suggestions for exercising control on the elements.

Several models of Operating Variation are developed each with a varying degree of information required for its application. The employment of a model consists of a two-phase procedure consisting of (a) predict the end-of-month values of the independent variables from their weekly observations and (b) from these end-of-month estimates predict the monthly Operating Variation. In addition, the most significant elements of Operating Variation are determined.

CHAPTER I

INTRODUCTION

The Standard Cost system of accounting is one in which advance estimates are made of the materials, labor, and expenses which will be required to perform operations of manufacture on a given product. A standard can be based on historical data and adjusted for anticipated changes which will make the standard a realistic objective for the period the cost will be used. This standard cost is used as a reference cost with which the actual cost figures may be compared for purposes of analysis to discover variations from the standard. These variations, or differences between the predetermined standard and actual costs, form the basis of study to ascertain the causes of such differences so that in efficiency and waste may be eliminated as far as possible.

Variation can occur in each of the three elements of the standard cost, namely Labor, Materials, and Expense. The total of these variations is sometimes referred to as Operating Variation. For any firm using the Standard Cost system of accounting the amount of Operating Variation is reported to management at the end of each accounting period. Accounting periods may vary between companies, but for the company studied in this thesis the accounting period was one month. However, management does not receive the operating variation results from the preceding month until during the first or second week of the following month because of the time required to collect and analyze the data. Management is aware of the factors used in the calculation of operating variation but it is unknown to accounting and management to what degree these factors actually influence the final value of operating variation.

It is the objective of this thesis to identify the variables which influence operating variation significantly and to develop a model which can be used to predict the monthly operating variation.

CHAPTER II

BACKGROUND AND GENERAL PROCEDURE

The field of mathematical economics, commonly referred to as econometrics, has a rich history of attempts to analyze economic systems or components of an economic system. Allen's[1] text, Mathematical Economics, summarizes past attempts to analyze economic systems by use of classical mathematics. Models developed by economists such as Domar[4], Harrod[9], Hicks[10], Kalecki[14], Phillips[19], and Samuelson[20] represent attempts to describe dynamic economic behavior using a limited number of variables.

The growth of the computer encouraged the use of computer simulation for the analysis of large-scale dynamic systems. Simulation models at the level of the firm include those of Bonini[2], Cyert and March[3], Forrester[6], Hoggatt[12], Nord[17], Packer[18], Kinsley[15], Hicks[11], and Walker[21]. Luedtke[16] has developed a simulation model of a real-world company, specializing in the manufacture of electronic equipment, to analyze the effects of selected variables on the company's overall performance.

The general procedure to be used in formulating a model of Operating Variation is the following:

1. Identify variables
2. Correlation Analysis
   a. Serial
   b. Cross

3. Principal Components Analysis

4. Stepwise Regression Analysis

   a. Analysis of Residuals

      (1) Scatter plot of residuals against independent variables which might seem reasonable to enter the model. These other variables could be new variables or transformations of the old variables.

      (2) Autocorrelation of Residuals.

      (3) Transformations and/or addition of new variables.

      (4) Repeat Step 4.

5. Test model on new data.

There are at least two approaches which can be followed to reach the objectives of this thesis. They are (1) predict the monthly Operating Variation directly from the weekly observations of the independent variables or (2) a two-phase procedure consisting of (a) predict the end-of-month values of the independent variables from their weekly observations and (b) from these end-of-month estimates predict the monthly Operation Variation.

The latter approach is being followed because all the historical data that could be obtained for use in developing a model was end-of-month data. Therefore, to apply the models one must first predict the end-of-month values of the variables required by the model and then enter these quantities into the model and calculate the predicted value of end-of-month Operating Variation. If a model could be developed which used variables on which weekly results were known or could be collected, then as each week of the month passed more information would be known about the variables resulting in a better forecasted end-of-month value which in turn when substituted into the model would give a better predicted value of the month's Operating Variation.

CHAPTER III

DESCRIPTION OF OPERATING VARIATION

General

Operating Variation is incurred when the actual cost of manufacturing a product differs from the standard cost of the product. The standard cost of a product is developed using past history as a foundation, and adjusting for anticipated changes which will make the standard a realistic objective for the period the cost will be used. That is, hours to make the product are updated to reflect improvements in manufacturing methods; yields are changed based on current and anticipated performance; material costs are modified for predicted price trends; expenses are adjusted to reflect changes in their levels, etc.

Operating Variation is divided into three main elements: Labor, Expense, and Material and Other. The objective of this chapter is to define and discuss each of these main elements.

Labor Variation Defined

Fundamentally, any element of variation is merely the difference between the actual cost incurred and the corresponding standard cost recovered. If the Labor element of the Standard Cost gives a Labor Recovery of $100 for a given operation, and the actual cost of Labor incurred for that operation is $95, a variation of $5 has been incurred. In this instance the variation is a profit since more was recovered than spent. If,

FIGURE 1

ANALYSIS OF DIRECT LABOR

1.	Beg. Inventory - Base Hours	3319
2.	End. Inventory - Base Hours	3637
3.	Change In Inventory	318
4.	Base Hours In Output	7579
5.	Base Hrs. In Production (L3+L4)	7897
6.	Non-Base Hrs. Rec. (Own)(% X L5)	3641
7.	Total Bulletin Hrs. Rec. (L5+L6)	11538
8.	Hours Worked on K-Order	9555
9.	% Efficiency Unadj. (L7 L8)	120.8
10.	Total Hours Chg. - Cost Reduction	60
11.	Total Hours Chg. - Other	209
12.	Total Adj. Bull. Hrs. Rec. (L7+L10+L11)	11269
13.	% Efficiency - Adj. (L12 L8)	117.9
14.	Credit Hrs. Rec. (L7+ & Bull. Inc.)	13180
15.	Credit Hrs. Earned (L8+OR - % Earned)	11839
16.	Avg. Bull. Rate in Std. Cost (L19+L14)	2.262
17.	Avg. Act. Base Rate Earned (L20+L15)	2.387
18.	Variation in Rates (L16 - L17)	.125
19.	Dir. Labor Recovered (Sep Detail)	29803
20.	Dir. Labor Earned (Labor Run)	28261
21.	Variation Due To:	
22.	Chgs. - Cost Red. (L10+Bull.Inc.) XL16	156
23.	Chgs. - Other (L11+Bull.Inc.) X L16	540
24.	Hrly. Rates Diff. From Bull (L15 X L18)	1480
25.	Daywork & Non-Base Effc'y - Other (L26 - 22 - 23 - 24)	2326
26.	Total Variation (20 - L19)	1542

however, the actual cost had been $105, there is still a variation of $5, but in this case it would be a loss.

The Calculation of Direct Labor Variation

The basic tool used by the cost accountant in this analysis or calculation of Direct Labor Variation is a form similar to the form headed "Analysis of Direct Labor" in Figure 1. An understanding of this form is necessary to the understanding of Direct Labor Variation.

The following paragraphs provide an analysis of the various entries which are made on this form:

Line 1 - Beginning Inventory - Base Hours - The previous month's inventory converted to Base Hours. The information is obtained from the shop supervisor or from a tabulation run. Once this number has been established it can be carried over to the next month by checking the previous month's accounting records.

Line 2 - Ending Inventory - Base Hours - The current month's inventory converted to Base Hours. The information is obtained from shop supervisor or from a tabulation run.

Line 3 - Change in Inventory - Difference "+" or "-" between beginning inventory and ending inventory, stated in Base Hours.

Line 4 - Base Hours in Output - Physical shop output for the current month converted to Base Hours. Information comes from a tabulation run of production.

Line 5 - Base Hours in Production (L3 + L4) - Total goods the particular shop produced and shipped during the month and goods produced during the month that remained on the floor in the form of inventory. This total is expressed in Base Hours of Production.

Line 6 - Non-Base Hours Recovered (Own) (% x L5) - The Non-Base % which cost bulletin allows to each labor center multiplied by the "Base Hours in Production."

Line 7 - Total Bulletin Hours Recovered (L5 + L6) - The Base Hours Recovered plus the Non-Base Hours Recovered which gives the total Hours Recovered for the month.

Line 8 - Hours Worked on K Order - Information comes from a "Labor Report" which applies to all K Orders. The tabulation run is a summarization of the weekly "Operating Labor Distribution" which tells how many direct hours and dollars were charged to each K Order for the current month.

Line 9 - % Efficiency Unadjusted (L7 ÷ L8) - The total Bulletin Hours in Production divided by Hours worked on K Order. This is unadjusted efficiency because the Standard Bulletin figures are used rather than adjusted Current Bulletin figures.

Line 10 - Total Hours Changed - Cost Reduction - These hours are stated in Base Hours saved per 100 units produced. To find total hours charged to Cost Reduction for the current month the number of hours saved is multiplied by the number of units shipped during the month. All Cost Reduction cases are analyzed and kept by Accounting in a cost reduction case book. The hours saved in making a specific unit are shown in this cost reduction case book. The output of the particular unit is found in the production report. The hours saved per 100 units made are then multiplied by the monthly output of the unit to give the total hours of Cost Reduction. The Non-Base factor is taken into account in the cost reduction case book.

Line 11 - Total Hours Changed - Other - All other rate changes which have resulted from some effort other than cost reduction. Total changes in Rate for the current month come from a tabulation run issued by Cost Bulletin. Total Rate Changes are issued in Base Hours. The Total Base Hour changes in rates for the month minus Cost Reduction Changes gives the "All Other" total.

Line 12 - Total Adjusted Bulletin Hours Recovered - (L7 + L10 + L11) - The Adjusted Bulletin Hours Recovered here are based on the current Bulletin Rates. All changes in Recoveries from the Standard Bulletin Hours are taken into account to arrive at Adjusted Bulletin Hours Recovered.

Line 13 - % Efficiency - Adjusted (L12 ÷ L8) - This represents the current month adjusted to the Current Bulletin (adjusted for the changes which have been made since the Standard Bulletin was established; i.e. change in rates).

Line 14 - Credit Hours Recovered (L7 + Bulletin Incentive) - In order to get the Bulletin Incentive here a composite rate must be found. This is because Daywork Hours are included in these total Bulletin Hours Recovered in Line 7; therefore, Daywork Hours must be included in figuring the Bulletin Incentive rate to be applied. The following method is used to determine the composite Incentive Rate:

(1) Base Hours (Piecework) are multiplied by Incentive %; i.e. 89,200 x 15.1% = 13,469 (Incentive Hours)

(2) Non-Base Hours (piecework) are multiplied by Incentive %; i.e. 48,257 x 15.1% = 7,287 (Non-Base Daywork Hours are not multiplied by the incentive since no incentive is given for Daywork).

(3) Total Hours (Base and Non-Base with Non-Base including Daywork Hours) are calculated; i.e. 89,200 + 52,182 = 141,382.

(4) Total Incentive Hours for Piecework are found; i.e. 13,469 + 7,287 = 20,756.

(5) Total Incentive Hours are divided by Total Base and Non-Base Hours to give composite rate; i.e. 20,756/141,382 = 14.68.

Line 15 - Credit Hours Earned (L8 + or - % Earned) - Piecework dollars earned from the labor run are divided by Total Base Dollars paid for the month. This procedure gives the % Piecework earned. This percentage (100% + % Earned) is then multiplied by line 8 to convert the % to Credit Base Hours Earned.

Before completing Lines 16, 17, and 18, Lines 19 and 20 must be calculated:

Line 19 - Direct Labor Recovered (Separate Detail) - Information for this line is obtained from a tabulation run. Base Hours in

Output plus or minus change in inventory gives Base Hours in production. These production hours multiplied by the Direct Labor Costing Rate by K Order equals Direct Labor Recovered.

Line 20 - Direct Labor Earned - The Total Direct Labor Earned is equal to total Direct Dollars Earned plus the Piecework Dollars Earned.

Line 16 - Average Bulletin Rates in Standard Cost (L19 ÷ L14) - This is the average Recovery Rate of Direct Labor based on the Standard Bulletin.

Line 17 - Average Actual Base Rate Earned (L20 ÷ L15) - Average actual rate paid to the employees for the current month.

Line 18 - Variation in Rate (L16 - L17) - Difference between Bulletin Rate and actual rate paid to the employees for the current month.

Line 22 - Changes - Cost Reduction - L10 (Total Credits for Cost Reduction changes including Daywork hours) + Bulletin Incentive x Line 16 - The Bulletin Rate here is actually the Composite Incentive Rate. Line 10 plus the composite rate equals credit hours for cost reduction changes. This number times the average actual Bulletin Rate gives total variation due to cost reduction changes made.

Line 23 - Changes - Other (L11 + Bulletin Incentive) x L16 - Rate changes "other" plus the Composite Incentive Rate equals credit hours for other reduction or increases.

Line 24 - Hourly Rates Different from Bulletin (L15 x L18) - Difference between Average Hourly Rate recovered in Bulletin and Actual Average hourly rate paid to the employees for the current month.

Line 25 - Day Work and Non-Base Efficiency - Other (L26 - L22 - L23 - L24) - All variation other than Cost Reduction Variation (i.e. Due to a change in methods or a group's inefficiency, actual Non-Base charges for a month may be more than allowed for in the Bulletin).

Line 26 - Total Variation (L20 - L19) - Total of what was paid the group versus what the group recovered during the month.

Analysis of the calculations that were just made indicates that Direct Labor Variation is concerned with fundamental differences between current conditions and the conditions anticipated in the bulletin - new layouts and new Methods of Manufacture resulting in changes in base hours, differences in the use of Non-Base and Daywork, and perhaps the most fundamental of all, the difference between the rates of pay of the direct employees. The first two items, Manufacturing Changes and the use of Non-Base and Daywork, are controllable by the shop supervision. The third category is covered by union contract and upper management policy.

Indirect Labor Variation

For the elements of Indirect Labor, of which the organization or department has control, the Indirect Labor incurred and recovered for the current month is obtained from a tabulation run. The actual amount of Indirect Labor paid each month is divided into the various categories to which payments were made for the current month.

This tabulation run also lists the amount of Indirect Labor recovered according to category based upon the Labor Increment in the Standard Bulletin. Each of the categories make up a certain part of the Labor Increment; based on its specific percentage of the Increment, a certain amount of the Indirect Labor Recovered is allocated to each category (for example, if the Labor Increment rate for an operation is 35.5% and Overtime Allowance accounts for 1.53% in this rate, then 1.53 is 4.31% of 35.5, and therefore 4.31% of total Indirect Labor Recovered will be allocated to Overtime Allowance).

The variation is the difference between Incurred and Recovered for the current month. This is simply a comparison, by total and by categories, of the actual Indirect Labor paid and the actual Indirect Labor recovered based on the Bulletin Labor Increment.

Expense Variation

Of the three main Cost Elements, Expense is probably the most diverse of these Cost Elements. Expense has many forms and is ever present; for that reason, Expense is the most difficult Cost Element to control. Historically, Expense has been subdivided into the following main categories:

(1) Salaries and Wages

(2) Changes and Repairs

(3) Supplies

(4) Product Conformance Cost

(5) Other Direct Expense

(6) Depreciation, Taxes and Insurance

(7) Services Rendered and Received

So that these terms are clearly understood, a brief description of each is given in the following paragraphs:

Salaries and Wages - Payments for standard and overtime hours worked by expense employees including supervision. This includes absences, vacation, and holiday salary expense for these employees, and also wages of hourly rated employees charging time to "A" Orders.

Changes and Repairs - Changes cover any modification to building, building service facilities, machinery, small tools and furniture and fixtures to improve performance or quality, reduce costs or eliminate an accident hazard. The everyday word for "Repairs" is Maintenance. Charges to this account include expenditures for work performed by the Plant Maintenance Organization or by other Works Service Employees against "C" Orders classified to departmental expense. These charges are obtained by summarizing for each plant and expense order the labor, labor increment and loading value of charges from assignment cards, plus the value of material drawn from storerooms and the value of non-stock material purchased from Outside Suppliers or Other Works.

Supplies - This category covers (1) stationery, (2) blueprints, (3) fuel, (4) water, gas and power purchased, (5) packing materials, (6) expense tools and other expense supplies. Charges to this account include expenditures for material used in the shop drawn from storeroom on expense tickets or payments for non-stock material purchased from supplier not included as part of the material cost of the product.

Product Conformance Cost - This category is comprised of expense incurred in junking, converting, repairing, replacing or other disposition of merchandise (and a portion of the material used in plant and expense effort) which is defective, obsolete or which becomes unusable. In Electron Device manufacture, Product Conformance Cost are treated as a separate element of cost.

In the manufacture of products which have near perfect yields, adequate information is available from the three basic cost factors of Labor, Expense, and Material. However, in the manufacture of Electron Devices, where dimensions are critical and the components are fragile, yields are not at a very high level. This is inherent in designs where minaturization and exact electrical parameters are required and any flaws due to quality of materials or errors in assembly will cause the product to fail the various process checks during assembly or at the final test stage. By the very nature of assembly, repair of Electron Devices is the exception rather than the rule, and the cost of defective work becomes a significant item that must be recovered in the cost of the finished product. It is therefore imperative that defective work be measured against the yield capabilities established by the Engineers and built into the Standard Cost. This is accomplished by including the cost of expected defective production as a separate Expense item instead of allowing additional Labor, Expense and Material in the total cost. Following is a simplified one-operation example of an item costed both ways:

3 Element Basis/100

	Base Hours	Labor Value	Load Value Reg.	Load Value Shrink	Mat'l.	Total Cost
Good Cost	5.78	$25.02	35.98	xx	50.15	$111.15

4 Element Cost/100

	Base Hours	Labor Value	Load Value Reg.	Load Value Shrink	Mat'l.	Total Cost
Good Cost	5.25	$22.69	32.67	13.32	42.47	$111.15
Shrinkage Allow.	.53	2.33	3.31	xx	7.68	13.32
Total Gross Prod.	5.78	25.02	35.98	13.32	50.15	124.47
Less Shrink Prod.	.53	2.33	3.31	xx	7.68	13.32
Good Prod.	5.25	$22.69	32.67	13.32	42.47	$111.15

Under the three element cost system the allowances for defectives have been included in the three basic elements. Any significant change in yields will be reflected in Efficiency and therefore Labor Variation, as well as Loading and Material Variation, because the total gross allowance will be recovered for every 100 good items produced. Under the 4 element system, for every 100 good items produced, the allowances for Good Cost only will be recovered for hours, and each basic element of cost, plus $13.32 for allowed defectives. The actual defectives produced are also evaluated in terms of base Hours, Labor Load & Material. If the actual defectives matched the Bulletin allowance the evaluated cost would be $13.32 and Product Conformance Cost would be stated as $1.00 of Expense per Dollar of Recovery. Any variation from Bulletin allowance of actual defective production would result in a Product Conformance rate of (+ or -) $1.00, but would not distort Efficiency, nor Labor; Other Expense; and Material Variation, because the recoveries for defective work are based on the actual junking or product.

<u>Services Rendered and Received</u> - Services Rendered are credits to Expense which includes the cost of services furnished to resident organizations. Examples of Services Rendered are rent for floor space, house services, and

personnel loaned. Services Received are debits to Expense. Services Received includes such items as Cornet charges billed to a plant for its' portion of Cornet usage.

Other Direct Expense - As the name indicates, this is the "catch all" for the balance of the operating expenses. Some of the principal items included here are (1) security accruals on expense employee's salary expense (2) rental on equipment, (3) telephone and telegraph service, (4) travel and living, (5) local moving expense, and (6) shop work on cost reduction and other development cases.

Expense variation is determined by comparing the total expense dollars charged to the five major categories of expense (i.e., Salaries and Wages, Repairs, Supplies Expense, Product Conformance Cost, and Other Direct) to the loadings recovered for those expenses. The Bulletin level of costs has been computed in terms of dollars per base labor hour of work produced in the load center involved. Accordingly, total production is used as the base to which these Bulletin cost factors are applied to get the total Bulletin level of costs recovered. This is commonly called the Loading Recoveries. This is the standard value to which actual charges incurred are compared to identify the difference or variation.

Loadings are a means of assessing Manufacturing Expense into the cost of the product. This is accomplished in this company by the establishment of a loading rate which can be applied to Base Hours representing product shipped or in inventory on the floor. To determine the total loadings recovered in production by a particular department or load center, each Base Hour that is recovered in production is extended by the total dollar value of the loading rate. This total must then be allocated to the proper class of expense. This is done by applying to the various breakdown of expense a percentage applicable to that particular class after transfer to Headquarters their portion of the Loadings. In the discussion of variation in expense and also in labor, it was found that the only means of offsetting the costs incurred in the operation of the Works is by the recovery obtained through the application of the standard costs to the productive efforts. The company provides paid holidays and vacations up to five weeks for eligible employees, depending on length of service. It is also obvious that when Direct Employees are on vacation, or the plant is shut down for a holiday, there is no productive effort to offset the expenses that are continually being incurred. Whether at work or on vacation, the employees will still be paid; and whether the plant is in operation or shut down, tax liabilities and other elements of fixed charges are still being incurred. If steps were not taken to provide recovery for vacation and holiday costs, those months in which they occur would reflect significant changes in variation from other months of the year, merely because costs were being incurred for which there was no possibility of productive effort to offset them. Therefore, a system for equalization of these vacation and holiday costs by withholding in reserve a certain portion of labor recovery and loading recovery obtained from normal production has been established. This recovery is used to offset costs in those periods in which there is no production. The basis for the equalization calculation is the relationship of the labor recovered, as applied to the total annual cost of vacations and holidays.

The causes of variations from standard in expense, whether profit or loss, are many and varied. In Salaries and Wages, there are changes in basic rates of pay, just as in Direct Labor, or more or less overtime than had been anticiapted. Product conformance cost can fluctuate due to the efficiency or inefficiency of the shop operation, which would produce more or less scrap. Changes in design necessitating disposal of parts in process could adversely affect this item. Acquisitions or disposal of machinery can affect Depreciation charges; also the company, as is any property owner, is subject to changes in the tax rate structure.

Acquisitions, or conversely, lack of acquisitions, of machinery can affect changes and repairs expense; new machinery ordinarily will not require as much repair as older equipment.

There are as many reasons for changes in Other Direct Expense as there are subclasses within the category. These are only a few of the many causes of variation in expense.

Some of these expense categories are within each supervisor's area of action. Listed below are some of the key items which, by close observation, can bring better operating results.

Salaries and Wages - Assuming that each supervisor is observing the Expense Direct Ratio for employees, the second area of limiting this expense lies in the supervisor's control of the overtime worked by his expense people. It is, of course, recognized that overtime has been the safety valve which enables some flexibility around the E/D ratio control. But overtime, too, has budgetary limits which have to be observed.

Supplies - The supervisor's authority to draw expense supplies from the storeroom places him squarely in the position to see that only the proper quantities of supplies are requisitioned; and secondly, that these supplies are properly and fully consumed before additional supplies are drawn.

Product Conformance Cost - Shop supervisors can minimize this expense by keeping a closer watch on maintenance procedures and minimize the use of tools, fixtures or machinery which are out of adjustment or are too worn for acceptable production standards.

Other Direct Expense - Because of the wide variety of the expenses included in this category, no pattern can be offered for minimizing this expense by supervisory action except to suggest that wherever the supervisor can exercise control, he should make a consistent effort to use restraint in such expenditures.

Material and Other Variation

The broad heading of "Material and Other Variation" covers all of those operating variations which are incurred in the manufacture of the product which do not properly fall in either the Labor or Expense categories. The subject of Material Variation is an important one because it concerns profit and loss to the Company. To the extent that the company is able to convert raw materials into finished goods at an actual cost that is less than the Standard Cost allowed in the Bulletin, they earn profits. If, on the other hand, the actual cost to manufacture exceeds the Bulletin Standard, then losses are incurred against the Standard. Material Variation should not be confused with Material Price Variation since the latter is in no way the responsibility of the Shops. Material Price Variation is the profit or loss which results when materials are bought from outside suppliers at prices which differ from the standard costs. This Variation is charged or credited to Non-Operating Variation; and because the profit or loss is usually the result of changing Market Prices, and therefore out of Shop control, it does not get published in the Monthly Operating Variation Report.

Material Variation, as has been stated, occurs when the value of material used in production differs from the value of material provided for in the standard cost of the product. The material shown on the Cost Form "Cost Bulletin Input Details", is the material that was listed on the latest issue of Engineer of Manufacture stock list at the time the Bulletin was revised. The costs per hundred figures are the standard costs for the various component parts. The product of the quantities called for on the E of M stock list and the standard cost per hundred is calculated to obtain "the materials cost per hundred". The total of these values, the material cost per hundred, appears at the bottom of the Bulletin Cost Record. When this total is added to the total labor value and the total load value, the result is the Standard Bulletin Cost per hundred of the unit produced.

The key thing to note in this brief explanation of how a Bulletin Cost is made up is this: The Standard Cost of the unit or of any code, once it has been established, becomes fixed and will not ordinarily change for the duration of the Bulletin. Every time 100 units of a particular product are shipped to Merchandise, Merchandise is billed the amount shown on the Input Form (or the MD cost if the product is multi-sourced, see Material Variation) for that product. If all and only the components shown on the Bulletin Cost Record are used, and in the exact quantities shown, then when Merchandise is billed, the value of the material actually shipped is recovered. If, on the other hand, the value (at Standard Cost) of the material actually used differs from the value shown on the "Cost Bulletin Input Details," then Material Variation is incurred.

Analysis of Material Variation

The "Material and Other" section of the Variation Report is divided into six separate categories:

(1) Material - Cost Reduction

(2) Material - Other

(3) Local Versus Manufacturing Division Cost

(4) Inventory Difference

(5) Development Expense

(6) Other

In the following paragraphs, definitions and methods for calculating each category will be given. However, since there may be exceptions to any method that is presented, no uniform work sheet is used in determining these different variations.

Material - Cost Reductions - Represent the difference between the value of material included in the Bulletin Standard Cost and that included in subsequently issued Manufacturing Layouts, provided that the change is a result of an actual cost reduction case initiated by the Engineer of Manufacture. This line, in general, is the result of the variation created by parts substitution or deletion as a result of closed cost reduction cases. To determine variation, the monthly output of the unit is multiplied by the cost reduction savings per hundred units produced. The cost reduction savings come from the "Closed Clerical Cost Reduction Case" book and the output quantity from the output tabulation run.

Material - Other - Represents other parts changes current versus bulletin stock list. These are changes other than cost reduction cases which have resulted in variation. These changes may come about as a result of employee's suggestions or errors, omissions and corrections in the Standard Bulletin (i.e.; The amount of a unit needed to produce the product might have been overstated in the Bulletin.) The variation for this line can be found by subtracting "Material Variation - Cost Reduction" from "Total Material Variation." "Total Material Variation" is stated on the output tabulation run.

Local Versus Manufacturing Division Cost - Represents the difference between this Plant's or Works' local and M. D. cost used for billing purposes. Very often the same items that are manufactured at this Works' are manufactured at more than one Works' location within the Company. Each Works' will, of course, establish its own local cost on these items. The Company, however, will want only one cost to be used in billing to Merchandise. Therefore, one Works' local cost will be designated as the Manufacturing Division Cost, commonly referred to as M. D., in most instances this will be the lowest of several costs; however, if the Works having the lowest cost is only a relatively minor producer of the item, Headquarters may designate a Works which is a major manufacturer of the item as M. D. even though its cost is higher than that of the other Works .

<u>Inventory Difference</u> - Represents the difference in book value of Inventory and evaluated physical count. The actual physical count of Inventory is taken at the end of September each year. Up to that time, Inventory Difference is estimated for the year ending; then, each month (until September when actual inventory is taken) this figure is prorated so that the effect is equalized over the entire year in which it accumulated.

<u>Development Expense</u> - Represents expenses authorized by Headquarters for major development cases and is billed to their books. This positive variation in Material and Other Variation is offset as a negative variation in Expense Variation, with no effect on local Works' Variation.

<u>Other Variation</u> - Represents a miscellaneous catch-all. This category takes into account any other Material

Variation which would not be explained under any of the above major categories. For example, a cause could be the reissuing of the E of M layout for a part that was formerly purchased from an outside supplier or drawn from another Works'. In these cases, the local standard cost is based on the purchase cost or on the standard cost of the Works from which the part was drawn. If the new E of M layout calls for manufacture of the part in ones' own Shops, a special recovery cost is worked up on a Bulletin Cost Record Form detailing the local cost of manufacture. Differences between the standard cost and the special recovery costs are categorized as variation due to differences between billing and recovery.

These are sources of the "Material and Other Variation" figures which appear each month on the Variation Report. Great care is exercised in accounting for this variation since it reflects the profits and losses of the Company in a manner that makes them traceable to the organizations involved.

The question may be raised at this point: Since in a very large measure some of these elements are beyond individual Shop control, why are the Shops held responsible for them? The answer is that the Shops are held responsible for them only to the extent that they are able to exercise control over them.

It may well be that a particular Shop can exercise very little control over some forms of variation, but it should be remembered that departmental variation becomes a part of the divisional variation and finally of the Works total variation. The controls, therefore, which Lower Management may be unable to provide are often available at higher levels. To take action, however, Upper Management will need to be informed, by those closer to the job, as to the nature or type of variation that is occurring and its cause.

In discussing the control of Material Variation, one is primarily interested in those controls with which Line Supervision is directly concerned. Some of these controls are as follows:

(1) Adhering to Layout Allowances - The Material Value of the Standard Cost of any unit is based solely on the layout allowance for that unit. Any deviation from the layout, no matter how slight, is a source of Material Variation. If for any reason a layout allowance is not being followed, the responsible Cost Unit should be notified so that the resulting variation may be properly accounted for.

(2) Proper Accounting for Scrap Material - There are two classes of scrap material; namely, Process and Residue scrap. Process is that material which is normally used as component material in a unit, but which for various reasons has become unusable and must be

scrapped. This material must be accounted for when junked in order to relieve the Shop investment. Residue scrap is material which is provided for as allowance in the Standard Shop Cost of the product. The Line Supervision should guard against any possibility of process material being junked as residue. Process and residue scrap should be segregated physically to eliminate any possibility of mixing the two types.

(3) Adherence to Cost Reduction Cases - All cost reduction cases should be strictly followed as to both the reduction itself and the effective date.

There are a number of types of variation which do not appear in the Operating Variation Report because they are beyond Shop control. These are referred to as Non-Operating Variations. They include such items as interim cost changes, purchased material-price variation and variation due to subcontracting work normally performed by the Shop. They are mentioned here because these are closely related to Material Variation, but they are not actually a part of it.

CHAPTER IV

MODEL DEVELOPMENT

In this chapter several models for predicting Total Operating Variation will be developed. The difference between the models is the amount of data needed by each model. The amount of data required influences the accuracy of the model. Therefore, which model to be used is an economic decision balancing the cost of collecting data and the degree of accuracy needed.

Model of Operating Variation Using Major Variations

Since Operating Variation is divided into Labor, Expense and Material and Other Variations, an obvious model is:

$$\text{O.V.} = \text{Labor Var.} + \text{Expense Var.} + \text{Material and Other Var.}$$

Although this model will predict Operating Variation and is easy to apply, a large amount of data is required before the model can be applied. The amount of data may be reduced by using either of two abbreviated forms of the model, namely,

$$\text{O.V.} = 303.90 + .919\ (\text{Expense Variation}) \qquad (4\text{-}1)$$

or

$$\text{O.V.} = 9.09 + 1.19\ (\text{Expense Variation}) + 1.18\ (\text{Material and Other Var.}) \qquad (4\text{-}2)$$

TABLE 1

Correlation Coefficients of Operating Variation And Its Elements

Total Labor Var.	1.00			
Expense Var.	.412	1.00		
Material and Other	.076	-.406	1.00	
Operating Variation	.709	.803	.159	1.00

The model given by (4-1) has a multiple correlation coefficient (M.C.C.) of 0.803 and a F-ratio of 58.01 while the other model given by (4-2) has a multiple correlation coefficient of .962 and a F-ratio of 194.40.

One can conclude that Expense Variation is the most significant factor of Operating Variation with Material and Other Variation and Labor Variation the next most significant respectively. Therefore, for purposes of predicting and controlling Operating Variation the priority should be Expense, Material and Other, and Labor Variation respectively. However, this may only be true of the plant being studied and should not be applied to other plants employing the Standard Cost system without further investigation.

Under the assumptions of linearity, Expense Variation has the highest degree of association with Operating Variation. Labor Variation is slightly less than Expense Variation in its correlation with Operating Variation and Material and Other Variation.

A further reduction in the amount of data required could be recognized if the principal components of each of the variations were known.

Model of Expense Variation

As was discussed in the previous chapter Expense Variation is subdivided into the following categories of variations.

(1) Salaries and Wages

(2) Changes and Repairs

(3) Expense Supplies

(4) Product Conformance

(5) Total Other Direct Expense

(6) Depreciation of Plant

(7) Depreciation of Small Tools

(8) Depreciation of Furniture and Fixtures

(9) Taxes and Insurance

Applying principal component analysis the above variations pointed out a high intercorrelation between the variables Salaries and Wages, Depreciation of Plant, and Taxes and Insurance. There also existed a high correlation between Changes and Repairs and Depreciation of Small Tools. This could be interpreted as meaning that as plant assets increase, the amount of taxes and insurance paid are also increased. In addition, an increase in salaries and wages occurs indicating an increase in expense people.

Stepwise regression was used to obtain the following model of expense variation.

$$\text{Expense Variation} = 5.22 + 1.45\,X(1) + 1.32\,X(2) + 1.32\,X(3) + 0.98\,X(4) \qquad (4\text{-}3)$$

where

X(1) = Salaries and Wages Variation

X(2) = Expense Supplies Variation

X(3) = Product Conformance Variation

X(4) = Total Other Direct Expense

TABLE 2

Correlation Coefficients of Expense Variation

Variable	1	2	3	4	5	6	7	8	9	Exp. Var.	O.V.
1	1.00										
2	.087	1.00									
3	-.463	.247	1.00								
4	-.089	.130	-.204	1.00							
5	.309	-.061	-.298	-.128	1.00						
6	.634	-.315	-.413	.140	.236	1.00					
7	.209	.740	.021	.101	-.166	-.256	1.00				
8	.481	.288	-.296	.464	-.017	.449	.549	1.00			
9	.721	-.115	-.445	.006	.145	.796	.007	.433	1.00		
Exp.Var.	.710	.401	-.185	.308	.543	.532	.314	.598	.500	1.00	
O.V.	.492	.544	-.019	.458	.104	.436	.484	.608	.393	.803	1.00

Variable No.	Quantity
1	Salaries and Wages
2	Changes and Repairs
3	Expense Supplies
4	Product Conformance
5	Total Other Direct Expense
6	Depreciation of Plant
7	Depreciation of Small Tools
8	Depreciation of Furniture and Fixtures
9	Taxes and Insurance

This model has a multiple correlation coefficient of 0.963 and a F-ratio of 93.2.

With the addition of a term involving Changes and Repairs Variation the multiple correlation coefficient was increased to 0.983 and the F-ratio to 162.5. This model was of the form:

$$\text{Expense Variation} = -8.30 + 1.33\ X(1) + 1.03\ X(2) + 1.18\ X(3) + .98\ X(4) + .88\ X(5) \qquad (4\text{-}4)$$

where

$X(5)$ = Changes and Repairs Variation and $X(1)$ through $X(4)$ are the same as in the previous model.

Correlation coefficients between the variables comprising Expense Variation are given in Table 2.

Model of Labor Variation

Labor Variation is composed of Direct and Indirect Labor Variation. As can be seen from Table 5, Direct Labor Variation correlates more closely with Total Labor Variation than Indirect Labor although each are of approximately the same magnitude. Thus, if one would observe the magnitude and trend of Direct Labor Variation he would have approximately the same information about the Total Labor Variation. The model relating Direct Labor Variation and Total Labor Variation has the following form.

$$\text{Labor Variation} = -21.58 + .941\ (\text{Direct Labor Var.}) \qquad (4\text{-}5)$$

The above model has a M.C.C. of .786 and a F-ratio of 51.61.

TABLE 3

COMPONENTS OF DIRECT LABOR VARIATION

1. Hourly Rate Paid Different from Standard
2. Changes in Rates - C.R.
3. Changes in Rates - Other
4. Other Direct Labor Variation

TABLE 4

COMPONENTS OF INDIRECT LABOR VARIATION

1. Overtime Allowance
2. Night Bonus
3. Wage Incentive Allowance
4. Vacation and Holidays
5. Security Accrual
6. Personal, Sickness, and Disability Absences
7. Other Indirect Labor Variation

TABLE 5

Correlation Coefficients of Total Labor Variation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Hourly Rate Pd. Diff. From Std.	1.00													
Changes in Rates-C.R.	-.700	1.00												
Changes in Rates-Other	-.373	.392	1.00											
Other Direct Labor Var.	.088	.165	-.066	1.00										
Overtime Allowance	.106	-.089	-.334	.434	1.00									
Night Bonus	-.072	.114	-.062	.116	.590	1.00								
Wage Incentive Allowance	.069	.019	.001	-.353	-.632	-.315	1.00							
Vacation and Holidays	.125	-.250	.034	-.281	-.355	-.508	.186	1.00						
Security Accrual	.128	-.020	.088	.329	.788	.650	-.448	-.198	1.00					
Personal, Sickness, & Dis. absences	.069	-.072	-.017	-.174	-.401	-.254	.170	.429	-.304	1.00				
Other Indirect Labor Var.	.034	.009	.070	-.246	-.015	.340	-.211	-.321	.054	-.035	1.00			
Direct Labor Var.	-.114	.458	.859	-	-.170	-.016	-.056	-.092	.217	-.057	.007	1.00		
Indirect Labor Var.	.229	-.197	-.132	-	.529	.445	-.309	.297	.698	.348	.103	-.079	1.00	
Total Labor Var.	.046	.260	.635	.327	.187	.263	-.239	.107	.615	.168	.070	.786	.555	1.00

More insight into Labor Variation may be gained by investigating the components of Direct and Indirect Labor Variation. The components of Direct and Indirect Labor are given in Table 3 and 4 respectively.

The correlations coefficients between Direct Labor Variation, Indirect Labor Variation, and their components can be observed from Table 5. Changes in Rates due to Changes Other than Cost Reduction correlated the highest with Direct Labor Variation while Security Accrual Variation correlated the highest with Indirect Labor Variation.

Using the components of Indirect and Direct Labor Variations, the following models of Total Labor Variation were obtained.

$$\text{Total Labor Var.} = .716 + 2.05\,X(1) + 1.24\,X(2) + .814\,X(3) + .935\,X(4) \tag{4-6}$$

$$\text{Total Labor Var.} = 8.19 + 1.94\,X(1) + 1.17\,X(2) + .907\,X(3) + .921\,X(4) + 1.17\,X(5) \tag{4-7}$$

where

X(1) = Security Accrual Var.

X(2) = Personal, Sickness, and Dis. Absences Var.

X(3) = Changes in Rates Other Var.

X(4) = Other Dir. Labor Var.

X(5) = Hourly Rate Paid Diff. from Std.

The model given by (4-6) has a M.C.C. of .95 and a F-ratio equal to 67.43. The model given by (4-7) has a M.C.C. of .96 and a F-ratio of 72.97. By the fact that three of the five variables in (4-7) are components of Direct Labor Variation, the dependence of of Total Labor Variation on Direct Labor Variation is further pointed out.

Model of Material and Other Variation

Material and Other Variation is subdivided into the following categories of variations:

1. Material
2. Local vs. M.D.
3. Billing vs. Recovered Cost
4. Inventory Difference
5. Development Expense

It can be seen from Table 6 that Material and Other Variation is composed almost entirely of Development Expense. The correlation is so high that the two quantities could be interchanged. This is reasonable since the plant investigated is mainly a pilot site for the introduction of semiconductor and thin-film devices. Material Variation is the next most closely related variable with Material and Other Variation.

TABLE 6

Correlation Coefficients of Material and Other Variation

	1	2	3	4	5	6
Material	1.00					
Local vs M.D.	-.138	1.00				
Billing vs.Recovered Cost	-.244	-.097	1.00			
Inventory Difference	.034	-.101	-.116	1.00		
Development Expense	.112	.174	.060	-.404	1.00	
Material & Other Variation	.424	.190	-.020	-.351	.944	1.00

Mat'l and Other Variation = 24.03 + 1.05 (Dev. Exp. Var.)

(4-8)

The model given by (4-8) has a M.C.C. of .944 and a F-ratio of 259.74. Addition of Material Variation to the above model produced a model which almost completely explained Material and Other Variation. This model is given in (4-9).

Mat'l and Other Var. = -2. + 1.01 (Dev. Exp. Var.)

+ .919 (Mat'l Var.) (4-9)

This model has a M.C.C. of .997 and a F-ratio of 2300.63.

<u>Model of Operating Variation Using Sub-Variations</u>

In the previous models, the most significant variables of each of the three kinds of variation were determined. Applying regression analysis to these variables, the following models were obtained.

$$O.\ V. = -75.71 + .25\ X(1) + 3.55\ X(2) + 3.95\ X(3) + 3.53\ X(4) \quad (4\text{-}10)$$

and

$$O.\ V. = 28.82 + .41\ X(1) + 3.58\ X(2) + 3.81\ X(3) + 3.49\ X(4) + .56\ X(5) \quad (4\text{-}11)$$

where

X(1) = Salaries and Wages Variation

X(2) = Hourly Rate paid different from Standard Variation

X(3) = Changes in Rates - Cost Reduction Variation

X(4) = Changes in Rates - Other Variation

X(5) = Expense Supplies Variation

The model of Operating Variation given by equation (4-10) has a M.C.C. of 0.934 and a F-ratio of 49.97. The model given by equation (4-11) has a M.C.C. of 0.946 and a F-ratio of 47.44. The variables contained in these models are all components of either Expense Variation or Labor Variation. These Variations were the two most highly correlated with Operating Variation.

These two models also give models of Operating Variation which require less data to be collected. Instead of being required to know the value of each of the main variations or even the values of their components, now data pertaining to only five variables are needed.

Other models of Operating Variation were obtained by adding more variables. Further insight into the prediction of Operating Variation is gained by noting the order in which the Stepwise Regression procedure added variables to the model given by (4-11). The order of addition, the M.C.C. of the model and the model's F-ratio is given in Table 7.

From Table 7, one can see that with the addition of more variables, the model is improved. It also aids in assigning priorities for further data collection, if one wishes to improve the model. It is also interesting to note that of the twenty-five categories of variations included under the main variations, it is

TABLE 7

Order of Addition of Variables to (4-9) And Their Contribution

Order of Addition	Sum of Squares	D.F.	Mean Square	F-Ratio of Variable	R^2 of* Model	F-Ratio* of Model
P. C. Conformance Var.	9193.260	1	9193.260	15.50	.952	43.49
Personal,Sickness,Dis.,Absence Var.	8683.166	1	8683.166	14.64	.957	41.24
Total Other Dir. Exp. Var.	9602.084	1	9602.084	16.19	.964	41.33
Development Exp.	17692.841	1	17692.841	29.83	.976	53.38
Changes and Repairs Var.	15649.009	1	15649.009	26.38	.986	81.36
Material Var.	3417.379	1	3417.379	5.76	.988	84.55
Changes in Rates-C.R. Var.	-1586.481	-1	1586.481	2.67	.987	89.17
Other Direct Labor Var.	3926.769	1	3926.769	6.62	.990	97.49
Security Accrual Var.	3202.114	1	3202.114	5.40	.992	107.68

* The model includes the variables of (4-9) plus all the variables down to and includ-ng the variable for which the ratio is given.

possible to predict Operating Variation extremely well with data relating to only eleven of these.

Until this point, Operating Variation has been modeled using other variations. A model of this form is best from the viewpoint of interpretation, for it is easier to relate variations to varations as opposed to Percentage Direct Overtime versus Standard Hours for instance. However, from the viewpoint of data collection it is better to be using a model whose variables are not Variations.

Model of Operating Variation in Terms of Non-Variation Variables

Again as in previous sections the approach will be to develop models with varying degrees of data requirements. Table 8 contains the variables which are now presently being reported on a weekly basis. They are available from either the Operating Labor Distribution Report, Value of Product Stocked Report, Hourly Overtime Report, or the Program Forecast.

Applying Stepwise Regression analysis to these variables the following model was obtained.

$$O.\ V. = -247.82 + 8.09\ X(1) - 1.93\ X(3) + 65.86\ X(7) \qquad (4\text{-}12)$$

where

X(1), X(3), and X(7) are so numbered in Table 8.

This model has a M.C.C. of 0.857 and a F-ratio of 27.72. Examination of the residuals plotted against the variables of Table 8 indicated

TABLE 8

VARIABLES AVAILABLE ON A WEEKLY BASIS

1. Actual Direct Labor Hours - Mdse
2. Actual Direct Labor Hours - Plant and Expense
3. Actual Direct Labor Charges ($)
4. Recovered Load - Plant and Expense
5. Total Direct Standard Hours
6. Direct Overtime Hours
7. Percentage Direct Overtime versus Standard Hours
8. Program Forecast

TABLE 9

LAGGED VARIABLES

1. Operating Variation
2. 46 and 48 Account
3. Development Expense Variation
4. Changes and Repairs Expense
5. Local Moves and Rearrangements
6. Cost Reduction and Other Development Expense (Other Direct Expense)

the model could not be improved by adding either a quadratic term of a variable or making a transformation of Operating Variation. However, a plot of the residuals versus Operating Variation indicated that the values of Operating Variation at each extreme were underpredicted. This would mean that the model needs some additional terms added.

In looking for variables which might be added to the model, there were not any more presently available on a weekly basis. It was decided to look for lagging variables which might be logically associated. The author arrived on the variables listed in Table 9.

Correlation analysis was applied to the variables of Table 9 progressively lagging the variables one month later each time. The variables were lagged by one to four months. This analysis pointed out that Operating Variation exhibited serial correlation. The correlation between Operating Variation and 46 and 48 account (lagged by 3 months) was also significant at the 95 percent level. There was no other significant correlation between the other variables of Table 9 and Operating Variation.

A scatter plot of the residuals of that model against the aforenamed lagging variables indicated that the addition of any of them to the model would not improve it significantly. Having exhausted the variables presently available on a weekly basis and lagged variables which might have a logical association, variables which other than weekly data could be collected on were examined. Those additional variables which the author thought data could be

TABLE 10

VARIABLES ON WHICH ADDITIONAL INFORMATION IS KNOWN WEEKLY

1. Number of Directs
2. Number of Expense
3. E/D
4. Employer/Supervisor
5. Total Direct Hours Worked
6. Unadjusted Efficiency
7. Direct Labor Variation
8. Total Production
9. Actual Direct Labor Changes
10. Recovered Direct Labor
11. Product Conformance Cost Variation
12. Actual Product Conformance Costs
13. Recovered Product Conformance Costs

collected most easily are contained in Table 10.

Principal Components Analysis was applied to the variables contained in Table 10. As a result of this the list of variables from Table 10 were reduced to seven (7). The principal variables were:

1. Number of Expense
2. E/D
3. Total Direct Hours Worked
4. Direct Labor Variation
5. Total Merchandise Production
6. Product Conformance Cost Variation
7. Actual Product Conformance Costs

A scatter plot of the above variables against the residuals of the model given by equation (4-12) indicated that the variables "Number of Expense" and "Direct Labor Variation" might improve the model. Using regression analysis these variables were added and due to intercorrelations some of the previous variables of equation (4-12) had to be eliminated. The resulting model is given by (4-13).

$$\text{O. V.} = 687.91 - 1.11\, X(1) + 3.30\, X(2) + 1.70\, X(3) \qquad (4\text{-}13)$$

where

$X(1)$ = Number of Expense, In total

$X(2)$ = Direct Labor Variation

$X(3)$ = Actual Direct Labor Hours - Mdse. Orders (value doubled for month of July)

The model given by (4-13) has a M.C.C. of 0.937 and a F-ratio of 71.82.

A model using the variable, "Number of Directs" was developed since the "Number of Directs" should have more variability than the "Number of Expense". The best model using the "Number of Directs" was:

$$O.\ V. = 1598.35 - .422\ X(1) - 29.52\ X(2) + 3.49\ X(3) + 1.77\ X(4) \qquad (4\text{-}14)$$

where

X(1) = Number of Directs, In Total

X(2) = E/D ratio

X(3) = Direct Labor Variation

X(4) = Actual Direct Labor Hours - Mdse

This model has a M.C.C. of 0.939 and an F-ratio of 54.40. The addition of a term also gives the model more flexibility than the model given by (4-13).

Examination of the residuals of the models given by (4-12) and (4-13) indicated that the largest residuals occurred during the months of September through December. The explanation for this is that a physical inventory is conducted by the company auditors during the month of September. This usually results in an adjustment of the September results and may carry over into the following months. Operating Variation for the month of December is usually abnormal due to the closing of the yearly books. Being the end of the year the December books are kept open longer than is the case during the rest of the year so all transactions for that year can be recorded in the year. This suggested a model for the months January through August and a different model for the months September through December.

$$O.\ V. = 959.79 - 1.19\ X(1) + 2.80\ X(2) + .10\ X(3) \qquad (4\text{-}15)$$

$$O.\ V. = 2329.68 + 3.43\ X(2) - .10\ X(3) - 56.41\ X(4) \qquad (4\text{-}16)$$

where

X(1) = Number of Expense, In Total

X(2) = Direct Labor Variation

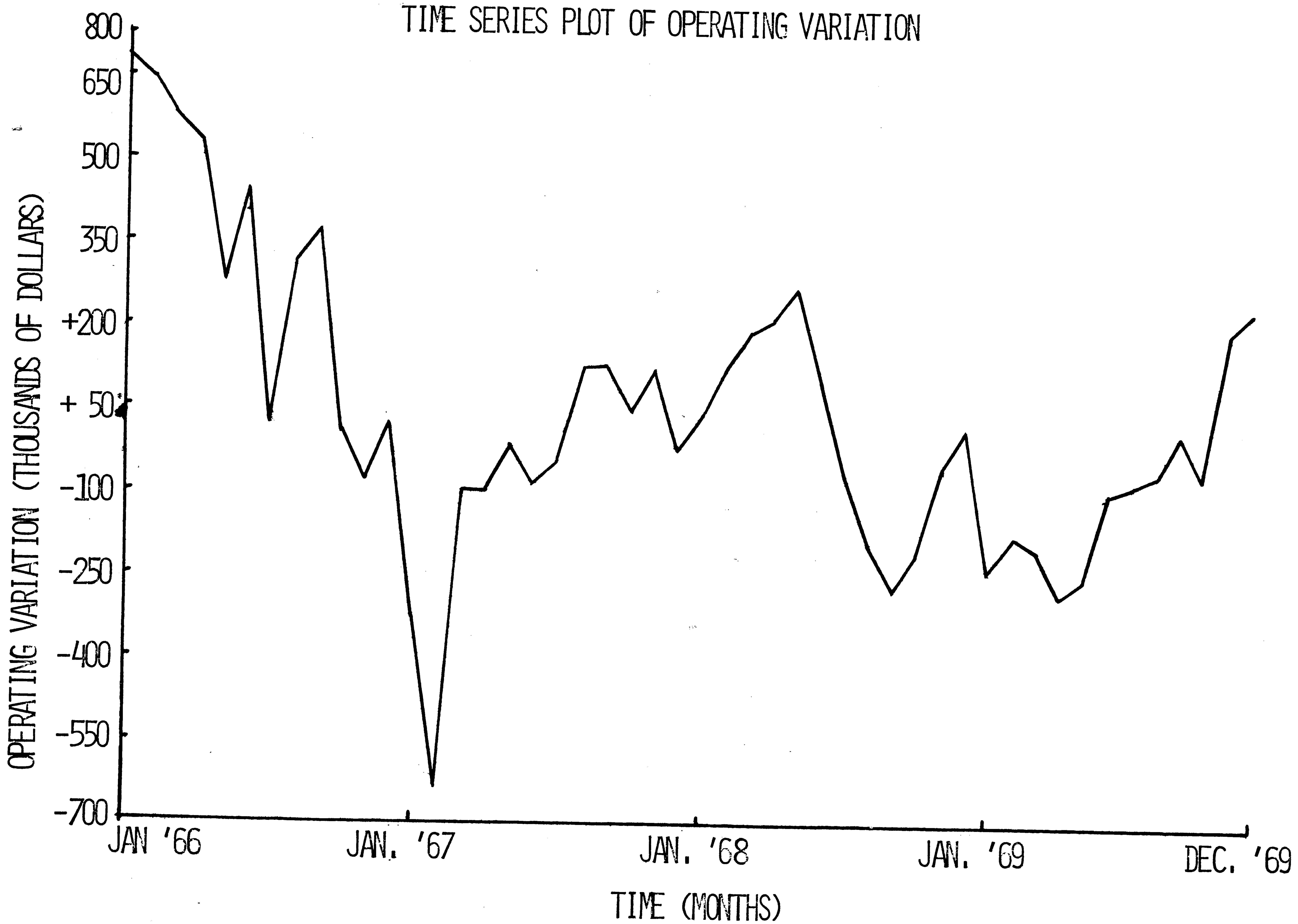
X(3) = Total Mdse. Production

X(4) = E/D ratio

The model given by (4-15) applies to the months of January through August whereas, the model given by (4-16) applies to the months of September through December. The model given by (4-15) has a M.C.C. of 0.946 and an F-ratio of 50.59. The corresponding values for the model given by (4-16) are 0.989 and 106.76 respectively.

Time Series Analysis

The next approach to modeling Operating Variation was to apply Time Series Analysis Techniques. A time series has been defined as a series of measurements of statistical data arranged in chronological order. The recording of Operating Variation over the past several years certainly fulfills this definition. A time series plot of the Allentown Plant's Operating Variation is presented in Figure 2. From a visual inspection of this plot there appears



TIME SERIES PLOT OF OPERATING VARIATION
OPERATING VARIATION (THOUSANDS OF DOLLARS)
800
650
500
350
+200
+ 50
-100
-250
-400
-550
-700
JAN '66
JAN. '67
JAN. '68
JAN. '69
DEC. '69
TIME (MONTHS)

FIGURE 2

to be a cyclic pattern with a period of two years. Tests for serial correlation was significant at a 0.01 level.

Since the Standard Costs are revised every two years, the zero for the Operating Variation time series may be shifted up or down. For this reason it does not seem logical to smooth a time series across the boundary of a bulletin period. Therefore, an exponential smoothing model with and without trend was constructed using only the data of one bulletin period (24 months). The smoothing constant (α) was selected using the criteria of minimum mean square error between the actual and the predicted values. As a result, the following model was developed.

$$O.V._T = O.V._{T-1} + [(1-\alpha)/\alpha]\ TR_{T-1} \qquad (4\text{-}17)$$

where

$$TR_{T-1} = (O.V._{T-1} - O.V._{T-2}) + (1-\alpha)\ TR_{T-2}$$

a value of = 1.0 was selected as the best smoothing constant on the criterion stated above. Thus, the model given by (4-17) reduces down to simply, the expected value of next month's Operating Variation is the value of this month's Operating Variation.

Production Functions

The Production Function assumes the form:

$$O(t) = C\ [X_1(t)]^{A_1}\ [X_2(t)]^{A_2}\ \text{--------}[X_m(t)]^{A_m}$$

where

$U(t)$ = output at time t

C = constant

$X_i(t)$ = the level of the i^{th} factor at time t.

If the exponents A_i are constant (which they are assumed to be) then by taking the derivatives with respect to the factors X_i it can be seen that

$$\frac{du(t)}{u(t)} \Big/ \frac{dX_i}{X_i} = A_i$$

This can be interpreted as the percent change in output due to a percent change in the i^{th} factor of input. The constant A_i is termed, "Elasticity" of the i^{th} factor in Economic theory.

To utilize this model for predictive purposes it is necessary to estimate the parameters C and A_1, A_2, ------A_m. Taking logarithms to the base e converts the model into the linear form

$$\ln O(t) = \ln C + A_1 \ln X_1(t) + A_2 \ln X_2(t) + \text{--------} \ln E$$

where E is a random variable.

The Production Function has obtained wide acceptance in the field econometrics for relating output and the factors of production. The elasticity of a factor is useful to know from the control point of view. Frequently, a plant will experience a change in required production volume. This affects the Operating Variation since the amount of Recoveries is directly affected. One of the first questions asked by management is, how will the change in volume affect Operating Variation? This question can be answered by determining the elasticity of production volume. A change in volume will not only affect Operating Variation, but may affect efficiency and the number of direct people required. In addition, any change in the number of direct people required will affect the E/D ratio.

The parameters of a Production Function type model were determined in an attempt to answer some of the above questions. The model is as follows:

$$\text{O.V.} = 6.39[X(1)]^{-10.24}[X(2)]^{11.76}[X(3)]^{-2.42} \qquad (4\text{-}18)$$

where

X(1) = E/D ratio

X(2) = Unadjusted Efficiency

X(3) = Total Mdse. Production

No statistical test can be made to verify the "goodness" of the model, but the logical interpretation of the factors indicates the model is unreasonable. The negative exponent of X(3) means that as a percentage increase occurs in Total Mdse. Production there will occur approximately twice a percentage decrease in Operating Variation.

CHAPTER V

EVALUATION OF MODELS

The purpose of this chapter is to test and compare the models developed. This will be done by substituting the actual values of the variables during 1970 and comparing the resultant predicted value with the actual value of Operating Variation. The values predicted and the actual values are plotted in Figures 3 and 4. A summary of the models is contained in Table 11.

Tables 12 and 13 contain the values predicted by the models and their differences from the actual value respectively. Assuming the differences can be treated as a sample from a normal population the paired t-test[7] was used to test the hypothesis that the mean of the differences equals zero. The t-values obtained are contained in Table 14. From Table 14 it can be seen that the average differences between the predicted and the actual values of Operating Variation did not differ significantly from zero, at the noted confidence levels, in Models I, II, VI, and VII. The t-value for Model III was not calculated in considering the magnitude of its differences. Therefore, one can conclude that Models I, II, VI, and VII can be used with the noted confidence for predicting Operating Variation. However, Models III, IV, and V gave biased predictions of Operating Variation.

Models III, IV, and V were further examined to determine what the reasons were for the significant differences. In examining the variables of Model III it was found that the variable "Percentage Direct Overtime versus Standard Hours" had trended upward over the years 1967-1969 but reversed directions and began a downward trend in 1970. Since this had not been experienced by the model before, it biased its results.

In examination of the differences of Models IV and V it was seen that the models predicted reasonably well until the month of September. It was found that a decrease in production, a substantial increase in efficiency and yield occurred in September. All of these factors caused a decrease in the number of Direct employees needed. This decrease stopped an upward trend over the past three years in the number of Direct employees. The increase in efficiency resulted in the value of Direct Labor Variation doubling the maximum positive quantity it had experienced in the last three years. In addition, the increase in efficiency coupled with the decrease in production resulted in a downward trend in the Actual Direct Hours Worked-Mdse. This downward trend contradicted the upward trend experienced by the model over the latter three years. The reversing of the trends in the number of Direct employees and Actual Direct Hours Worked-Mdse and substantial increases in efficiency and yield resulted in significant differences between the actual Operating Variation and those predicted by the models.

The models can be improved by including the results of 1970 and reevaluating the parameters of the models. This was done using

Model IV and differences between the predicted and actual values is contained in Table 13. One can see that by updating the model, both the mean and the variance of its differences were reduced. The average differences of the updated model was tested and found not significantly different from zero with a confidence level of 0.01. Thus, by updating the model monthly as more data became available the model adapted to the trend of the variables.

The required data was not available on a weekly basis such that the models could be tested for predicting the moneh-end Operating Variation given the results of the first week, second week, and third week as the month progressed.

This would be a good application of the model if the data for the variables could be obtained weekly. This would give management a predicted value of month-end Operating Variation based on the results of the first week's operation. Then successive predictions could be obtained based on the results of the first two weeks' operation and three weeks of operation.

TABLE 11

Summary of Models

Model	Form	Equation Number
I	O.V.=9.09+1.19X(1)+1.18X(2)	4-2
II	O.V.=28.82+.41X(3)+3.58X(4)+3.81X(5)+3.49X(6)+.56X(7)	4-11
III	O.V.=-247.82+8.09X(8)-1.93X(9)+65.86X(10)	4-12
IV	O.V.=687.91-1.11X(11)+3.30X(12)+1.70X(13)	4-13
V	O.V.=1598.35-.422X(14)-29.52X(15)+3.49X(12)+1.77X(13)	4-14
VI	O.V.=959.79-1.19X(11)+2.80X(12)+.10X(16)	4-15
	O.V.=2329.68+3.43X(12)-.10X(16)-56.41X(15)	4-16
VII	O.V.=Last Month's Operating Variation	4-17

where X(1) = Expense Variation

X(2) = Material and Other Variation

X(3) = Salaries and Wages Variation

X(4) = Hourly Rate Paid Different from Standard Variation

X(5) = Changes in Rates-Cost Reduction Variation

X(6) = Changes in Rates-Other Variation

X(7) = Expense Supplies Variation

X(8) = Actual Direct Labor Hours-Mdse.

X(9) = Actual Direct Labor Charges

X(10)= Percentage Direct Overtime versus Standard Hours

X(11)= Number of Expense, In Total

X(12)= Direct Labor Variation

X(13)= Actual Direct Labor Hours-Mdse.(value for July doubled)

X(14)= Number of Directs, In Total

X(15)= E/D Ratio

X(16)= Total Own Good Mdse. Production

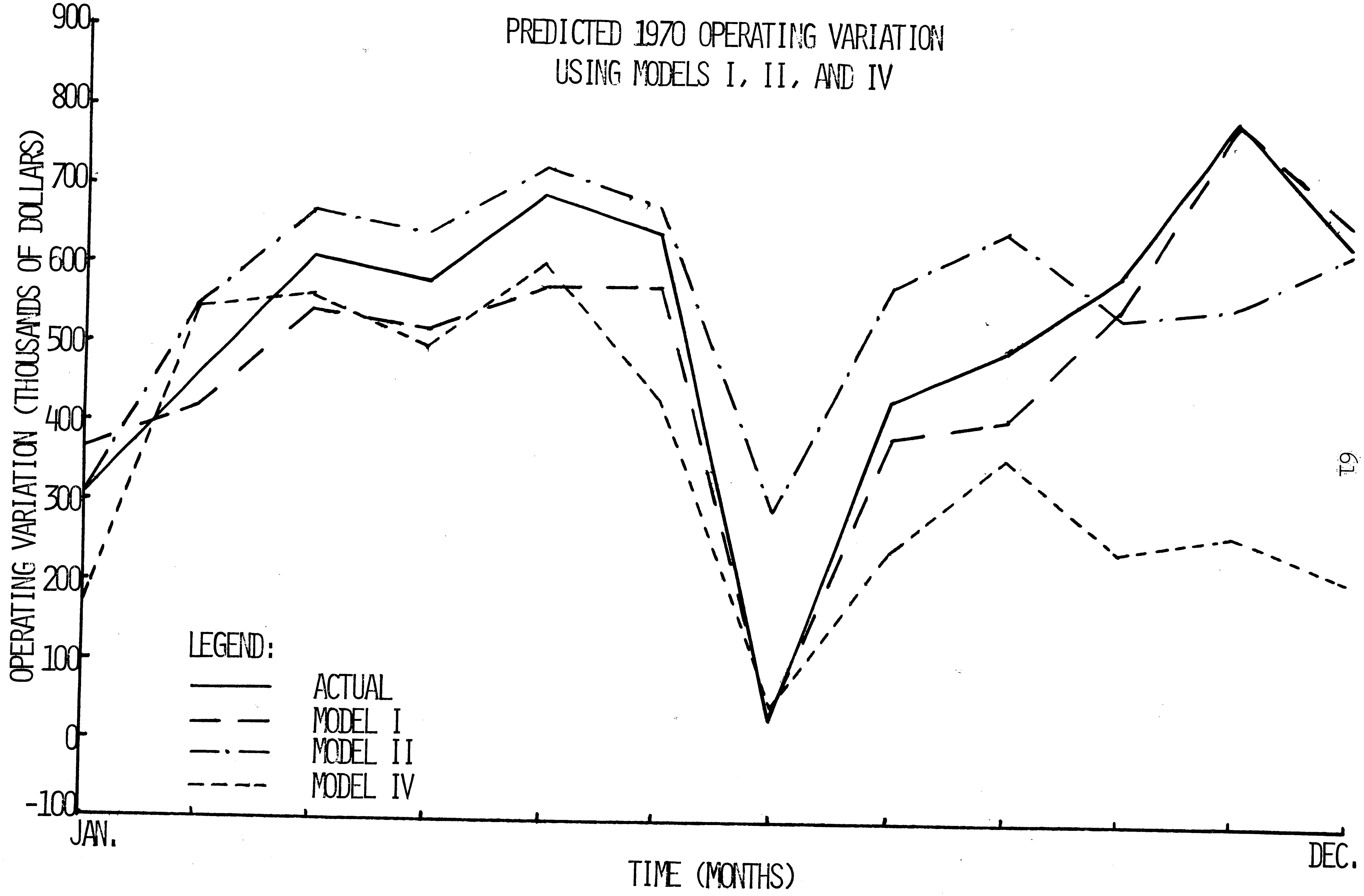

PREDICTED 1970 OPERATING VARIATION
USING MODELS I, II, AND IV
OPERATING VARIATION (THOUSANDS OF DOLLARS)
900
800
700
600
500
400
300
200
100
0
-100
LEGEND:
ACTUAL
MODEL I
MODEL II
MODEL IV
JAN.
DEC.
TIME (MONTHS)

FIGURE 3

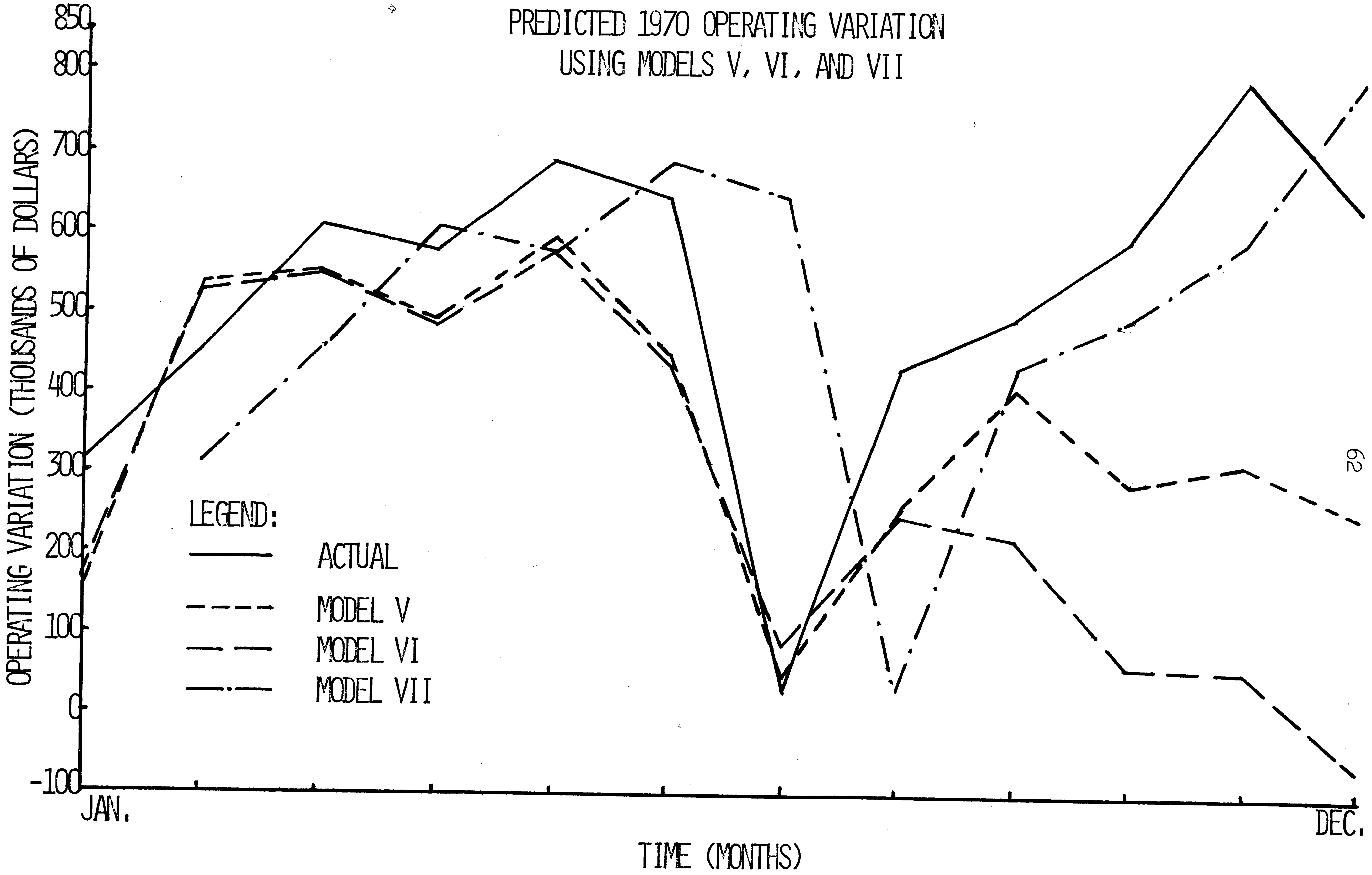

PREDICTED 1970 OPERATING VARIATION
USING MODELS V, VI, AND VII
850
800
700
600
500
400
300
200
100
0
-100
OPERATING VARIATION (THOUSANDS OF DOLLARS)
LEGEND:
ACTUAL
MODEL V
MODEL VI
MODEL VII
JAN.
DEC.
TIME (MONTHS)

FIGURE 4

TABLE 12

Predicted Values of Operating Variation

MODELS

Months	I	II	III	IV	V	VI	VII	IV Updated	Actual
January	363	305	215	170	157	167	-	170	310
February	420	549	179	541	535	523	310	582	452
March	542	668	82	560	549	543	452	558	607
April	518	640	-118	499	490	485	607	509	578
May	572	722	-193	600	593	576	578	627	689
June	574	673	-111	434	446	432	689	490	642
July	31	294	-238	47	45	85	642	145	30
August	386	577	-386	244	258	245	30	333	431
September	411	649	-576	361	408	220	431	449	496
October	557	539	-631	246	285	60	496	332	593
November	788	555	-642	270	312	58	593	394	795
December	663	621	-692	212	251	-69	795	367	634

TABLE 13

Differences Between Predicted and Actual Results of 1970

	MODELS							
Months	I	II	III	IV	V	VI	VII	IV Updated
January	-53	5	95	140	153	143	-	140
February	32	-97	273	-89	-83	-71	142	-130
March	65	-61	525	47	58	64	155	49
April	60	-62	696	79	88	93	-29	70
May	117	-33	882	89	96	113	91	63
June	67	-31	753	208	196	210	-47	152
July	-1	-264	268	-17	-15	-55	-612	-115
August	45	-146	817	187	173	185	401	98
September	85	-153	1072	135	86	276	65	47
October	36	54	1224	347	308	533	97	261
November	7	240	1437	525	483	737	202	401
December	-29	13	1326	422	383	703	-161	267
Ave. error	35.8	-44.6	-	172.8	160.5	244.2	25.33	85.2
Variance	2344.8	15484.9	-	32422.4	26573.4	74009.1	66288.1	23742.9

TABLE 14

T-Values for Testing $H_o: \mu_p - \mu_A = 0$

Model	t-value
I	2.56**
II	-1.24*
IV	3.32
V	3.41
VI	3.11***
VII	.33*
IV Updated	1.91**

* Rejected H_o at 0.10 level

** Rejected H_o at 0.05 level

*** Rejected H_o at 0.01 level

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

Conclusions

The objective of this thesis was to develop a model to be used for predicting Operation Variation. Several models were developed based on the amount of information available. A comparison of these models and a statistical test of their significance is contained in the preceding chapter. These models were developed by applying Stepwise Regression to data collected over the years 1967-1969. The monthly data was transformed to an equivalent four-week month such that all the data was relatively equal in time spans. The following paragraphs contain the conclusions drawn from the investigation done in developing these models.

Operating Variation proved to be cyclic as was brought out by a time series plot and a test of serial correlation. The length of cycle was approximately two years. The cycle length is also the length of time that a single Standard Cost is in effect. Operating Variation generally has a positive rate of increase during the first year of a Standard Cost period and a negative rate of increase during the second year.

One explanation of the cyclic pattern of Operating Variation lies in its influence by management. If Operating Variation has decreased over the last six months, management will probably apply pressure on Engineering for improved processes and/or methods in order to reverse the trend. This pressure will be applied until

Operating Variation has started upward and has reached a satisfactory level. The pressure is then lessened or removed since an extremely high positive Operating Variation is not desired just as an extreme negative Operating Variation is undesirable. With the pressure removed from Engineering and Operating Variation reaches a peak and then starts a downward trend. The length of the trends can be viewed as a result of the response time of the system.

Expense Variation is the most significant element of Operating Variation with Material and Other Variation and Labor Variation the next most significant respectively. Since Expense Variation comprises such an important part of Operating Variation, a method of controlling Operating Variation is to control the elements of Expense Variation. The most significant elements of Expense Variation are Salaries and Wages Variation, Expense Supplies Variation, Produce Conformance Variation, and Total Other Direct Expense Varaiation. Little control can be exerted on Salaries and Wages Variation by local management other than limiting overtime by expense personnel. To the average employee, the amount of paper, pens, paper clips and the number of copies of a certain blueprint used by him have no effect on the operation of the company. When added to the other items included in Expense Supplies the aggregate plays an important role. Operating Variation can be improved by making the average employee aware of these facts and ask that he use all the supplies that are needed but not to be wasteful of these items. In the manufacture of Electron Devices, the yield of a process plays an important role in the Product Conformance Variation since repair of these devices is the exception rather than the rule. Product Conformance Variation might be reduced by the use of process modeling to better understand the causes of changes in the yield of a process. Included in Other Direct Expense Variation is a collection of Variations which either do not fit under any of the other categories or is so small in value that it is not deemed important enough to be made a separate category. However, due to the influence this aggregate category exerts upon Operating Variation it may be worthwhile for Other Direct Expense Variation to be further broken down such that the elements contributing to Variation can be identified and controlled.

The most significant element of Labor Variation is Direct Labor Variation. Breaking it down further, the most important element of Direct Labor Variation is Variation due to "Changes in Rates-Other than Cost Reduction". This is made up of the difference between the present rates of pay of the direct employees and the rates of pay used in establishing the Standard Cost. This difference is dictated by union contract and upper management policy.

Material and Other Variation is composed almost entirely of Development Expense. The correlation is so high, the quantities can be interchanged. This is to be expected since the plant studied engaged in pilot operations where the methods and processes of manufacture were developed and then the product was transferred to another location for permanent manufacture.

The model developed using variables on which formal weekly reports are now made performed badly in predicting Operating Variation. Thus, for the purposes of predicting and controlling the monthly Operating Variation the variables on which formal weekly reports are now made are inadequate. Consideration should be given to collecting weekly data pertaining to the aforementioned elements of Expense Variation and Development Expense.

Weekly data might be easier attained about the variables, Number of Expense Personnel, In Total; Direct Labor Variation; and Actual Direct Labor Hours-Mdse. Orders. When these variables are combined into a model (4-13) and the parameters of the model updated to include the results of the previous month, the model was able to predict Operating Variation at a 0.20 significance level.

The final conclusion is that it is possible to develop a predictive model of Operating Variation using a significantly smaller number of variables than used in the actual calculation of that quantity. The use of such a model would allow management to shorten its response time in controlling Operation Variation. Using a model of this type, management would have an idea what the month's Operating Variation was going to be after the first week of the month. This would allow the proper controls to be applied immediately to correct the situation if management so desired. Presently, the plant may operate a full month in an undesirable manner before management receives the month's Operating Variation which will bring it to their attention.

The above conclusions are based on the analysis of a manufacturing plant engaged in the manufacture of Electron Devices. The plant was engaged in pilot operations where the methods and processes of manufacture were developed and then the product was transferred to another location for permanent manufacture. These conclusions may not apply to plants engaged in manufacturing other types of products.

<u>Recommendations For Further Study</u>

Further investigation into modeling Operating Variation should include the collection of data on other variables which might correlate with Operating Variation. A model to predict Operating Variation at a lower level than the total plant would be helpful. In addition, a control model of Operating Variation rather than a predictive model will be beneficial. Operating Variation being cyclic lends itself to the application of spectral analysis. Further investigation in any of the above areas would be helpful to management. In addition, the development of a predictive model of the Operating Variation of a plant engaged in manufacturing another type of product and a comparison of that model with the model developed for the plant in this thesis would provide additional insight into Operating Variation.

BIBLIOGRAPHY

1. Allen, R. D. G., Mathematical Economics, MacMillan and Company, Ltd., London, England, 1963.

2. Bonini, Charles P., Simulation of Information and Decision Systems in the Firm, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1963.

3. Cyert, Richard M., and March, James G., A Behavorial Theory of the Firm, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1963.

4. Domar, E. D., "Capital Expansion, Rate of Growth, and Employment", Econometrica, Vol. 14, pp. 137-147.

5. Draper, N. R. and H. Smith, Applied Regression Analysis, John Wiley & Sons, Inc., New York, 1966.

6. Forrester, Jay W., Industrial Dynamics, The MIT Press, Cambridge, Massachusetts, 1961.

7. Freund, J. E. and I. Miller, Probability and Statistics For Engineers, Prentice-Hall Inc., Englewood Cliffs, New Jersey, 1965.

8. Goldberger, A. S., Econometric Theory, John Wiley & Sons, Inc. New York, 1964.

9. Harrod, R. F., Towards a Dynamic Economics, MacMillan and Company, Ltd., London, England, 1948.

10. Hicks, J. R., A Contribution to the Theory of the Trade Cycle, Oxford University Press, Oxford, England, 1950.

11. Hicks, P. E., "An Industrial Dynamics Study of Selected Factors Affecting Company Growth," Ph.D. Dissertation, School of Industrial Engineering, GIT, Atlanta, Georgia, 1967.

12. Hoggatt, Austin C., "Simulation of the Firm," IBM Research Paper RC-16, IBM, White Plains, New York, August, 1957.

13. Johnston, J., Statistical Cost Analysis, McGraw-Hill, New York, 1960.

14. Kaleneki, M., Studies in Economic Dynamics, Allen and Unwin, London, England, 1943.

BIBLIOGRAPHY (cont'd)

15. Kinsley, E. R., "The Managerial Use of Industrial Dynamics as Illustrated by a Company Growth Model," M.S. Thesis, Sloan School of Management, MIT, Cambridge, Massachusetts, 1959.

16. Luedtke, Arthur, Jr., "An Industrial Dynamics Study of an Electronic Equipment Company," M.S. Thesis, GIT, Atlanta, Georgia, 1967.

17. Nord, Ole C., Growth of a New Product, The MIT Press, Cambridge, Massachusetts, 1963.

18. Packer, David W., Resource Acquisition in Corporate Growth, The MIT Press, Cambridge, Massachusetts, 1964.

19. Phillips, A. S., "Stabilization Policy and the Time-Form of Lagged Responses," Economic Journal, Vol. 67, 1957, pp.265-277.

20. Samuelson, Paul A., "Interactions Between the Multiplier Analysis and the Principle of Acceleration," Review of Economic Statistics, Vol. 12, May, 1938, pp. 75-78.

21. Walker, G. H., "A Study on the Simulation and Optimization of a Hypothetical Total Firm," Ph.D. Dissertation, University of Texas, 1967.

VITA

PERSONAL HISTORY

Name:	Ted Mims Upton
Birth Place:	Alexander City, Alabama
Birth Date:	June 27, 1944
Parents:	Mims and Mae Upton
Wife:	Roberta K. Upton

INSTITUTIONS ATTENDED

Troup High School
LaGrange, Georgia — 1958-1962

New Mexico State University
Las Cruces, N. M. — 1962-1967 B.S.E.E.

Lehigh University
Candidate for Master of Science
Degree in Industrial Engineering

HONORS

Eta Kappa Nu
Sigma Tau
Blue Key
Alpha Pi Mu

EXPERIENCE

Western Electric
Planning Engineer
Winston-Salem, N. C. — 1967-1969

Development Engineer
Princeton, N. J. — 1969-1971