1973

Influences of demand patterns and capital expenditure programs on manufactured progress: a progress function approach

Robert S. Breeden
Lehigh University

INFLUENCES OF DEMAND PATTERNS AND CAPITAL EXPENDITURE PROGRAMS ON MANUFACTURING PROGRESS: A PROGRESS FUNCTION APPROACH

by

Robert S. Breeden, Jr.

A Thesis

Presented to the Graduate Committee

of Lehigh University

in Candidacy for the Degree of

Master of Science

in

Industrial Engineering

Lehigh University

1973

CERTIFICATE OF APPROVAL

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

April 23, 1973
Date

Arthur F. Gould
Professor in Charge

Arthur F. Gould
Chairman of the Department of
Industrial Engineering

ACKNOWLEDGEMENTS

The author expresses his appreciation to Professor A. F. Gould for his helpful advice and guidance during the preparation of this thesis. Mr. J. W. O'Leary of the Western Electric Research Center staff deserves special appreciation for suggesting the topic, his counsel, and his support.

The author also thanks Miss P. A. Renzo for her cooperation in typing this thesis.

Finally, the author wishes to express his deepest gratitude to his wife, Jackie, for her patience, encouragement, and understanding during the course of this effort.

TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

The main objective of this study was to determine if the production effectiveness of a manufacturing organization is influenced by demand and/or capital spending. With regard to the overall objective this investigation examined the possibility of an organization experiencing different degrees of production effectiveness in conjunction with the demand pattern it faces. Also the study sought a means of relating differing rates of progress through the capital spending pattern. The power law form of the manufacturing progress function was the device utilized to measure the organization's production effectiveness. Basically, the approach taken was qualitative in the sense that the demand patterns and capital spending patterns were plotted and examined for general characteristics. The determination of these general characteristics did not employ statistical analysis or modelling techniques.

The findings of this investigation were based on production data concerning five high technology products manufactured by the Western Electric Company, Incorporated. The results indicate the existence of regional progress functions which infer that a manufacturing organization undergoes changes in production effectiveness. These changes in effectiveness coincided with the changing characteristics in demand. In addition, the capital spending programs provided insight in relating these changes in production effectiveness.

CHAPTER I

INTRODUCTION

Many of those associated with problems of industrial manufacturing recognize that as time passes and the manufacturing process continues, the production effectiveness of the concerned organization increases. This increased effectiveness is the result of many different influencing factors which may be peculiar to the particular industry under observation. However, there is one problem common to all industries, how can this increased effectiveness or progress be measured? Considerable studies have been undertaken in an effort to develop a relationship that accurately quantifies progress. One particularly significant empirical relationship has evolved from these studies. The relationship links cost or labor requirements and cumulative production count. The vast majority of the studies that point to the cost-cumulative production were conducted in the aircraft industry and they formulate the basis for progress function theory.

Progress functions are also known as learning curves, experience curves, and improvement curves. This author prefers the term "progress function" as opposed to the traditional "learning curve." It is the author's considered opinion that learning curve carries the connotation of operator learning. While operator learning does indeed contribute to the reduction of the cost and/or labor requirements during the production process, it is a formidable task to quantify its contribution, in addition to those of engineering change, managerial innovation, pre-production planning, methods improvement, and the like. For this reason, progress function is considered to be a better descriptor of the entire process.

At this point, it should be emphasized that the progress function is not an universal or proven mathematical law. It is an empirical relationship that has been applied to various and sundry industries with different degrees of success. Also, the form of the progress function may vary depending on the influencing factors being considered.

The author does not wish to give the allusion that the progress function is the only means of measuring increased production effectiveness. There is a large body of knowledge involving more complex relationships known as "production functions," which can be utilized in measuring progress. However, this thesis will address itself solely to progress functions.

CHAPTER II

BACKGROUND

The concepts of the progress function stem from Dr. T. P. Wright's [32] findings in his 1936 study of the airframe industry. Wright proposed the following model:

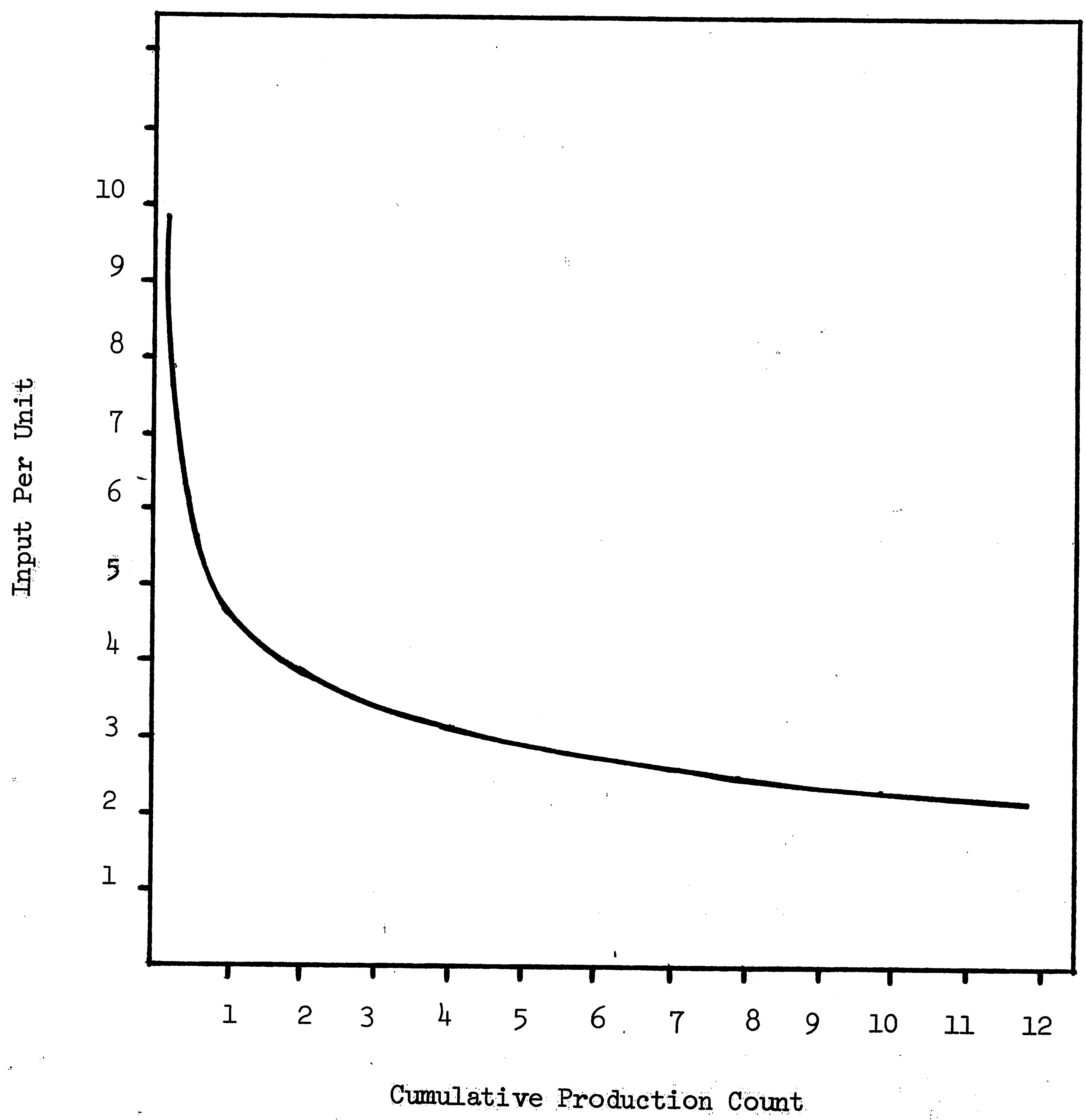
$$Y = AX^b$$

The term Y is the cumulative average cost or cumulative average direct labor hours per unit associated with the total output or production count, X. The defining parameters, A and b, are to be determined. The parameter, A, is the theoretical first unit cost or labor requirement, therefore, when X has the value 1, the value of Y should be equal to A. The adjective "theoretical" is necessary since the actual incurred first unit cost or labor requirement is considered somewhat indeterminable. The b parameter is negatively signed and it may assume a value between 0 and 1. With the aforementioned conditions on A and b, it becomes apparent that Y is a decreasing function of X. If the model was plotted as Y versus X on Cartesian coordinates it would have the appearance of a hyperbolic curve.

Since Wright's expression assumes a power law form it exhibits two attractive characteristics:

1. Through the use of logarithmic transformations the original formulation becomes a linear relationship involving logarithms.

Manufacturing Progress Function
Plotted on Cartesian Coordinates



$$\log Y = \log A + b \log X$$

This characteristic enables the analyst to plot the raw data on log-log coordinate paper and results in a straight line.

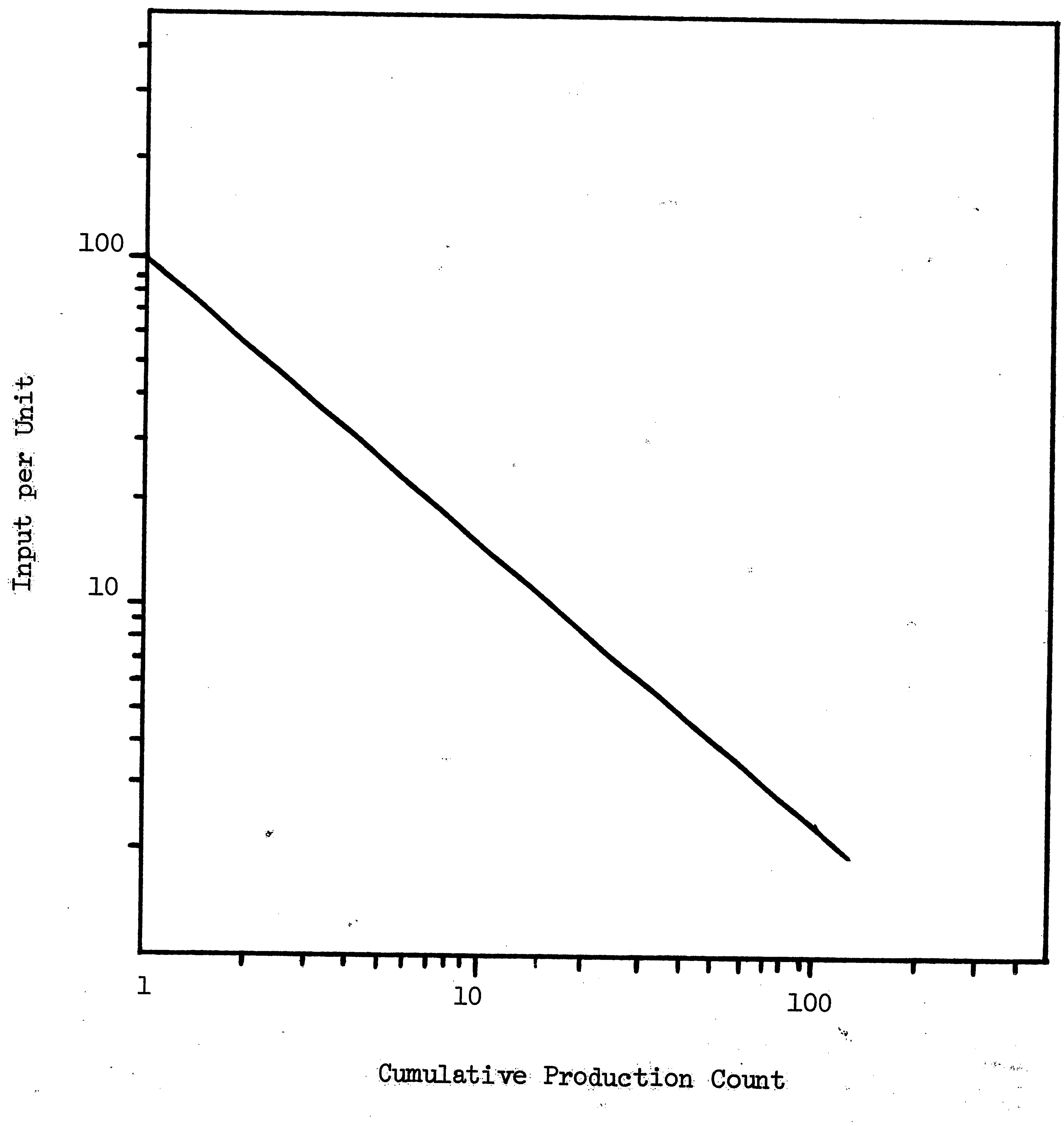
2. For each constant percentage increase in the independent variable, X, there is a constant percentage decrease (usually not equal) in the dependent variable, Y.

The actual value of b is not used to describe the rate of progress, rather, the complement of the percent decrease of cost or labor requirements resulting from the two-fold increase of the cumulative production count. To illustrate by means of an example, a 75% progress function implies a 25% reduction in the labor requirements each time the cumulative output is doubled. The rate of progress is also called the progress index or slope. It should be noted that the term "slope" carries its conventional mathematical meaning i.e., the first derivative of the function when referring to the log-log model.

Wright's original model has led to many modifications, one of the more commonly used was proposed by J. R. Crawford [9]. Crawford's functional relationship also assumes a power law form and is given by:

$$Y' = A'X^{b}$$

Manufacturing Progress Function
Plotted on Logarithmic Coordinates



where A' and b are parameters defined in a fashion similar to those corresponding to Wright's model.

X is the total production count,

Y' is the labor (cost) requirement of the X^{th} unit.

Crawford's curve is often referred to as the unit curve or marginal cost curve and in general, it is the more commonly used form of the manufacturing progress function [23]. Concerning the criteria for determining whether Wright or Crawford has the more appropriate model, Conway and Schultz state:

> "Since proponents of neither model are able to establish their positions by logic, and empirical evidence is far from sufficient to establish the superiority of one alternative, the choice in usage has been largely a matter of computational convenience;.... Since in either case the two curves are parallel for large quantities of production, the difference is important only during initial stages of production and hence for many applications, not crucial [8]."

In comparing Wright's cumulative average curve and Crawford's unit curve, it should be noted that Wright's model has the property of smoothing perturbations, especially at the higher levels of production. In contrast, Crawford's model is more sensitive to variations in the data.

As previously stated Wright's model assumes a linear relationship between the natural logarithms of the labor requirements and the total production count. This linear hypothesis has been challenged by several factions including G. W. Carr [5], Boeing Airplane Company [29], and Stanford Research Institute [29]. It was Carr's contention that the logarithmic form of the cumulative average curve is S-shaped with three distinct segments. In particular, Carr maintained that the first segment was concave downward and it was the result of new, unexperienced workers at the beginning of a program. The other two segments were the consequence of introducing additional unexperienced crews into the labor force, giving the total work universe a non-uniform degree of learning. The S-curve concept was found to apply only to certain models in the airframe industry and is not a generalization to be applied universally.

The Boeing Airplane Company developed a modification of the manufacturing progress function that has gained widespread application by the aerospace industry. This modification or the "Boeing Hump Curve" as it has come to be known, is similar to Carr's curve in that it also is concave downward in the early stages of production. The Boeing Hump Curve does not have a constant slope (b value) over the entire production program. It is usually broken into two segments. However, based on judgements of past program performances, it may have as many segments as deemed necessary to accurately characterize the production situation. Each segment will have its own slope.

Researchers at the Stanford Research Institute noted that sets of airframe data did not comply with Wright's classical progress function expression. Rather than use a variable slope condition as Carr and Boeing did, the researchers introduced a new variable whose purpose would be to provide a measure of the experience or carry-over progress at the outset of the manufacturing program. The Stanford model took the form:

$$Y = A(\mu + X)^n$$

where:

Y = direct man-hours per unit

X = total production count

n = an exponent that describes the asymptote of the curve

A = first unit cost when μ is zero

μ = a constant number of units that is determined empirically.

The reader should recognize that the b value from Wright's model and the Stanford group's n value are equavalent. The mu, μ , parameter measures the carry-over progress in terms of a number of equivalent units. This is a constant number and it represents the quantity of units a new producer would have to complete in order to attain the competence level of an experienced producer. The Stanford model has not enjoyed widespread acceptance [17]. However, it did make an effort to consider the transfer of experience. Transfer of experience is an important concept in progress function application, in particular, it is of great value in considering dual sourcing (simultaneous production of the same unit by two different sources).

Prior to the mid 1950's, virtually all of the development and application of manufacturing progress functions was limited to the aircraft industry. The aerospace industry acquired this "monopoly" since the progress function was conceived in the airframe industry and the United States Air Force expressed an interest in using the progress function as a production planning and control tool during World War II. In addition, the Air Force sponsored several in-depth studies that further contributed to aerospace's pool of knowledge.

In the last twenty years industry, in general, has slowly recognized the value of the progress function. This increased interest has prompted empirical studies by Andress [1], Baloff [3], Billion [4], Cochran [6], Conway and Schultz [8], Hirsch [15], Hirschmann [16], and Lubell and Bequette [22] to name a few. These studies have encompassed a wide variety of industries such as: automotive, petroleum, textiles, musical instruments, and electronics. These studies and others have demonstrated that the progress function does not belong solely to the aerospace industry, but to the entire manufacturing environment. In addition, new concepts have been added to the main body of progress function knowledge:

1. Non-homogeneous production environment
2. Two sources producing the same product
3. Effect of progress funtion on an incentive system
4. Influence of variable production lot sizes
5. Application of progress function theory to overhead
6. Effect of changes in production rate
7. Relationship of total cost progress function and component progress functions.

It is evident from various publications that the progress function has become a tool of management with considerable value and importance. Some of the specific ways in which management can utilize the progress function will be presented via a quotation from Dr. S. A. Billion's article in the Management International Review. Dr. Billion states:

> "... the learning curve (progress function) makes possible that the amount of improvement is forecast on an objective quantitative basis. The other cost elements are estimated in turn on the basis of the man-hour forecast. Many large firms use the time forecast for a manufacturing project as the basis in estimating costs, pricing, setting delivery schedules, determining floor space, tooling, inventory, manpower, working capital, and other manufacturing needs. It has also been used in make-or-buy decisions, cost and budgetary control, determination of economic lot size, and evaluating facility performance [4]."

Now that industry, in general, has awakened to the existence and usefulness of the progress function, management should be aware of its capabilities and limitations before applying it blindly to every manufacturing situation. Progress functions are based on empirical findings; therefore, these relationships are not universal or mathematically proven laws. The nature of a manufacturing process may be such that a progress function simply does not exist. Next, since progress curves are the results of empirical studies, they are subject to the problems of industrial studies, specifically -- reliability of data. Conway and Schultz state:

> "The authors had had enough experience in industrial situations to believe that most firms which use individual incentives such as piece rates for wage payments and control

purposes also create an environment in which output is restricted, actual labor times are seldom accurately recorded, and considerable doubt exists as to the validity of operator times charged to direct vs. indirect accounts.... many accounting and cost accounting procedures also operate in such a manner that the information necessary for such studies is either unavailable in proper form or is buried in a total that included irrelevant information...[8]."

The usefulness of the progress function can be quickly cancelled if it is not based on current production conditions and the most accurate data available. The third and last point to be mentioned is one concerning the statistical analysis necessary to determine the values of the defining parameters of the progress function. It is not the author's intention to outline the correct statistical procedure, rather to simply point out that if basic techniques of data analysis are not observed, the empirical progress function may be misleading, and any decisions based on it may be inaccurate and unfounded.

In a relatively brief time span, less than four decades, the manufacturing progress function has evolved from a simple cost-quantity expression to a powerful management device that enjoys almost universal acceptance in manufacturing environments. The forms and uses of the progress function are as varied and widespread as the nature of the industries to which it has been applied. The basic concepts of the progress function can be employed at all levels of production, the foreman on the shop floor may use a simple form to help schedule his work flow while an executive may use another modification to determine his company's position in contract negotiations. However, as with many relatively new techniques, the progress function has a few limitations which must be recognized in order to make its results meaningful.

CHAPTER III

STATEMENT OF THE PROBLEM

This thesis will address itself to the measurement of production effectiveness as achieved by a manufacturing organization. The measuring device utilized will be the power law form of the manufacturing progress function. This increased effectiveness or progress may be attributed to many factors, and listed below are some of the more widely referenced in articles and journals [27]:

1. Individual operator learning
2. Training
3. Management innovation
4. Inventory and quality control
5. Previous experience
6. Methods improvement
7. Preproduction planning
8. Advanced scheduling and routing techniques
9. Recognizing and seeking progress

It is not an objective of this investigation to quantify the individual contribution of each of the above mentioned factors, but to investigate the possible influences of demand and capital spending on manufacturing improvement. Intuitively, demand and spending are two somewhat related aspects of manufacturing that affect production effectiveness. At this point it should be emphasized that the expression "increased effectiveness" denotes a reduction of production resources, such as direct labor.

Capital Spending

Spending is considered to be sum total of monies that have been invested in or allocated for the acquisition and installation of machinery, equipment, tools, and fixtures for a particular production line. Based on the preceding definition, the term, capital spending, will be primarily used to distinguish manufacturing monies from the preproduction research and development expenditures.

An alert management considers capital spent during the manufacturing process to be of prime importance, since management continually seeks an acceptable return for its investments, or simply stated, a better job done for the dollars spent. This "better job" will be evaluated through the use of the manufacturing progress function. At this point the author wishes to introduce the concept of technology class or product class. The terms, "technology class" and "product class," will be used interchangeably to denote what degree of production improvement is available to the manufacturing organization. If a product is in a high technology class, it is in a fast-moving state of the art with great opportunities for increased production effectiveness. In contrast, a product in a low technology class is in a slow-moving state of the art with relatively little opportunity for production betterment. The concept of technology class is important in conjunction with levels of spending. A product determines its technology class and the level of spending associated with that product determines the product's position within its technology class. For example, transistors would be considered to be high technology products. The manufacturing processes required to fabricate the transistor may utilize highly sophisticated and automated equipment for assembly, mechanical testing, and electrical testing. In addition, depending on its use, the transistor enjoys the advantage of material substitutability, e.g., metal or plastic encapsulation. The degree to which the manufacturing organization commits itself to these high technology opportunities will be reflected in its capital investment and the progress achieved.

The means by which capital is allocated to a product is highly dependent on such conditions as: current economic environment, management inclination, and the availability of the desired equipment. This thesis, in its examination of capital spending programs, will not attempt to model the spending programs, instead it will examine spending qualitatively. This qualitative examination of capital investment will be primarily concerned with the general characteristics such as; increases, stabilization, and cutbacks.

In order to authorize monies for a manufacturing program management requires justification which may vary from industry to industry. However, most industries anticipate a steady or increasing demand for the product to warrant any sizable investment, and hopefully such a demand will allow the organization to utilize the economies of scale, i.e., more efficiently employ the factors of production. The better employment of the factors of production demonstrates a short term application of demand while anticipated demand as a long term consideration will influence spending decisions and the effectiveness of the concerned organization. This aspect of manufacturing will be discussed.

Demand

The demand pattern of a product is defined as the various quantities of the product per unit of time the consumer will remove from the market [20]. The manufacturing organization realizes the influence of demand through the production requirements it must meet. Admittedly, the actual demand for a product and the program requirements may not coincide due to schedule changes and the like. However, this thesis will not address itself to a system involving backorders, holding costs, etc., rather, its main concern is the general demand a product faces. For this reason, the production program is considered to be a suitable indication of demand.

P. D. Lubell and J. W. Bequette [22] conducted a study to determine the effects of production programs on an organization's improvement. Lubell and Bequette used a modified form of the progress function which included a production rate variable in the log-linear form of the function.

In addition to the Lubell and Bequette study, demand patterns or growth patterns have been the subject of considerable interest in the trade journals and periodicals. Many consider demand patterns to be generally S-shaped with respect to time. The S-shape indicates a rapidly increasing early growth which gradually flattens out. This flattening out denotes a saturation of the market.

Demand, prior to market saturation, has been mathematically modelled with the exponential form being the most popular [13]. In addition to the exponential form, empirical studies have shown that demand may be of a power law [13] or a logistic [12] nature. This author does not intend to model growth or statistically analyze demand, rather, simply describe qualitatively the demand for a product.

In summary, the overall objective of this thesis is to examine the demand and capital spending patterns of a production-oriented organization and determine if they influence the manufacturing effectiveness of the organization. The capital spending and demand patterns will be described by general characteristics as opposed to a stringent statistical analysis and the increased effectiveness of the organization will be determined by means of the unit value form of the manufacturing progress function.

CHAPTER IV

PROCEDURE

The environment in which an organization exists may vary among different industries. Since the progress an organization realizes is highly dependent on its operating environment, all the production data that forms the basis of this thesis came from the same industry, i.e., electronic devices. There are several techniques available to fit a progress function to a set of data. The technique selected was the logarithmic variance stabilizing transformation on the original data. Such a transformation converts the original power law form of the function into a linear relationship. Now that a linear relationship exists, the standard linear least squares technique can be employed. Before the regression was performed the data was examined for outlying observations. An outlier or maverick point could exert a strong influence on the final estimates of the slope and first unit labor requirements (the b and A parameters, respectively) and as a result possibly provide misleading information. For this reason, if a datum point was determined to be an outlier, it was removed from the data set.

One of the crucial assumptions of the linear least squares technique is that the errors or residuals of the linear model are additive and normally distributed with a mean zero and some constant variance, σ^2. When the linear relationship involving the logarithms is transformed back into its power law form, this error structure becomes a multiplicative. This bias can be removed if the estimate of the residual variance from the linear regression is known. For a more detailed explanation of this procedure the reader should consult reference [30].

How well a progress function fits a set of data will be defined through the use of the following criteria:

1. Correlation coefficient
2. Durbin-Watson statistic
3. Deviations

The correlation coefficient measures the degree of association between the two variables, cumulative production count and unit labor requirements. In general, the correlation coefficient can assume values between zero and one, with a value of one implying a perfect linear fit and a value of zero implying no linear relationship. The sign of the correlation coefficient may be either positive or negative; for progress function usage, it should be negative denoting an increase in cumulative production results in a decrease in unit labor requirements. Values between -0.7 and -1.0 will be considered acceptable.

Serial independence of the residuals from the linear model is another important assumption of linear regression. If the residuals or error terms are not serially independent, they are said to be autocorrelated. The presence of autocorrelation as a model has three main consequences:

1. While the values of the slope and first unit parameters are unbiased estimates, they are not necessarily the minimum varianced estimates.
2. The t and F distributions, which are often used in making confidence statements, lose their validity.
3. The expression for the variance of an estimate is no longer accurate, and may result in a serious underestimate of the true variance [11].

The Durbin-Watson statistic measures autocorrelation and its values are tabulated based on the sample size and number of independent variables. As a general rule of thumb, a value between 1.5 and 2.5 is desirable in progress function analysis.

In addition to the previous statistical criteria, how well the function predicts with respect to the actual production data will be considered. The term, "deviation," will be used to describe the difference in the actual and forecasted values of the power law form of the progress function. The reader should distinguish between the terms, "deviation" and "residual." The term, "residual," applies to the difference in the actual and forecasted values of the logarithmic linear form of the function. The above criteria and considerations are used to evaluate how well a progress function fits a set of data.

Capital Spending and Demand Patterns

The approach selected to examine the capital spending and demand patterns will be qualitative one. The approach is qualitative in the sense that patterns will be inspected for regions which display unique characteristics. This approach is to be distinguished from a quantitative approach where the patterns would be expressed as exact mathematical expressions which explicitly relate demand to time and capital to time. For both patterns, each set of data must be of a time sequenced nature, and the unit of time considered, days, months, or years, must be the same throughout the entire range of the data. However, the unit of time considered may differ between sets of data, e.g., the program requirements for widgets may be in units per day, while wadget demand may be on an annual basis. The demands and spending levels are then plotted with respect to time and examined for general characteristics such as: increases, saturation, marked drop, and the like.

After obtaining the production data and performing the required mathematical manipulations to convert the raw data into a usable form, the overall progress function, demand pattern, and capital spending pattern were determined. The demand pattern, in particular, was scrutinized for the general characteristics previously mentioned. The pattern was then divided into two or more regions with each region demonstrating one particular aspect of the program requirements. Each of the demand regions were then related to its associated interval of production. That portion of the cumulative production was investigated for a "regional" progress function until the entire range of the original data was covered by these regional functions. Conceivably, there could be an overlap of the regional functions, i.e., one function may use a datum point in an adjoining region.

Due to the dynamic nature of the manufacturing process and the virtual impossibility of adjusting to an abrupt demand increase or decrease instantaneously, this overlap is reasonable to expect. Then the overall progress function and the regional progress functions were compared. The capital spending patterns would give insight as to how well the organization progressed during its entire production program and how it performed when faced with intervals of differing program requirements.

To summarize, the procedure used in this thesis entailed the determination of an overall progress function that covered the entire range of the production data available. In addition, a set of two or more regional progress functions was determined, whose components covered an interval of production that coincided with a particular aspect of the production program requirements as demonstrated by the demand pattern. The overall function and the regional functions were compared in connection with the capital spending pattern of the manufacturing organization. This procedure was adopted as part of an empirical study into the possible influences of demand and capital on the progress of an organization as measured by Crawford's form of the manufacturing progress function.

CHAPTER V

RESULTS

The results of this investigation are based on data obtained from three manufacturing locations of the Western Electric Company, Incorporated. For proprietary reasons, the exact descriptions of the products, the plant locations, and the periods of time over which the data was collected must be withheld. In addition, the original raw data was coded in order to protect the identity of the products. However, in no way do the aforementioned restrictions of disclosure compromise the validity of this investigation.

The first step of the study was to determine the overall progress function for each product. The adjective "overall" is used to infer the fact that the function covers the entire range of the original production data as opposed to the regional function which covers only a portion of the original data. Table I is a summary of the results of fitting the original data to the power law model. All five of the products exhibit very good correlation coefficients which indicate a strong degree of association between labor per unit and cumulative production. The Durbin-Watson statistic (abbreviated D-W) for the products under consideration had a wide range of values (0.45 to 2.75). Recall that the acceptable values of the D-W statistic are based on sample size and number of independent variables. As a result no valid statement concerning autocorrelation can be made in connection with products I, III, and IV because these products do not meet the minimum sample size requirement of fifteen. Products

II and V did meet the minimum sample size requirement, however, the progress function models for these products did show signs of autocorrelation when tested at a 5% level of significance. It has been this author's experience that progress functions traditionally have values of the D-W statistic which indicate the presence of autocorrelation.

The plots of the demand and capital spending patterns are located in the Appendix. However, Table II is a summary of the demand pattern characteristics. The demand pattern of each product was divided into two or more regions based on the characteristics the pattern displayed. In every case region 1 was characterized by steadily increasing demand. The traits displayed by subsequent regions varied, e.g., permanent saturation, temporary saturation accompanied by an upswing, and abatement. Then the period of time each region covered was related to its respective portion of the original production data and the regional function was fit to that portion of data.

Table III is a comparison of the correlation coefficients of the overall and the regional progress functions. In progress function analysis the correlation coefficient indicates what proportion of the variation in the dependent variable, direct labor per unit, can be attributed to the linear relationship of the independent variable, total production count. Examination of the correlation coefficient values reveals that the model for product V in region 2 had the minimum percent of explained variation, 75.7%, while the vast majority of the other regions considered had percentages exceeding 90%.

The values of the D-W statistic for the overall and regional progress functions are summarized in Table IV. Since it was previously noted that the overall progress function for products I, III, and IV were based on sample sizes not meeting minimum requirements, thereby precluding any judgements on serial correlation, the same reasoning applies to the regional functions of these products. The overall function for products II and V did show signs of serial correlation at the 5% level of significance. In product II the serial effects were removed in region 1 but continued to exist in region 2. Similarly, in the product V the serial effects were reduced in region 1 while region 2 did not meet the minimum sample size requirement, and region 3 continued to show signs of serial correlation.

Table V is a summary of the comparisons of the overall and the regional progress function slopes. The reader should be warned not to anticipate any relationship between the overall and the regional slopes. For this investigation the value of the slope of the progress function is a relative measure of the constant decreases of the direct labor with respect to constant proportional increases is total production output. This constant decrease is maintained throughout the entire range of the function. It is not necessary that any definite relationship concerning these constant decreases should be sustained when comparing portions of the original data set to the original data set in its entirety. The reader's attention is directed to the regional slope values within each product. In products I, II and V the slope value(s) of the region(s) subsequent to region 1 is(are) less than that of region 1. In progress function analysis a smaller slope value indicates a larger percent improvement, therefore, a more desirable rate of progress. Consequently, the region(s) following region 1 had better rates of progress. In the case of products III and IV the opposite condition existed, i.e., the better rate of progress existed in region 1.

Based on the regions identified in the examination of the demand patterns, the capital spending data was partitioned into similar regions. These regions were scrutinized for general characteristics and these findings are summarized in Table VI. For the most part, all the products displayed sharp rises in capital spending during region 1, however, product III did have a sudden decline in spending at the end of region 1. The levels of spending in those regions subsequent to region 1 for products II, III, and V were maintained at those levels attained during region 1. Products I and IV demonstrated increased capital spending in region 2 over the levels attained in region 1.

Finally a comparison of the deviations resulting from the overall function and the regional functions was performed on a frequency basis. The comparison revealed that in the case of each product 60% to 80% of the deviations from the regional functions were less than those resulting from the associated overall function.

The empirical results of this investigation have been summarized in Tables I through VI located at the end of this chapter. These results have been considered and conclusions drawn which will be stated in the succeeding chapter.

TABLE I

OVERALL PROGRESS FUNCTION SUMMARY

Product	Number of Observations	Correlation Coefficient	Durbin-Watson Statistic	Slope(%)
I	8	-0.993	2.68	61.9
II	60	-0.961	1.14	68.9
III	13	-0.991	2.02	69.9
IV	8	-0.993	2.75	77.7
V	80	-0.975	0.45	64.5

TABLE II

DEMAND PATTERN CHARACTERISTICS

Product	Region	Characteristics
I	1	Increasing steadily
	2	Saturation
II	1	Increasing steadily
	2	Temporary saturation followed by an upswing
III	1	Increasing steadily
	2	Slight increase followed by a fall off
IV	1	Increasing steadily
	2	Temporary decline followed by an upswing
V	1	Increasing steadily
	2	Saturation
	3	Renewed increase

TABLE III

CORRELATION COEFFICIENT COMPARISON

Product	Number of Regions	Overall Function	Regional Function
I	2	-0.993	-0.991 -0.995
II	2	-0.961	-0.938 -0.895
III	2	-0.991	-0.981 -0.954
IV	2	-0.993	-0.989 -0.958
V	3	-0.975	-0.971 -0.757 -0.946

TABLE IV

COMPARISON OF DURBIN-WATSON STATISTIC VALUES

Product	Overall Function	Region Function
I	2.68	3.34 2.97
II	1.14	2.87 1.08
III	2.02	2.23 1.55
IV	2.75	3.38 2.99
V	0.45	1.50 1.31 1.08

TABLE V

SLOPE COMPARISONS OF PROGRESS FUNCTIONS

Product	Overall Slope(%)	Region	Regional Slope(%)
I	61.9	1	60.3
		2	57.3
II	68.9	1	76.1
		2	63.7
III	69.9	1	69.9
		2	77.2
IV	77.7	1	78.3
		2	89.7
V	64.5	1	71.2
		2	60.8
		3	65.6

TABLE VI

CAPITAL SPENDING CHARACTERISTICS

Product	Region	Description
I	1	Rises sharply
	2	Continues to rise
II	1	Rises slowly
	2	Stable with slight increase
III	1	Rises sharply, sudden drop
	2	Stable at lower level
IV	1	Rises sharply
	2	Continues to rise
V	1	Rises sharply
	2	Stable at region 1 level
	3	Rises again

CHAPTER VI

CONCLUSIONS

The primary objective of this investigation was to determine the influence of demand and capital spending on the production effectiveness of a manufacturing organization. In conjunction with the primary objective there were two particular aspects of manufacturing to be examined:

1. Does a manufacturing organization exhibit different degrees of production effectiveness based on the demand it faces?
2. Can these differing degrees of production effectiveness be related through capital spending?

The demand pattern for each product was plotted and inspection revealed that each pattern had at least two regions that exhibited distinctive characteristics. Based on the correlation coefficients and the values of the Durbin-Watson statistic, it was judged that a regional progress function existed over the interval of production that coincided with the regions displayed by the demand patterns. In addition, the regional progress functions within each product did not have the same slopes, ergo, the manufacturing organizations experienced different rates of progress. Thus, the production effectiveness of each organization was altered as it was subjected to different demand trends. Based on this study, it appears that an organization can expect its rate of improvement to change after the organization has experienced an initial period of steadily increasing demand. However, the study did not indicate the duration of this initial period of increasing demand.

The capital spending pattern for each product was divided into the same regions as indicated by the demand patterns and the levels of spending within these regions examined to associate the different progress rates. Recall that products I, II, and IV had more desirable progress rates in the region(s) subsequent to region 1, while products III and IV had more desirable rates of progress in region 1. All of the products, with the exception of III, had spending patterns that indicated continual investment of capital. This continual investment of capital reflects the organizations' attitudes to advance their levels of technology. Such an attitude was not evident in the spending associated with product III. Specifically, in an effort to substitute another product for product III, capital investment and program requirement were cutback markedly. Since the product III had a poorer progress rate in period of time that encompassed cutbacks in demand and capital investment, it appears that these curtailments reduced the organization's production effectiveness. Conversely, the remainder of the products had demand patterns that demonstrated increases or maintenance of the demand level achieved during the initial period of growth. In addition, the amount of capital invested associated with these products continued to increase. Therefore, it appears that a steady demand and continuous investment of capital may increase an organization's production effectiveness. Product IV is an exception to the preceding premise in that, despite an increase of capital, it has a poorer rate of progress in that region succeeding the initial growth of the product. During the period of lesser production effectiveness the organization was participating in a program to improve the quality of the product. The program was not concerned with bettering the productivity of the production line or yields of the process but rather to extend the performance characteristics of the product. Specifically, the organization sought to increase the life of the product in an effort to meet stricter manufacturing requirements of the future. The program required large amounts of capital yet its results were not reflected in the progress rates since the organization's direct labor per unit did not decrease. Therefore, capital spending coupled with its motivation and objectives does provide an insight into the relationship of progress rates during different demand trends.

All of the products that formed the basis of this investigation belonged to the electronics industry and were considered to be high technology class products. The slopes of the overall progress functions ranged from 61.9% to 77.7% with four of the five products having rates of progress less than 70%. The progress rates encountered in this study indicated that manufacturing organizations have taken advantage of good opportunities for production improvement in the past. The good opportunities coupled with the fast-moving state of the art associated with these products make their classification as high technology products reasonable. There is one inherent assumption of this investigation that should be brought to the attention of the reader. The assumption is that throughout the time span of the study the technology class of the products remains unchanged. Therefore, changes in progress rates are primarily dependent on the products' demand and capital spending as opposed to changes in technology class.

To summarize, this investigation indicated that the production organizations experienced different degrees of manufacturing effectiveness when confronted with changing demand patterns. This increased effectiveness was not discernable in the overall manufacturing progress function but through the existence of regional progress functions whose intervals of production coincided with the distinctive demand regions. Generally, during the initial period of growth the organization experienced a progress rate different from the progress rate of the succeeding period. The methods and objectives associated with the capital spending programs provided a meaningful link in associating the various rates of progress. This investigation gave an indication that a manufacturing organization may experience improved rates of progress during periods of stable or increasing demand following an initial growth stage as long as the organization maintains a capital investment program to improve productivity. In conclusion, the reader should note that this empirical study has pointed out possible influences of demand and capital spending on production effectiveness and before any industry-wide applications are attempted more analysis is required. The succeeding chapter indicates areas for further study.

CHAPTER VII

AREAS FOR FURTHER INVESTIGATION

As previously stated, many relationships may be used to measure the production effectiveness of an organization. This thesis concerned itself solely with the power law form of the manufacturing progress function. An area for further study would entail the use of a different form of the progress function to measure effectiveness. One form of the progress function that appears particularly applicable is the Stanford model. The Stanford model includes a term that allows for the carry-over or retained experience of an organization. The Stanford model would be best applied to the region(s) subsequent to the initial region, since we assume the organization has no prior knowledge to draw from.

A progress function, regardless of its form, is limited in its application since it is based on empirical findings. Therefore, it is conceivable that the true effectiveness of an organization could not be measured by any form of the progress function. Another area for further investigation would utilize a relationship other than a progress function to measure the organization's true effectiveness.

This thesis investigated electronic products that were considered to be in high technology classes. By extending this thesis to include not only products from other industries but also products from other technology classes, it could be ascertained if the results of this study were applicable to industry in general or restricted to certain types of production organizations. Such an extension would make additional contributions to the body of empirical progress function knowledge.

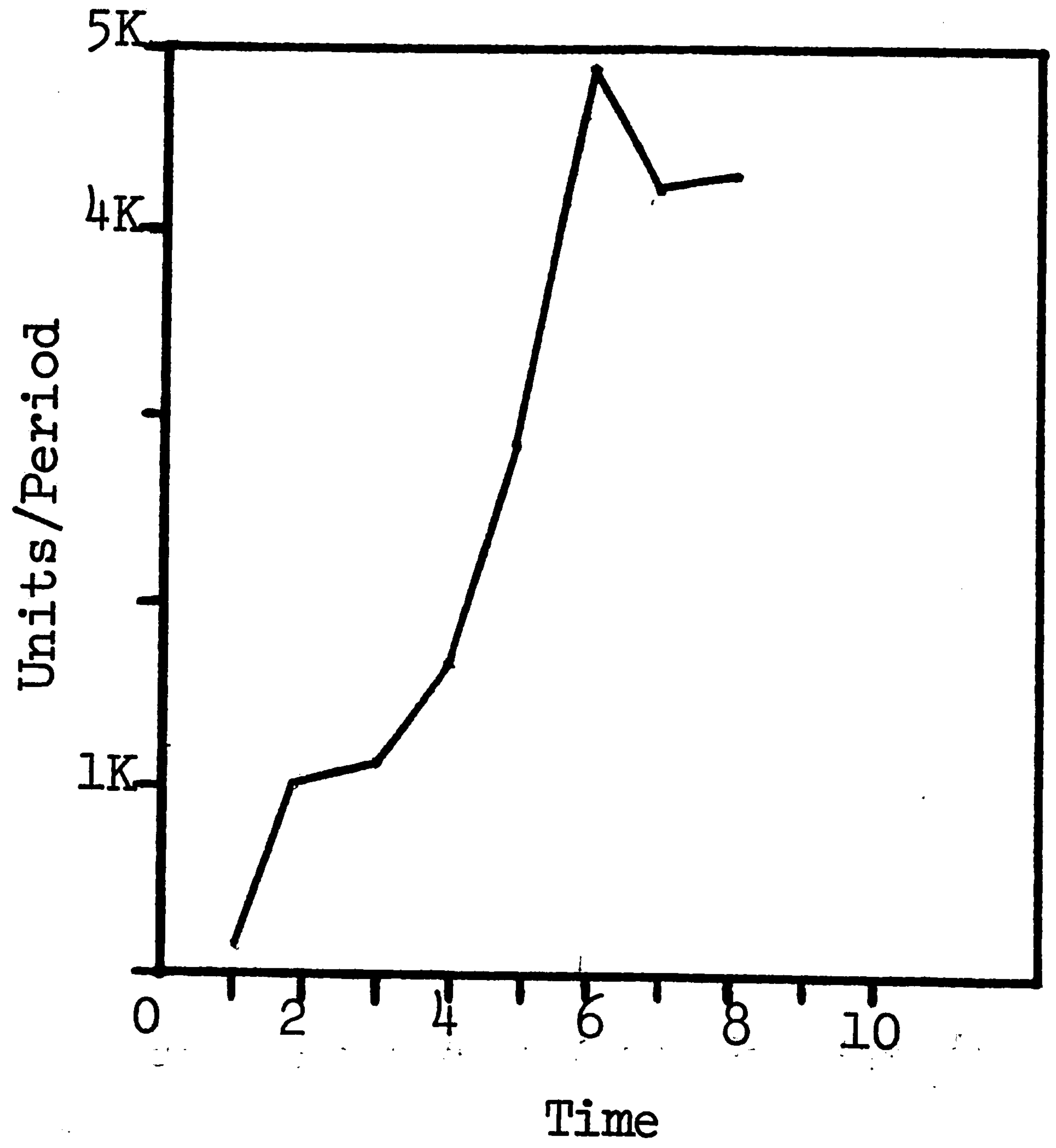
The products selected to form the foundation of this investigation were chosen on the basis that each product was the sole output of its organization. Often an organization produces one basic product with several modifications or codes, if this was the case, the product mix was reviewed to insure that it did not change. By removing the above restrictions on output the various combinations of the demand patterns would provide an interesting area for study.

The final area to be considered is one concerning approach. The qualitative approach employed by this thesis provided a means of aiding a manufacturing organization (at the product level) in assessing its position with respect to demand and capital spending. A quantitative approach would allow its findings to be applied at higher levels. The quantitative approach would require statistical modelling of the patterns and examination for specific and exact relationships, e.g., is the rate of change of demand related to the progress rate. The qualitative approach provides a foundation for subsequent quantitative analysis.

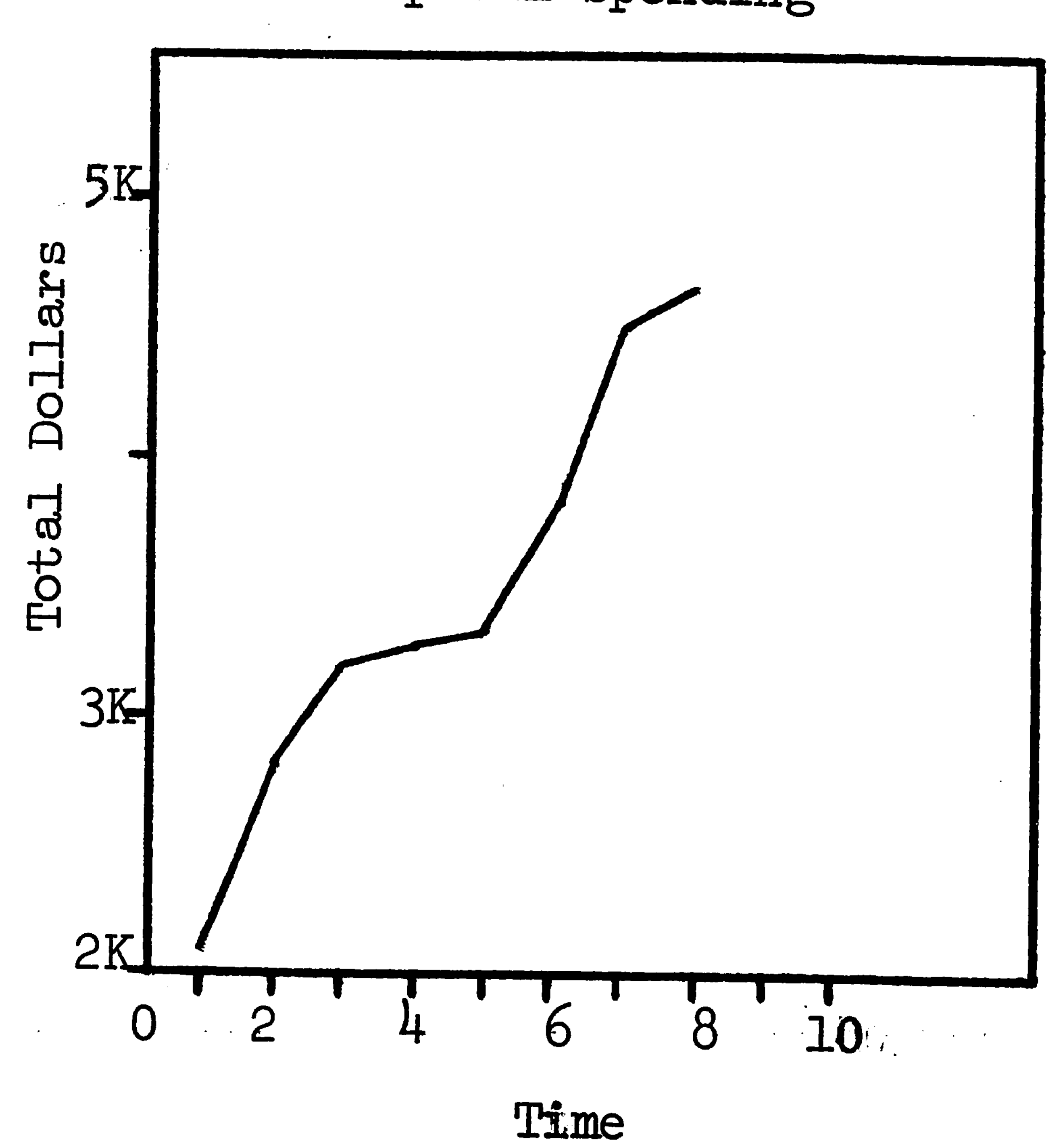
APPENDIX

Product I

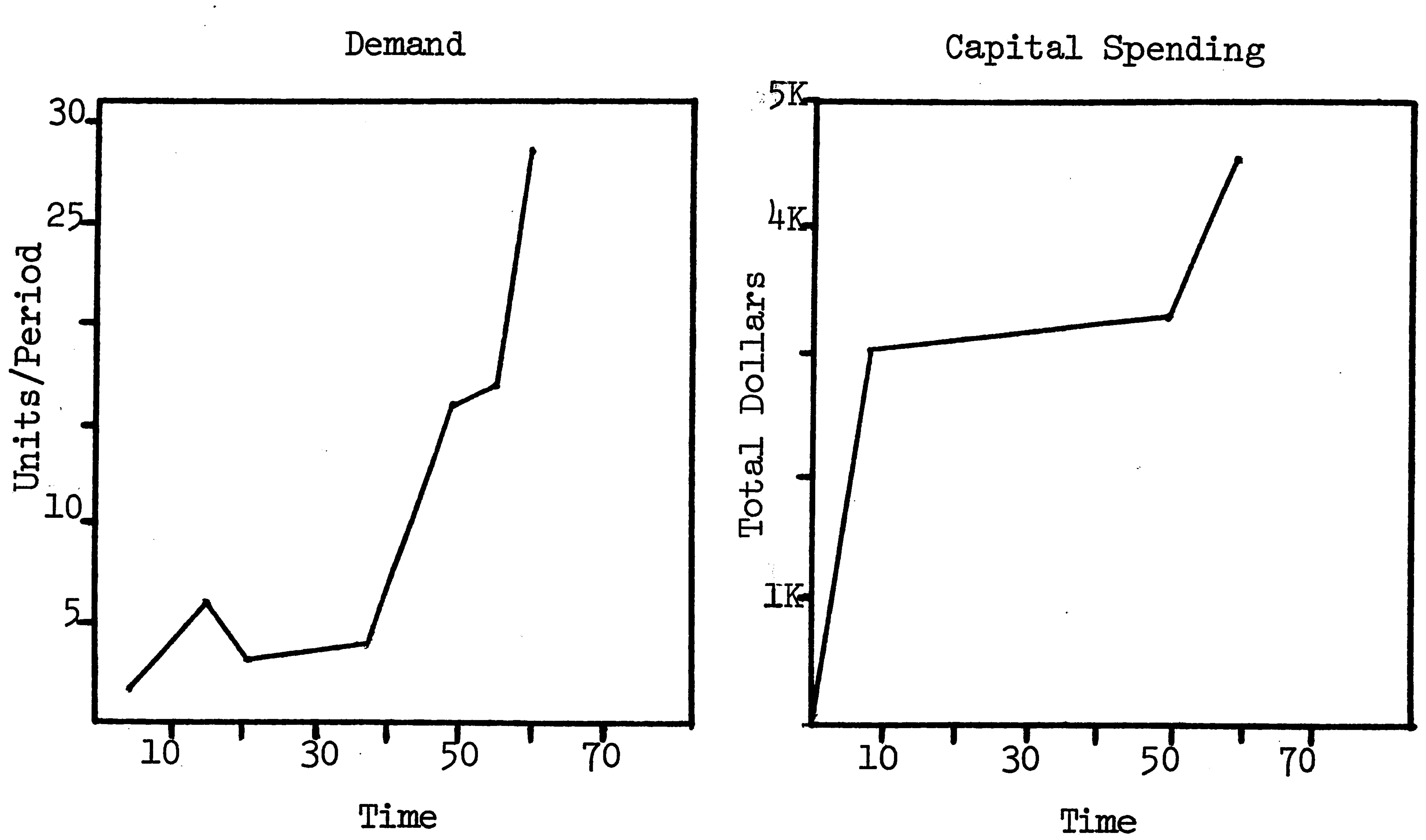
Demand



Capital Spending



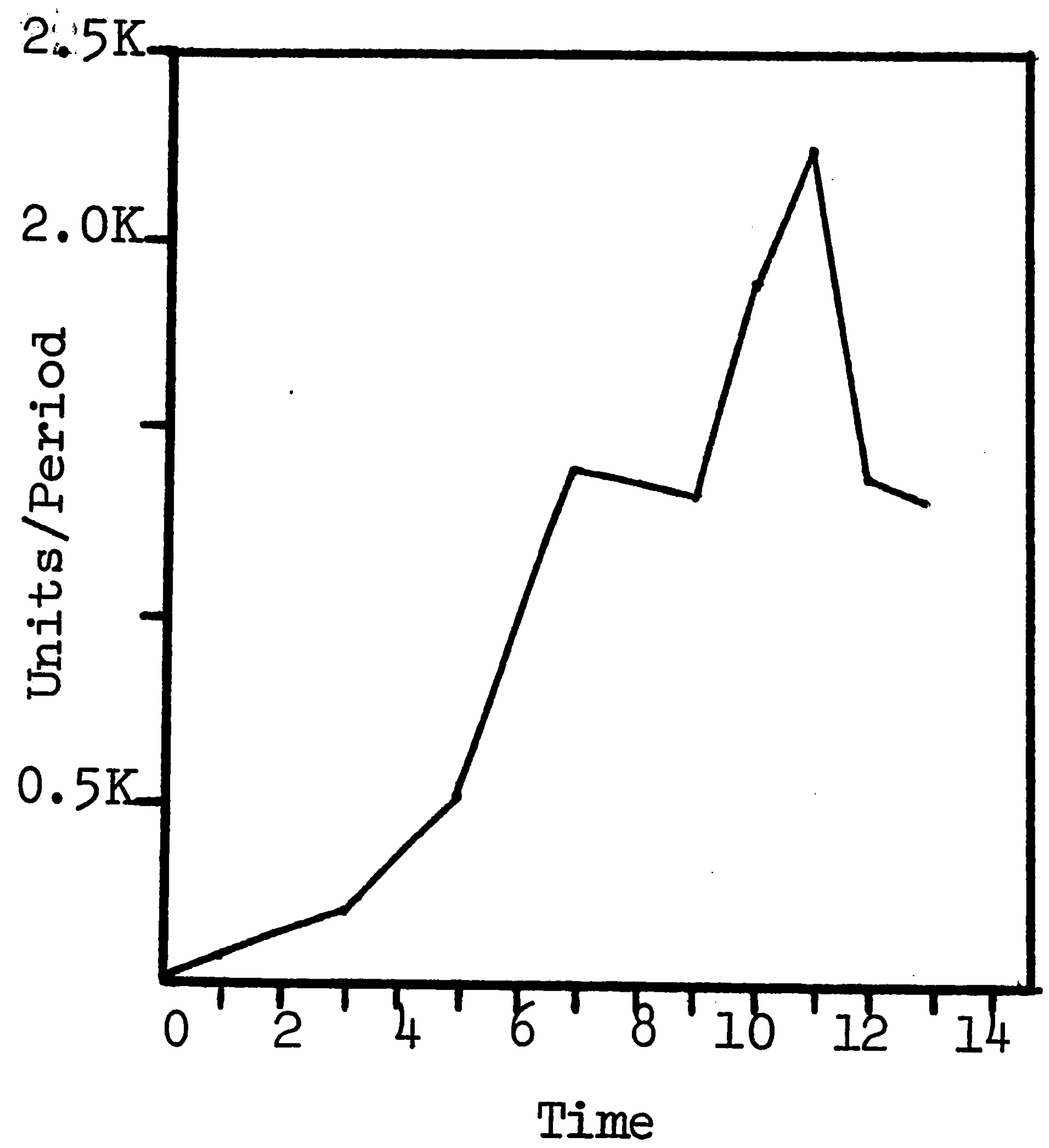
Product II



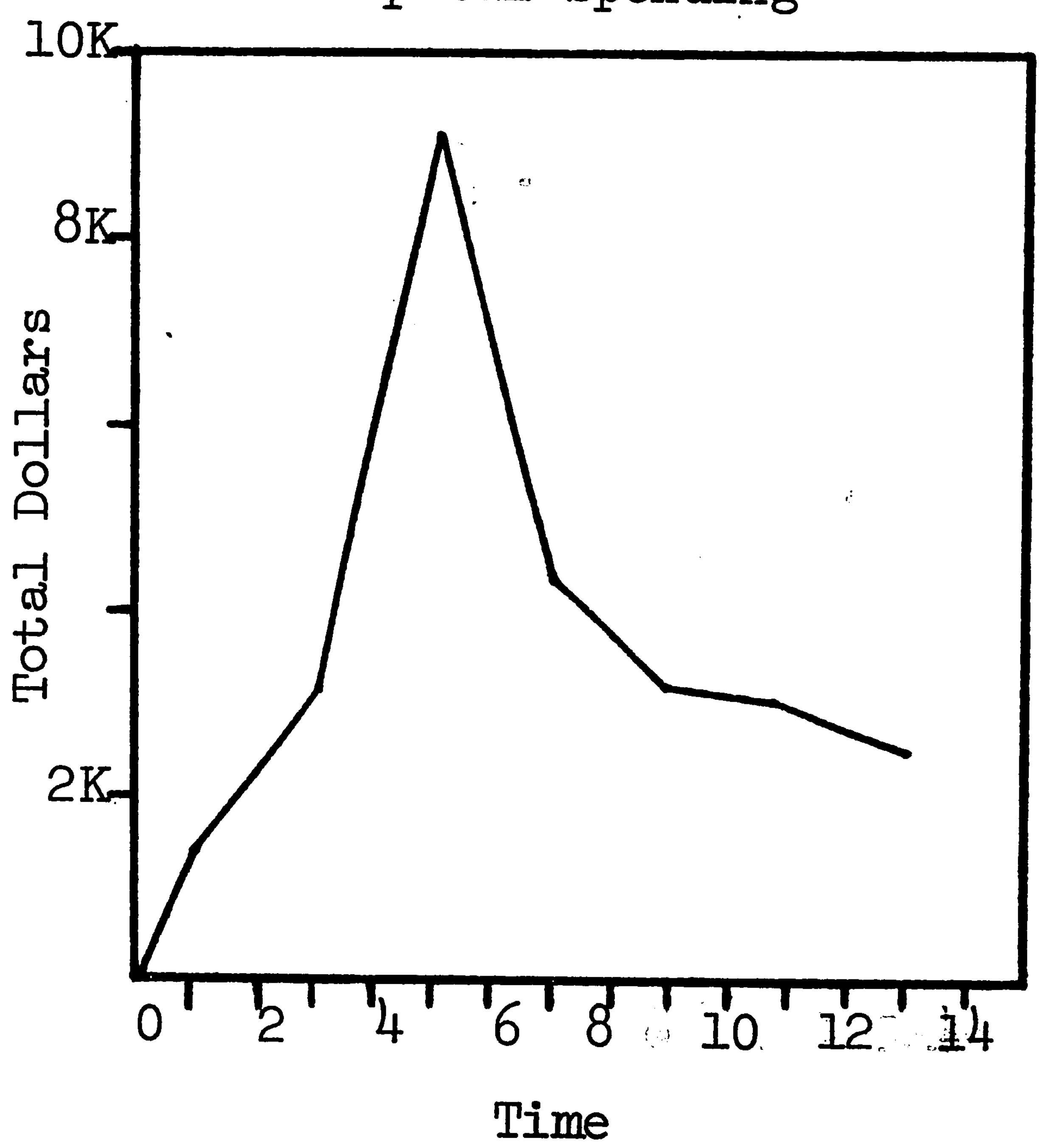
Demand
30
25
Units/Period
10
5
10
30
50
70
Time
Capital Spending
5K
4K
Total Dollars
1K
10
30
50
70
Time

Product III

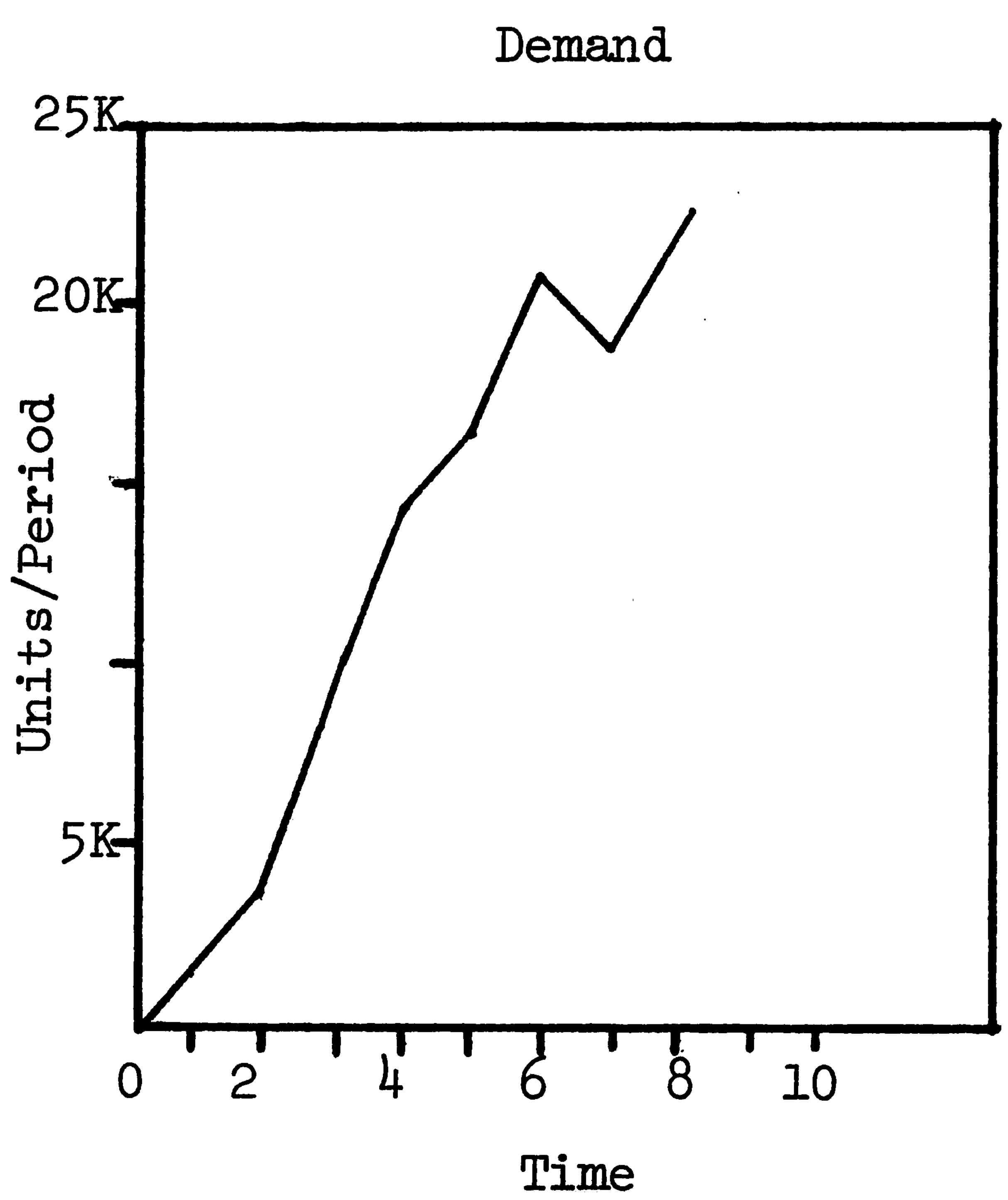
Demand



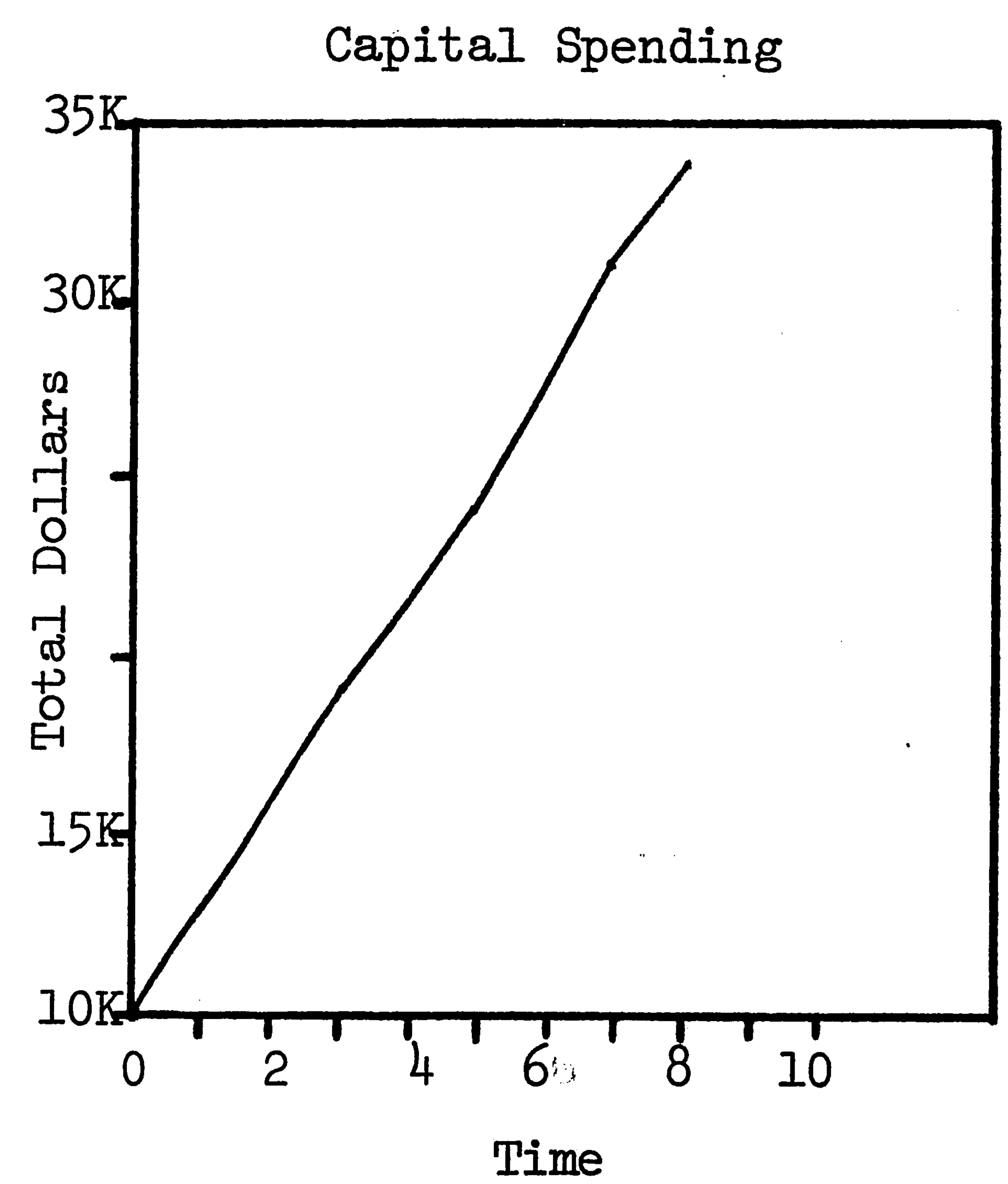
Capital Spending



Product IV



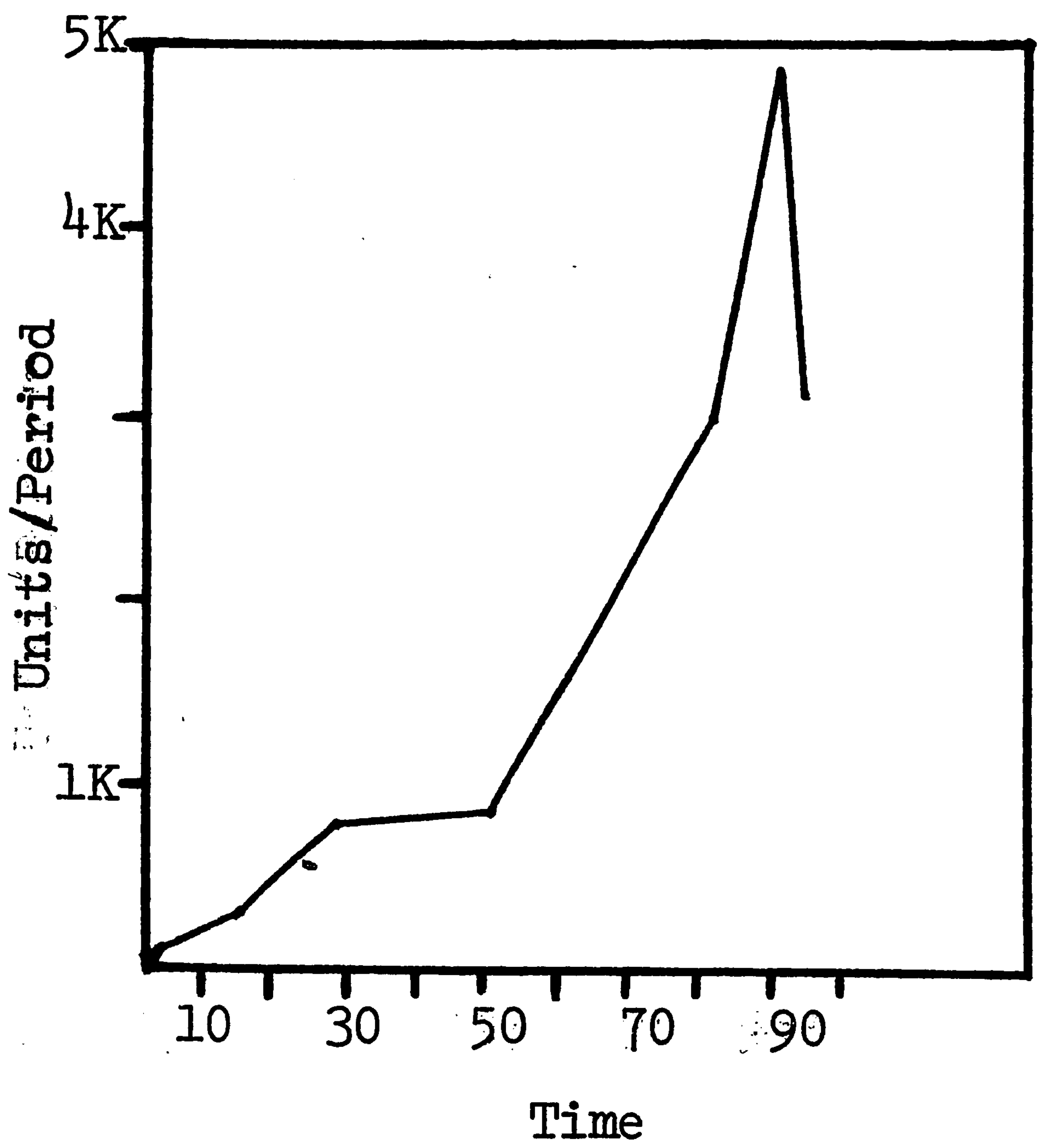
Demand
25K
20K
5K
Units/Period
0
2
4
6
8
10
Time



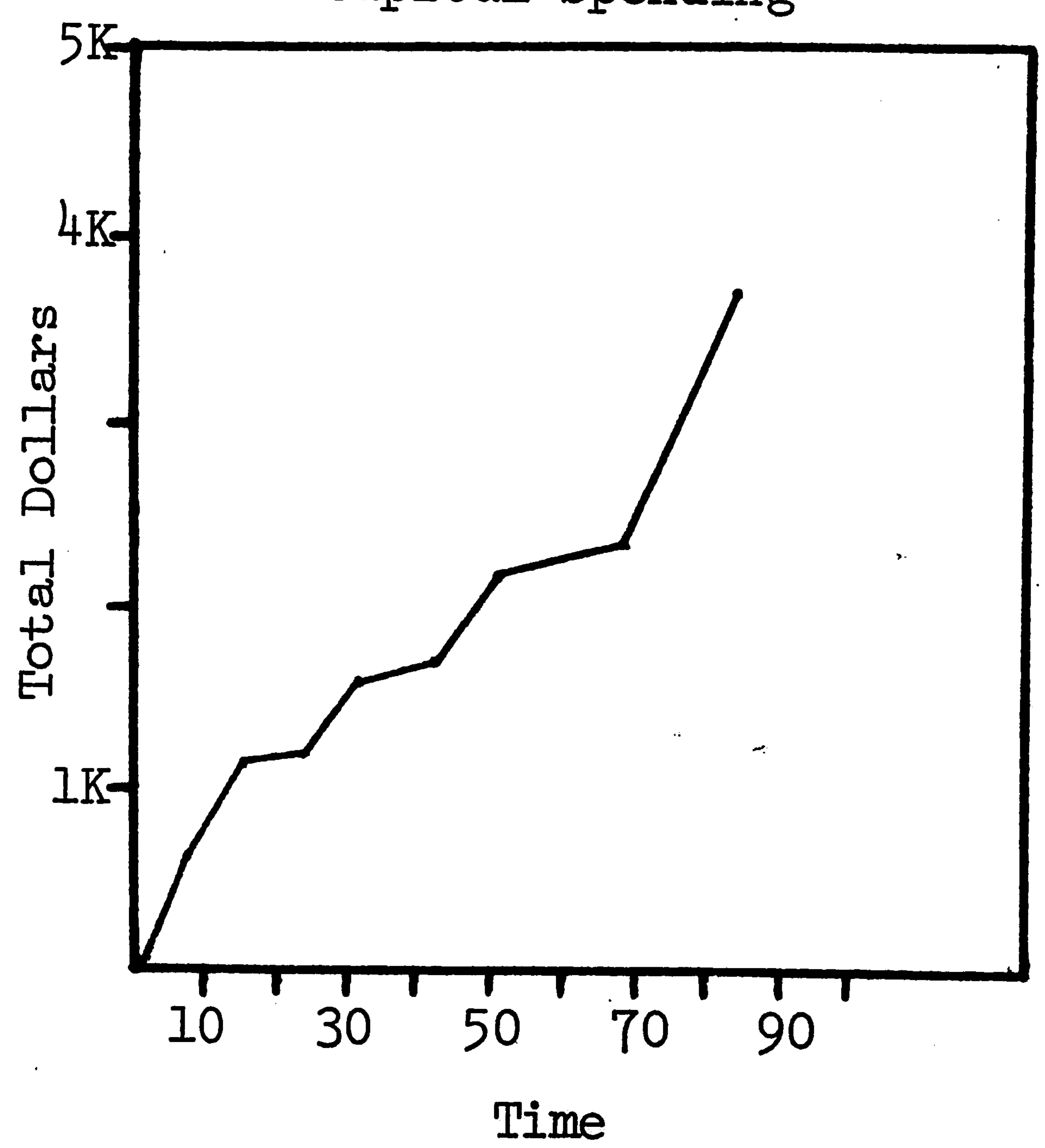
Capital Spending
35K
30K
15K
10K
Total Dollars
0
2
4
6
8
10
Time

Product V

Demand



Capital Spending



BIBLIOGRAPHY

1. Andress, Frank J., "The Learning Curve as a Production Tool," Harvard Business Review, Vol. 32, No. 1, January-February, 1954, pp. 87-97.

2. Ayres, Robert V., Technological Forecasting and Long Range Planning, McGraw-Hill, New York, 1969.

3. Baloff, Nicholas, "Extension of the Learning Curve - Some Empirical Results," Operational Research Quarterly, Vol. 22, No. 2, pp. 329-340.

4. Billion, S. A., "Industrial Learning Curves and Forecasting," Management International Review, No. 6, 1966, pp. 65-79.

5. Carr, G. W., "Peacetime Cost Estimating Requires New Learning Curves," Aviation, Vol. 45, April, 1946, pp. 76-77.

6. Cochron, E. B., "New Concepts of the Learning Curve," Journal of Industrial Engineering, July-August, 1968, pp. 317-327.

7. Colasuonno, Vincent, An Analysis of Progress Curve Conceptual Advances and Progress Curve Uses Since 1956, Master's Thesis, Air Force Institute of Technology, February 15, 1967.

8. Conway, R. W. and Schultz, Andrew, "The Manufacturing Progress Function," Journal of Industrial Engineering, January-February, 1959, pp. 39-53.

9. Crawford, J. R. and Strauss, E., "World War II Acceleration of Airframe Production," Air Material Command, Wright Patterson AFB, Dayton, Ohio, 1947.

10. Duncan, A. J., Quality Control and Industrial Statistics, Richard D. Irwin, Inc., Homewood, Ill., 1965.

11. Durbin, J. and Watson, G. S., "Testing for Serial Correlation Least Squares Regression I," Biometrika, Vol. 37, 1950, pp. 409-428.

12. __________, "Testing for Serial Correlation Least Squares Regression II, "Biometrika, Vol. 38, 1951, pp. 159-178.

13. Goddard, C. T., Private Communications with Permission, Bell Telephone Laboratories, Allentown, Pa.

BIBLIOGRAPHY (cont'd)

14. Himmelblau, D. M., Process Analysis by Statistical Methods, John Wiley and Sons, Inc., New York, 1970.

15. Hirsch, W. Z., "Manufacturing Progress Functions," The Review of Economics and Statistics, Vol. 34, May, 1952, pp. 143-155.

16. Hirschmann, W. B., "Profit From the Learning Curve," Harvard Business Review, January-February, 1964, pp. 125-139.

17. Hoffman, S. F., "Comment on the Modified Form of the Aircraft Progress Function," Rand Report, No. 464, Santa Monica, California, 1950.

18. Johnston, J., Econometric Methods, McGraw-Hill, New York, 1963.

19. Kolensky, W. R., The Application of a Manufacturing Progress Function to a High Volume Product with Missing Historical Data, Master's Thesis, Lehigh University, June, 1964.

20. Leftwich, Richard H., The Price System and Resource Allocation, Dryden Press, Inc., Hinsdale, Ill., 1970.

21. Lele, P. T. and O'Leary, J. W., "Applications of Production Functions in Management Decisions," AIIE Transactions, Vol. IV, No. 1, March, 1972.

22. Lubell, P. D. and Biquette, J. W., "Estimating for Production Rate Changes," Technical Paper presented at 23rd Annual AIIE Conference, Anaheim, California, 1972.

23. Manning, G. B., An Empirical Study of the Predictive Utility of an Exponential Progress Functions, Master's Thesis, Lehigh University, May, 1965.

24. Miller, Irwin and Freund, John E., Probability and Statistics for Engineers, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1965.

25. Moore, F. G. and Jablonski, R., Production Control, McGraw-Hill, New York, 1969.

26. Orsini, J. A., An Analysis of Theoretical and Empirical Advances in Learning Curve Concepts Since 1966, Master's Thesis, Air Force Institute of Technology, March, 1970.

27. Russ, W. D., Development of a Manufacturing Progress Function to Include the Transferability of Progress in Order to Relate to Dual Sourcing within a Firm, Master's Thesis, Lehigh University, May, 1970.

28. Russell, John H., "Progress Function Models and Their Deviations," Journal of Industrial Engineering, January, 1968, pp. 5-10.

29. Stover, Clyde N., Jr., Development and Application of Learning Curves, Master's Thesis, Polytechnic Institute of Brooklyn, June, 1965.

30. Thayer, R. P., Private Communications with Permission, Western Electric Co., Inc., Princeton, New Jersey.

31. Tooker, H. A. and Bodmar, M. W., "Economic Consideration in the Design and Manufacture of Integrated Circuits," The Western Electric Engineer, December, 1967, pp. 52-61.

32. Wright, T. P., "Factors Affecting the Cost of Airplanes," Journal of Aeronautical Science, Vol. 3, No. 2, February, 1936, pp. 122-128.

VITA

PROFESSIONAL EXPERIENCE:

Name:	Robert S. Breeden, Jr.
Date of Birth:	October 3, 1947
Place of Birth:	Fredericksburg, Virginia
Parents:	Robert S. and Shirley J. Breeden
Wife:	Jacqueline P. Breeden

EDUCATIONAL BACKGROUND:

James Monroe High School Fredericksburg, Virginia	Graduated 1965
Virginia Polytechnic Institute and State University Blacksburg, Virginia Bachelor of Science in Industrial Engineering	1965-1969
Lehigh University Bethlehem, Pennsylvania Candidate for a Master of Science Degree in Industrial Engineering	1971-1973

HONORS:

Alpha Pi Mu, Tau Beta Pi, Phi Kappa Phi

PROFESSIONAL EXPERIENCE:

Western Electric Company, Inc. Burlington, North Carolina Industrial Engineer	1969-1971
Western Electric Company, Inc. Princeton, New Jersey Development Engineer	1971-1973