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Development of a manufacturing progress function to include the transferability of progress in order to relate to dual sourcing within a firm

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DEVELOPMENT OF A MANUFACTURING PROGRESS FUNCTION TO INCLUDE THE TRANSFERABILITY OF PROGRESS IN ORDER TO RELATE TO DUAL SOURCING WITHIN A FIRM

by William D. Russ

ABSTRACT

The applicability of Progress Function concepts to the problem of dual sourcing a product at two manufacturing facilities within a firm is considered. Using Progress Function concepts, a model is formulated which considers the transfer of progress or know-how from the original manufacturing facility to the second facility. Manufacturing data on five products, dual sourced within a firm, are used to evaluate the model.

Results of the evaluation support the hypothesis that, given a suitable environment, a transfer of progress does occur between the two facilities. Further, the model formulated in this thesis effectively describes the transfer of progress for the five products studied.

The application of the model resulted in the conclusion that, given a dual sourcing program for a firm wherein certain basic conditions prevail, the progress achieved at the original source can be considered transferable to the second source. Furthermore, the amount of progress achieved at the original source is directly related to the cumulative production count at the time of dual sourcing. These facts, when used with a suitable time frame over which the transfer of progress occurs, enables the analyst to make reliable forecasts of the input requirements at the second source. Forecasts made for one firm, engaged in high volume production of electron devices, were found to be reliable for forecast periods exceeding three years and cumulative production exceeding one hundred million units.

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REFERENCES: Listed in Bibliography

INDEXING TERMS: Progress Function, Learning Curve, Experience Curve, Improvement Curve, Progress Index

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by
William D. Russ

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Lehigh University

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May 12, 1970
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Professor in Charge

Chairman of the Department of
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and cumulative production exceeding one hundred million units.

CHAPTER I
Introduction

The Manufacturing Progress Function is a mathematical model which has been used historically to forecast labor and/or cost data pertaining to a particular product as a function of the number of units of that product produced. Indeed, the progress function is an attempt to represent mathematically the intuitively accepted hypothesis that as one gains experience from repeatedly performing a task he becomes more adept and performs the task in less time. For industry this is interpreted to imply that as cumulative production increases unit labor requirements and/or unit cost decrease, hence, progress is realized.

Progress, in a manufacturing facility, is due to the collective efforts of many individuals working toward the common goal of improving overall performance. In order to use the manufacturing progress function one must accept the underlying assumption that in industry progress is sufficiently regular to be predictive. The fact that progress may be due to the interaction of many different factors does not alter this assumption.

It would be difficult, if not impossible, to catalog the many various factors which contribute toward the progress realized within a manufacturing organization. Even more difficult would be the task of quantifying the contribution of each factor. A partial listing of some of the more recognized factors are:

1) Learning by the operator.

2) Improved management techniques.

3) Better methods: redesign of tools, jigs, assembly lines, etc.

4) Preproduction planning.

5) Training.

6) Quality control.

7) Inventory control and procurement.

8) Improved scheduling.

9) State of the art.

10) Retained or transferred experience.

11) Environmental conditions.

12) Recognition that the potential for progress exists and seeking it.

There presently exists a large body of literature concerned with progress functions. Much of this is philosophical in nature and is primarily concerned with expounding the virtues of using the progress function as a management tool. Coupled with this is a number of substantial articles describing the successful applications of progress functions in various areas of industry. As a result, progress functions are now accepted in most areas of industry as an important forecasting tool. As their popularity has increased new areas for their potential application are being investigated. One such area, which will be the subject of this thesis, is the application of progress functions to the problem of dual sourcing within a firm.

The decision whether or not to dual source is one that is faced often in an expanding, multi-plant firm. When considering the option of dual sourcing production labor requirements at the second source can be of prime importance to the decision maker. An "estimating function"[7] that would forecast these requirements would be of obvious benefit. The progress function, itself and estimating function, appears to be a logical foundation on which to build an estimating model for predicting the labor requirements that will be required at the second source.

CHAPTER II
History and Development of the Progress Function

Progress function theory is some three decades old. During this time the technique has been known by various names such as learning curve,[2] experience curve,[18] time-reduction curve,[5] and improvement curve.[29] Of the various designations in use progress curve seems to be more applicable since it is less restrictive and at the same time more descriptive. (The term progress is defined in the preceding chapter.)

T. P. Wright[30] is recognized as contributing the original formulation of the progress curve concept in 1936 when he reported the results of an empirical study made in the air frame industry. Wright concluded that the average, direct labor hours required to produce an aircraft of a particular series diminished as cumulative production increased. He proposed the following power function as a model to describe the relationship between average, direct man hours and cumulative production:

$$\overline{Y} = AX^{b} \qquad (1)$$

where:

$\overline{Y}$ = cumulative average man hours per unit

X = cumulative production count

A = man hours required for first unit

b = rate of progress

In the above formulation b is a negative fraction, hence, $\overline{Y}$ is a decreasing function of X. The parameter A, in actual practice, represents the theoretical man hours required to produce the first unit. This is necessary because the actual man hours expended on the first unit is rarely, if ever, known. Typically, production data is recorded on a time basis (weekly or monthly) rather than on a unit basis. Hence, A is normally determined by considering a "lot," usually consisting of many units, produced over the time interval being used as an accounting basis. The smaller the "lot" the better.

For clarity rewrite equation (1) as

$$Y = AX^{-b} \qquad (2)$$

where:

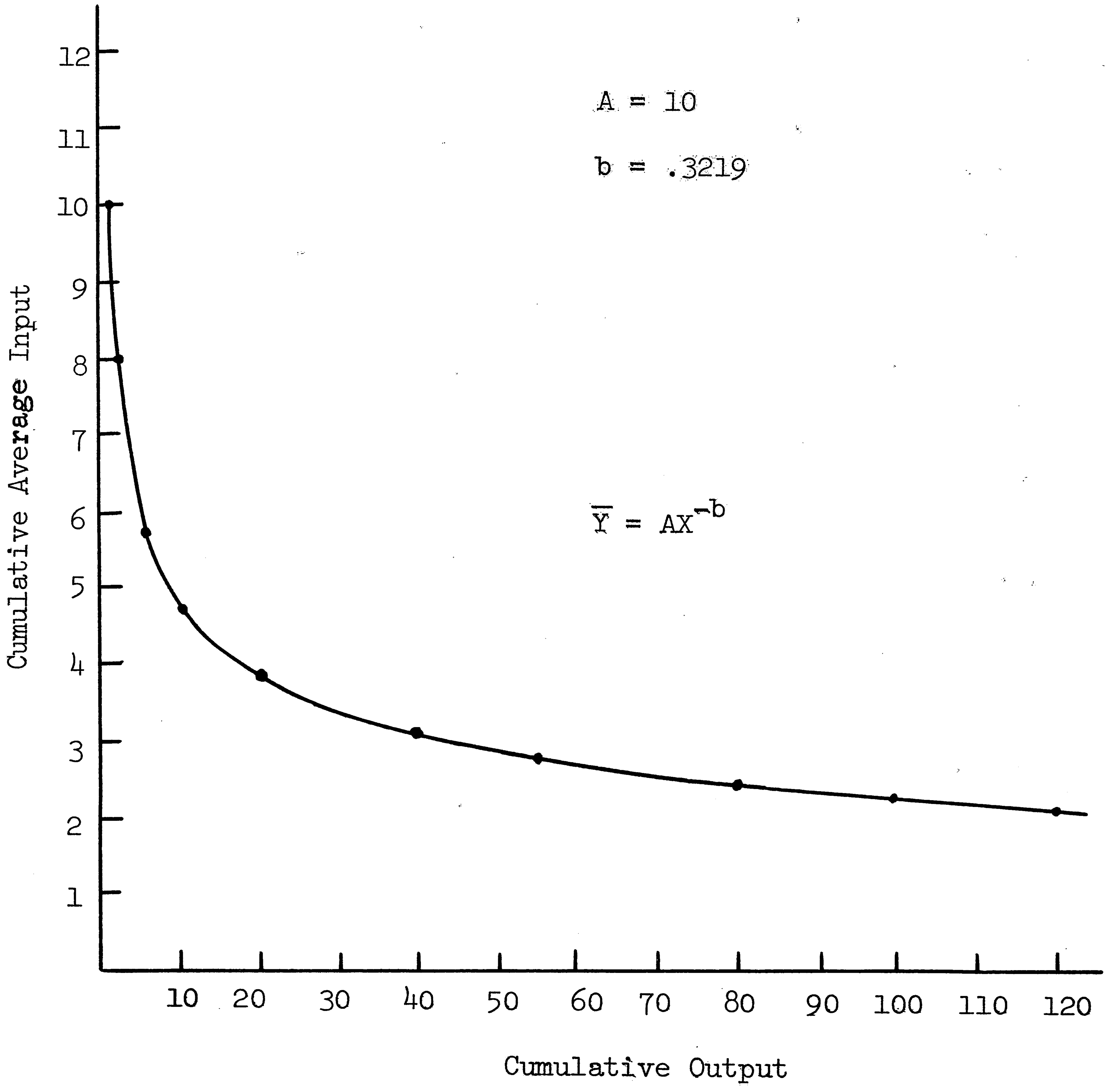
Parameters are as previously defined and $0 < b < 1$.

It is now clear that $\overline{Y}$ is indeed a decreasing function of X and that a plot of $\overline{Y}$ against X on Cartesian coordinates will produce a hyperbolic curve as shown in Figure I.

Before proceeding further it is necessary to define one additional term which is commonly used when dealing with progress functions. Researchers in general do not use the numerical value of b to describe the rate of progress. Instead they use a term called "slope." Slope here is not defined in the ordinary mathematical sense as being the first derivative of the function. Instead it is defined as the ratio of the average labor requirements at two points in production that vary by a factor of two. For instance, if a man hour figure $\overline{Y}_1$ is determined for output X_1 and a second man hour figure $\overline{Y}_2$ is determined for output X_2 where $X_2 = 2X_1$ the slope will be the ratio of $\frac{\overline{Y}_2}{\overline{Y}_1}$.

FIGURE I

80% Progress Function Plotted on Cartesian Coordinates



Hence,

$$\text{slope} = \frac{\overline{Y}_2}{\overline{Y}_1} = \frac{AX_2^{-b}}{AX_1^{-b}} = 2^{-b}$$

If, for instance, the parameter b was determined to have a value of 0.322 the slope of the progress curve would be $2^{-.322} = .8$ or in percentage terms 80%. Hence, the progress curve is said to have an 80% slope. The interpretation is that each time cumulative production doubles the average man hours required to produce a unit is 80% of its previous value. For the sake of clarity many researchers use the term "progress index" (PI) instead of slope. The term progress index will be used throughout this thesis.

Probably one of the most attractive characteristics of the progress function is noted when it is expressed in its so-called "log-linear" form. Taking the logarithm of equation (2) obtain:

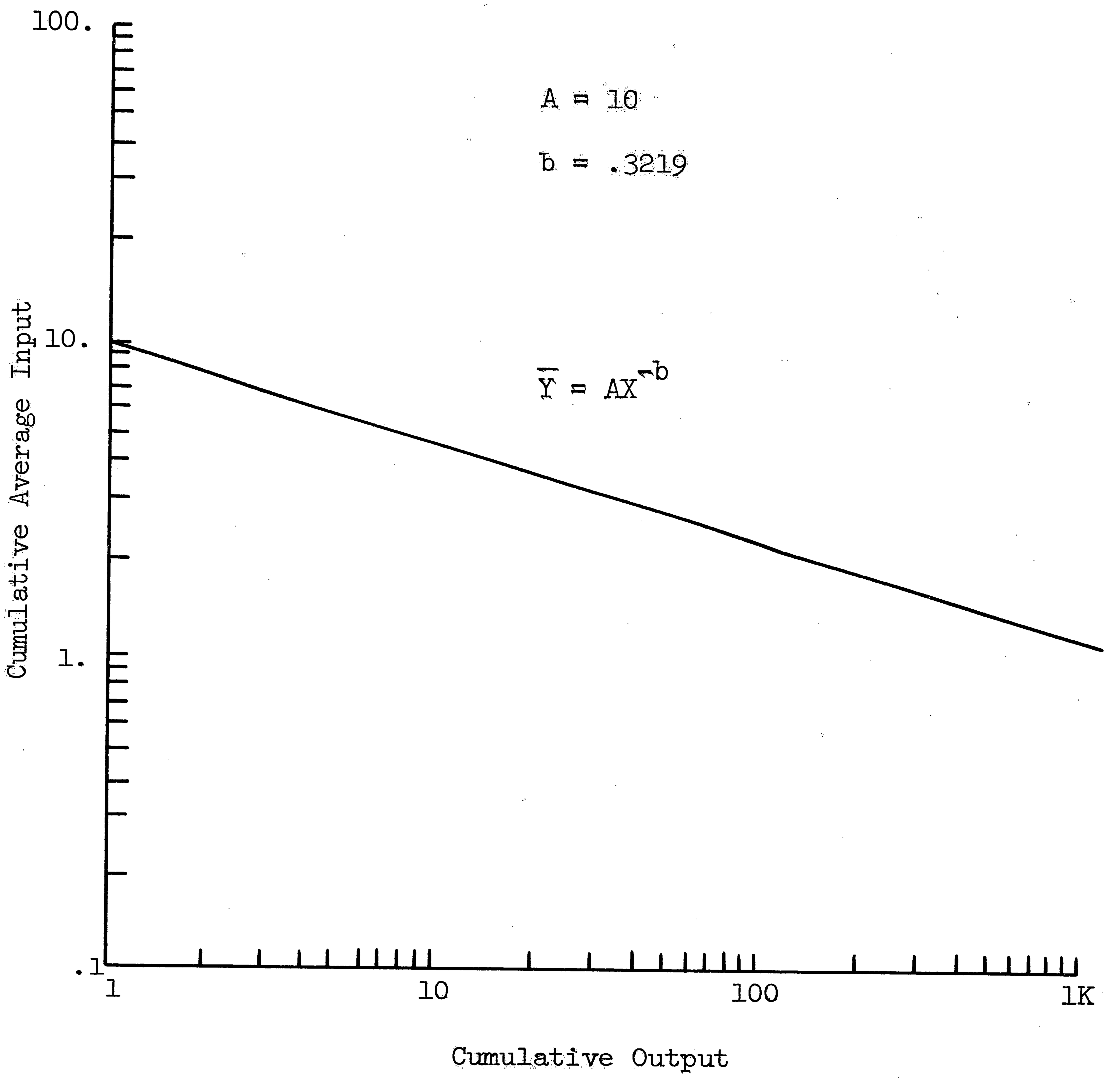
$$\log \overline{Y} = \log A - b \log X \qquad (3)$$

When plotted on logarithmic coordinates, equation (3) produces a straight line, as shown in Figure II. The desirability of using the function in this form is obvious. The log of $\overline{Y}$ and X are in linear relationship. Each time X doubles the successive values of $\overline{Y}$ are a constant multiple of the preceding value. In the log-linear form the progress curve can easily be plotted and interpreted.

The basic progress curve model as proposed by Wright has been the object of much analysis by researchers. Wright's model was based on his study of air frame data. Unfortunately, he gave no clue as to the methodology used in his analysis. He did imply, however, that the

FIGURE II

80% Progress Function Plotted on
Logarithmic Coordinates



improvement in the worker's proficiency as he repeatedly performed a task was a causative factor in the relationship. This would indicate that Wright considered operator learning as being the most important factor in determining the rate of progress. This opinion has been shared by other authors.[12] However, most authors do not agree with this line of reasoning.[11, 16]

It is generally conceded that operator learning does account for the initial large reduction inherent in the progress function. However, operator efficiency will, over a short period of time, stabilize. Since studies have shown that progress continues over very long periods of time and high production counts it is evident that there are other causative factors involved.[11] A partial listing of these were given in Chapter I.

A significant departure from Wright's model was made by J. R. Crawford.[12] Although significant the departure was only in terms of the definition of the dependent variable. Carwford's model is as follows:

$$Y = AX^{-b} \qquad (4)$$

where:

Y = direct man hours for the X^{th} unit

X = cumulative production count

A and b as previously defined

The cumulative average feature of the Wright model has the property of dampening variations, particularly at high levels of cumulative product. The Crawford model, referred to as the unit model, is much more sensitive to variations in the data which can, in practice, be of great importance in analyzing a particular product line.

There seems to be little conclusive evidence as to which model is superior. Conway and Schultz[11] state that, "since proponents of neither model are able to establish their position by logic, the choice in usage has been a matter of computational convenience."

Two other "modifications" to the progress function model have been suggested which deserve a brief comment.

G. W. Carr[5] suggested that the Wright model did not offer a good explanation of World War II aircraft production data. Carr found that in certain cases the rate of progress, $\underline{b}$, did not appear to be a constant but rather a variable. He suggested that two or more values of $\underline{b}$ would be needed, at various production quantities, to properly describe the data. Carr offered no formal relationship in support of his conclusions, but the model he suggests is analogous to the "Boeing-Hump Curve" which uses two values of $\underline{b}$.[5] Since this model has not received wide acceptance it will not be pursued further here. The interested reader is referred to the bibliography.[5]

The last modification to be mentioned is one suggested by researchers at the Stanford Research Institute while doing research for the Air Force.[31] The researchers, as did Carr, noted that the World War II airframe data were inconsistent and did not fit the Crawford unit model. Rather than use a variable rate of progress they suggested the addition of a new variable which would be a measure of the complexities that existed in a plant, relative to a product, prior to the production of that product. The model was as follows:

$$Y = A(B + X)^{-b} \tag{5}$$

where

B = a constant number of units and is determined empirically; all other parameters as previously defined

While this model did not enjoy universal acceptance,[17] it was an attempt to take into account such factors as "carry over experience" and "experience transfer," an area that deserves further investigation and is of considerable importance in considering dual sourcing within a firm.

All of the earlier development as well as application of the progress function was restricted to the airframe industry. There are three primary reasons for this. First, of course, is the fact that the progress function concept was conceived in the airframe industry. Secondly, the U. S. Air Force was interested in verifying the concept for the purpose of planning and controlling the various requirements of defense production programs prior to and during World War II. To this end they (Air Force) initiated and financed several in depth studies. These studies, based to a large degree on data taken from the airframe industry, made an important contribution toward the development and acceptance of the progress function concept. One of the most comprehensive and definitive studies was made by Harold Asher.[3] It is an important reference since it provides a summary of the various models current with the year of its publication (1956).

A third reason is that prior to the 1950's little reference to progress functions could be found in the trade journals.

Although other industries were slow to realize that the progress function concept was applicable in their areas, the trend started changing in the early fifties when articles concerning progress functions began appearing in the trade journals. This trend has continued as more and more industries have become aware of the potential usefulness of progress functions as a forecasting tool.

One of the first empirical studies outside of the airframe industry was made by W. F. Hirsch.[15] Following the study by Hirsch came studies by Andress,[2] Conway and Schultz,[11] Hirschmann,[16] Hoffmann,[18] Cochran,[9] Williams,[29] Billon,[6] and others. The result was to establish the fact that progress functions were not just the property of the airframe industry but to industry in general. Hirschmann,[16] writing in the Harvard Business Review stated, "no matter what products you manufacture or what type of operation you manage, there is a good possibility that you can profit from the learning curve" (progress curve).

Consequently, the progress function now enjoys almost universal acceptance throughout industry. The fact is that it is often blindly accepted without the user being aware of the dangers and pitfalls which exist. The progress function is a dynamic forecasting tool which can be used fruitfully in many areas of manufacture. But, as can any forecasting tool, its usefulness can be quickly negated if the progress curve in use is not based on the true conditions existing within a facility or is not "updated" whenever there is reason to believe that conditions have changed. To this end it is of great importance that the constants A and b be determined empirically using as accurate data as possible.

With the widespread availability of computing devices and mathematical programs values of A and b are best determined by the method of least squares[1] using paired data (X, Y) of the product being investigated. This method will provide the best linear fit to the data without making any assumptions about the distribution of the paired data. The one assumption is that the error exists in the dependent variable (Y). Further, by using this method (and assuming normality) one has the added advantage of having an indication of the linearity of the data by calculating the correlation coefficient. Also, if sufficient data points are available statistical tests can be made on the parameters.

CHAPTER III

The Progress Function and Dual Sourcing

The area of dual sourcing appears to have received less than its share of attention in the literature considering its wide applicability in the present day industrial environment of expanding, multi-product, multi-plant firms. In such firms it is not uncommon for a particular product, being produced at one plant, to become a candidate for manufacture at a second location. This may be due to capacity limitations at the first plant, reorganization of manufacturing responsibilities, or any one or more other reasons. Whatever the reason, the economic implications that are associated with dual sourcing require that this area of manufacturing be better understood. Faced with a dual sourcing decision management would do well to have a means of forecasting the requirements for production at the second source.

It has been stated that the intent of this thesis is to consider the application of Progress Functions to dual sourcing. In particular the objective is to investigate the usage of Progress Function concepts for forecasting production requirements at the second source. The investigation will be directed toward developing a Progress Function model for dual sourcing which will take into account the transfer of progress or "know-how" from the original source to the second. An evaluation of the model's utility will then be performed by using emperical data obtained from Western Electric Company manufacturing facilities. With this in mind it remains then to establish the boundaries within which the study will be conducted.

Two basic assumptions are required prior to developing the model for dual sourcing. The first is that the firm, for which the model will be developed, is one in which there is an unconstrained interchange or flow of information between plants. The second assumption is that the labor and management at the various plants within the firm are sufficiently uniform to allow the same rate of progress to be used in the Progress Function describing a particular product manufactured at two locations.

While these assumptions are required for the initial development of the model they can, in general, be found to actually exist in industry. The one most likely to be questioned is the second, which assumes that two plants within a firm realize the same rate of progress in producing the same product. But, if one considers the atmosphere of competition within which the plants are likely to be functioning the assumption is quite easily accepted. It goes almost without saying that management at one plant will not sit idly by and watch another plant perform more efficiently in the production of an identical product without taking corrective action. Later in the study situations where these assumptions might be violated will be discussed.

<u>Transfer of Progress</u>

W. B. Hirschmann[16] states that "there are two main factors which affect learning: (1) the inherent susceptibility of an operation to improvement, and (2) the degree to which that susceptibility is exploited." Similarly one might say that there are three basic factors which affect the transfer of progress between two facilities: (1) the amount of progress or "know-how" that has been obtained at the original manufacturing facility pertaining to a product, (2) the efficiency by which this know how can be transmitted to the second facility, and (3) the ability of the second facility to absorb this know-how. Since we have assumed that there exists an environment such that there is on unconstrained interchange of information available the second factor can, for the time being, be disregarded. Therefore, the first and third factors are left to be considered. These will be discussed in order.

The applicability of the Progress Function as a forecasting tool for predicting labor or cost requirements in various areas of industry has been well documented. (The interested reader is directed to the bibliography, especially 2, 3, 4, 5, 6, 11 and 16). Almost without exception these studies have pointed out that progress does exist, that it can be measured and that it is sufficiently regular to be predictive. On the basis of these findings one can conclude that the Progress Function which describes a particular manufacturing process is, itself, a measure of the amount of progress which a facility has obtained. If, in fact, from historical data the parameters A and b are determined then the cumulative production count (X) can be considered directly related to the progress obtained. Since, for any program which considers dual sourcing, the cumulative production count at the time of dual sourcing is known, a measure of the progress that has been accumulated is available.

There is left then one unknown factor, the ability of the second facility to absorb the know-how transferred to it. The initial approach to determining the impact of this factor on dual sourcing was to consider the specific conditions under which dual sourcing was initiated. On the basis of these conditions the affect of this factor would be estimated. The measure of progress achieved at the first plant along with the estimated ability of the second source to absorb this progress would then be used in the proposed model for dual sourcing which is developed in the succeeding paragraphs.

The Dual Sourcing Model

Assume that due to capacity limitations production of a particular product is to be initiated at a second plant and from historical data the process at the original location can be described by the function:

$$\bar{Y}_1 = A_1 X_1^{-b}$$

where

$\bar{Y}_1$ = Cumulative average input per unit

X_1 = Cumulative production count

A_1 = Input for first unit

b = Rate of Progress

Subscript 1 indicates original plant.

As previously discussed, the progress achieved at this location would be a function of the cumulative production count (X_1). Therefore, if there was a complete or total transfer of progress, the process at the second facility would continue, neglecting initial startup problems, as if dual sourcing never occurred. The Progress Function for the second facility would be

$$\bar{Y}_2 = A_1 \, (X_{1ds} + X_2)^{-b} \qquad (7)$$

where

$\bar{Y}_2$ = Cumulative average input per unit

X_{1ds} = Cumulative production count at time of dual sourcing

X_2 = Cumulative production count at the second source

b = Rate of Progress

Graphically this would appear as shown in Figure III.

Using similar reasoning if there was no transfer of progress, the process at the second location could be described by the function

$$\bar{Y}_2 = A_1(\psi + X_2)^{-b} \qquad (8)$$

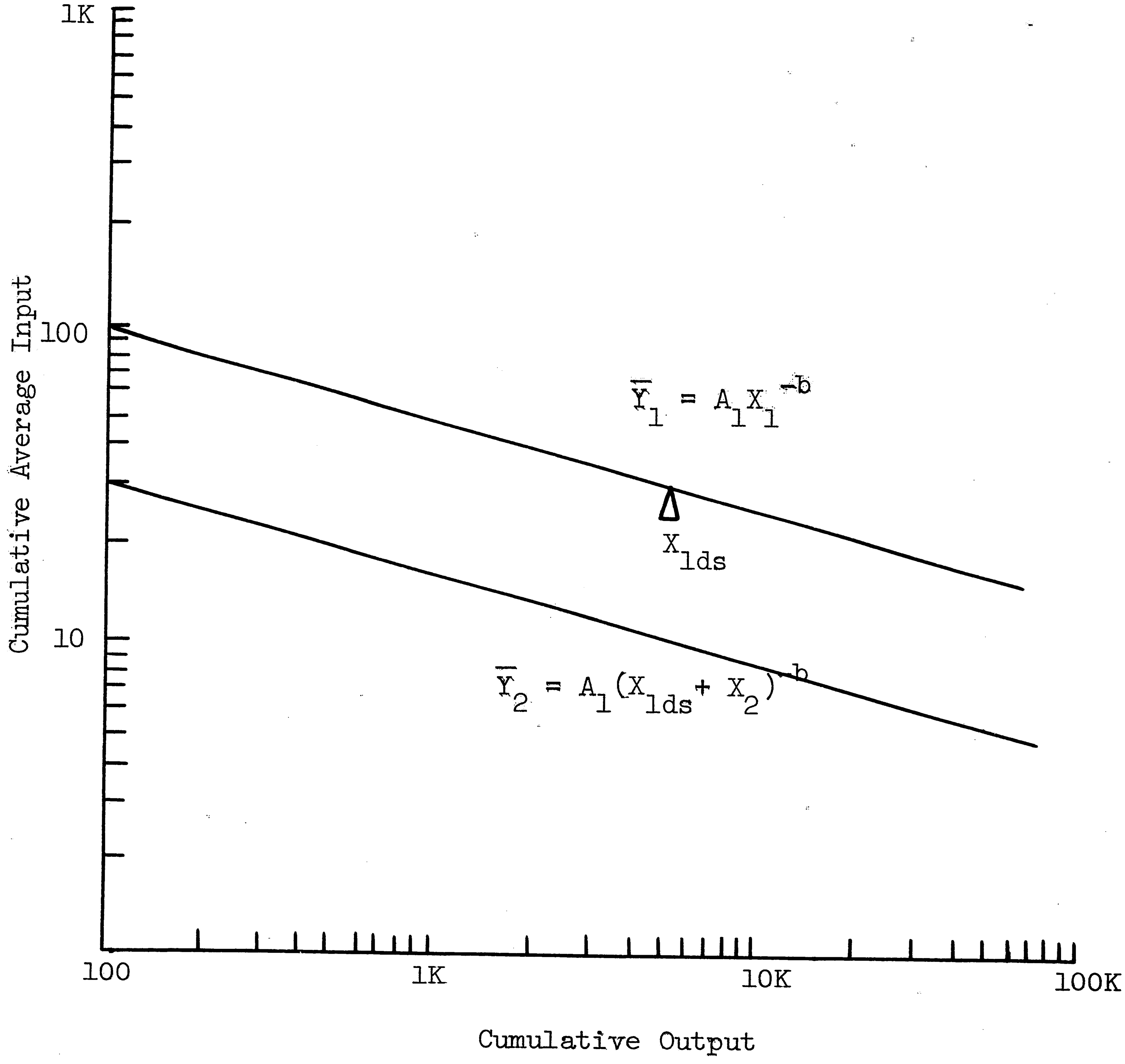
where

ψ = A constant number of units and represents manufacturing technology concerning the product which is of general knowledge.

Since it is unrealistic to assume that either of the two above conditions would exist, something less than (7) but greater than (8) would be expected. In reality then, the amount of know-how absorbed by the second facility would be some fraction, λ, of the progress achieved at the original location. The progress that is successfully transferred to the second facility would then be λX_1 and the Progress Function for the second facility would be expressed as

FIGURE III

Total Transfer of Progress



$$\overline{Y}_2 = A_1(\lambda X_{1ds} + X_2)^{-b} \qquad (9)$$

λ = A transferability factor and includes generally known technology.

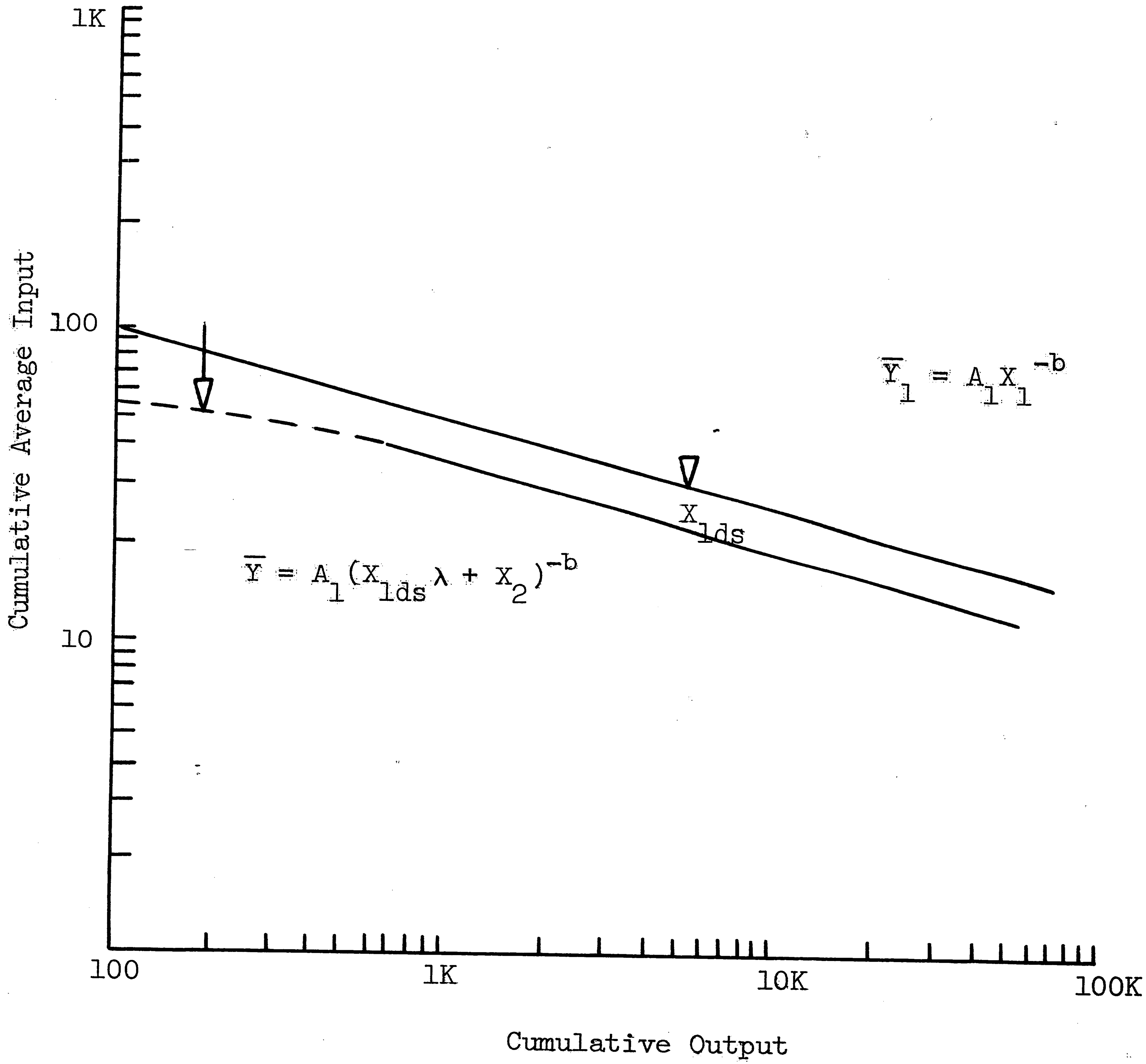
Graphically this function might appear as shown in Figure IV.

Data collected on products that had been dual sourced within Western Electric were used with equation (9) in order to obtain some initial estimates of the parameter λ. The values of λ found using equation (9) were quite small, usually less than 0.05, but more importantly the function failed to describe the process at the second location as the cumulative production count (X_2) increased significantly. Because of this, the logic by which the model (equation 9) had been formulated was re-examined. In particular the transferability parameter λ became the object of additional analysis.

In the model formulated the transfer of progress is considered to be a "one shot affair" with the transfer being accomplished instantaneously at the time dual sourcing is initiated. The amount of progress transferred is, in the final analysis, dependent upon the ability of the second source to absorb or use the know-how available from the original source. If the process is one that is technically difficult or involved and/or if the second source has had little experience in similar processes the ability to immediately put to use the progress available from the first source would be limited hence, the value of λ would be small. However, if the transfer is thought of as being accomplished over a period of time, say several months, a substantially different picture will emerge.

FIGURE IV

Fractional Transfer of Progress



It appears reasonable to assume that the ability of the second source to use the progress available from the original source would depend, to a large degree, on its understanding of the process involved. Once the process was fully understood, essentially all of the progress from the second source could be utilized. Obviously this cannot be the situation immediately upon the start up of the process at the second source. It would be more reasonable to expect an understanding of the process to increase as the cumulative production at the second source increased over a period of time. Consequently we might expect the transfer of know-how to also increase as cumulative production increases.

Under the foregoing assumptions, the problem becomes somewhat simpler to visualize inasmuch as values for the parameter λ do not have to be determined from qualitative facts about the conditions under which dual sourcing occurs. Instead a means of estimating the build-up of cumulative production at the second source, over the first several months of operation, is required.

It is an accepted fact that the second source does not start out, from day one, at its normal anticipated rate of production. Instead a manufacturing start up is normally characterized by a slow, ever increasing build up until the planned rate of production is reached. This is usually accomplished over a period of a few months.[5] It is suggested that under normal conditions the rate of build-up is dependent to a large degree on the rate of progress (b) that is associated with the particular product. This is meant to imply that knowing the Progress Function describing a process the build up of cumulative production, given constant inputs, can be estimated over the first few months.

Consider again the Progress Function model discussed earlier,

$$\overline{Y} = AX^{-b}$$

If $\overline{Y}$ represents the cumulative average input to the process for a cumulative production of X units then the total input is:

$$X_t = \overline{Y}X \qquad (10)$$

Substituting in (10) for $\overline{Y}$ obtain

$$Y_t = AX^{1-b} \qquad (11)$$

which by rearranging becomes

$$X = A^{-(\frac{1}{1-b})} \; Y_t^{(\frac{1}{1-b})}$$

or

$$X = A^* \; Y_t^{(\frac{1}{1-b})} \qquad (12)$$

While it is realized that (12) represents a continuous function, the fact remains that values for the parameters (X) and (Y) are normally available only on a monthly basis. Because of this, a step function will be generated to approximate this function, (12). This is accomplished by considering the input (6) to hold essentially constant each month over the first few months of production. Then the production count over time (monthly) can be estimated by

$$X_i = A \; i^{(\frac{1}{1-b})} \qquad (13)$$

where

$i = 1, 2, 3, \ldots, N$

N = Number of months

X_i = Production count at end of month i

A = Estimated production count at the end of the first month's operation

Since we have concluded that the ability of the second facility to use the progress transferred from the first source is related to the cumulative production at the second source, it follows that the transferability factor of equation (9) is related to (13) and becomes

$$\lambda_i = A\, i^{\left(\frac{1}{1-b}\right)} \tag{14}$$

λ_i = transferability factor through month i; i = 1, 2, 3 ..., N

With the further assumption that essentially all of the know-how available will be successfully transferred to the second facility over a time frame of N months it follows that

$$\sum_{i=1}^{N} \lambda_i = 1$$

hence

$$\lambda_N = A\, N^{\left(\frac{1}{1-b}\right)} = 1$$

and

$$A = N^{-\left(\frac{1}{1-b}\right)}$$

therefore equation (14) becomes

$$\lambda_i = \frac{i^{\left(\frac{1}{1-b}\right)}}{N^{\left(\frac{1}{1-b}\right)}} \qquad (15)$$

Equation (15) can be used to estimate the transferability factor for each month of the time frame that is required to successfully transfer the progress from source one to source two. While this time frame may be subject to variation, especially from firm to firm, it is considered to be relatively constant for a particular product line within a firm. Discussions with various personnel within Western Electric resulted in selecting a time frame of six months for dual sourcing applications in the manufacture of electron devices.

The dual sourcing model under the foregoing considerations then becomes

$$Y_{2,i} = A_1[(X_{1ds} + X_{2,N})\, \lambda_i]^{-b} \qquad (16)$$

where $i = 1, 2, 3 \ldots, N$

$Y_{2,i}$ = cumulative average input at the second source for month i.

X_{1ds} = cumulative production count at source one at time of dual sourcing.

$X_{2,N}$ = forecasted production count at source two over first N months.

λ_i = transferability factor for month i.

A_1 = input requirement for unit one at source one.

b = rate of progress experienced at source one.

N = time frame (# of months) to complete transfer of progress.

Using equation (16) forecasts are made for a time frame of N months. Using the cumulative average input forecasted and the cumulative production count at the end of N months, a hypothetical value for the input required for the first unit at the second source can be calculated by substituting into the basic function

$$\bar{Y}_2 = A_2 X_2^{-b} \tag{17}$$

where

$$A_2 = Y_2 X_2^{-b}$$

Now, using equation (17) forecasts for future input requirements for specified production counts can be made using standard Progress Function techniques.

The model, equation (16), was tested with data collected on five products which have been dual sourced within Western Electric. The results of the test are discussed in the following chapter.

CHAPTER IV
Application of the Dual Sourcing Model

The dual sourcing model (equation 16) developed in the preceding chapter was evaluated using data collected from four manufacturing facilities within Western Electric Company. The purpose of this chapter is to discuss the data and the application of the model.

Selection of Products

Selection of products with which to evaluate the model was made by considering certain basic criteria. For example, it was necessary for the product to have been manufactured at one facility and then dual sourced at one or more other facilities. In addition it was required that the product have a history of continuous production. Production volume throughout the life of the product, or period of study, had to be sufficiently large to justify the application of Progress Function concepts.

The manufacture of electron devices was one area which produced several products that satisfied these basic requirements. In all, five products were selected for investigation. They consisted of electron tubes, transistors, diodes and switches. The five products were dual sourced between two of the following four Western Electric manufacturing facilities: (1) Allentown, Pa.; (2) Reading, Pa.; (3) Kansas City, Mo.; and (4) Winston-Salem, N. C.

All of the products selected are of high volume production. The least yearly production volume for any of the five is measured in hundreds of thousands of units. For only one product is the period for which the study was concerned as short as for years.

The Unit of Measure

Prior to applying Progress Function concepts, the analyst must select a unit for measuring progress. The two most commonly used are (1) the relative inputs of direct labor and (2) the relative dollar inputs. Of the two, the latter is more desirable from a management point of view since the forecasts are in units which management is more accustomed to dealing. On the other hand, the analyst will usually find it more desirable to use relative labor inputs as a unit of measuring progress. This is found to be true even more so in dual source application. There are at least three major reasons why the analyst might prefer to use relative labor inputs as a measure of progress.

The first reason is that it eliminates the need of establishing a constant dollar value in order to account for economic changes. The second reason is that it allows the comparison of the data from two sources without having first to compare cost accounting procedures at each source. It is a generally accepted fact that no two cost accounting departments, even though they apply the same basic techniques, use the same procedures for allocating costs. This is especially true in the application of overhead expense. Finally, the use of relative labor inputs avoids the necessity of dealing with the different labor costs that exist in different geographical areas of the country. Because of these factors the analyst feels that forecasts made on the basis of relative labor inputs are often inherently more accurate than those dealing with relative dollar inputs.[11] Theoretically, however, the Progress Function is insensitive to the selection of the unit by which progress is to be measured.

In the evaluation of the dual sourcing model developed in the preceding chapter both labor inputs and dollar inputs were used as a unit of measurement. The decision as to which input unit of measurement to use for any particular product was made on the basis of the data existing at the two sources and how well it could be correlated between sources.

As in most cases that deal with high volume products, production data is normally available only on a "lot" basis (monthly or yearly). Because of this the cumulative average input per unit was used for measuring progress. This particular method coincides with Wright's original formulation. The particular products used in evaluating the dual sourcing model will not be described further for the usual proprietary reasons. In addition the actual data have been coded in such a manner as to prohibit immediate identity. Since the purpose of this thesis is to investigate the usage of Progress Function concepts for dual sourcing applications the above restrictions should in no way hinder the results of the evaluations.

Applying the Model

The methodology used in manipulating the data on the five products selected to evaluate the utility of the dual sourcing model is discussed in the following paragraphs.

Production data from the first source were collected and used as input to a computer program written in FORTRAN IV for the IBM 1130 computer. The program converted the data to logarithmic form, performed a linear regression, and calculated a correlation coefficient. Using the calculated regression coefficient (b) the program then determined the transferability factor λ (equation 15) to be applied during each of the first six months of production at the second source. By using equation 16, the calculated values of λ, and values obtained from the dual source program for X_{1ds} and $X_{2,6}$, the program then generated the step function for estimating the required inputs for the first six months of production. These estimated values were then used in the Progress Function model, $\bar{Y} = AX_2^{-b}$, to forecast production requirements following the initial six month period. The forecasted input requirements were then compared to the actual requirements at the second source. In order to obtain a plot of the results the actual data from the second source were inputted into the regression program. The results were plotted on log-log coordinates on the same graph that the forecasted values were plotted.

Performing a least square regression on the data from the second source also enabled a comparison of Progress Indices for the two sources. One of the basic assumptions in the formulation of the dual sourcing model was that two facilities, within a single firm, producing the same product experienced essentially the same rate of progress.

Results obtained from applying the model to actual data will be discussed in Chapter V.

CHAPTER V
Results and Analysis

Table I below shows the Progress Indices determined for each of the five products at both the first and second sources. It is noted that the rate of progress experienced at two facilities within a firm,

Comparison of Progress Indices

Product	Source 1	Source 2	Progress Index
1	79.9%	81%	+1.1%
2	70.2%	71%	+ .8%
3	73.6%	75.5%	+1.9%
4	71.9%	71.2%	- .7%
5	78.2%	80.7%	+2.5%

Table I

producing the same product, are in close agreement. The Progress Indices shown for the first source are calculated from actual data up to and including the time of dual sourcing. The indices for the second source are based on the actual data from the time production started at the second source through the last year for which production data were available (1969).

The largest variation between sources (2.5%) for a particular case occurs with Product 5. For some reason, the rate of progress at the second source decreased slightly for this product after the first eighteen months of production. A regression was performed using data for only the first eighteen months (206,540 units) of production and a Progress Index of 78.6% was obtained. This value is in better agreement with the Progress Index determined for the first source and indicates that there was a distinct reduction in the rate of progress after the first eighteen months of production. The causative factors for this decrease in the Progress Index were not determined.

Predicted input requirements at the second source for each of the five products were plotted on log-log coordinates along with the requirements determined by a regression of the actual data in order to obtain a visual presentation of the processes. These plots appear in Figures V through IX. The actual data acquired from each source, the regression results and the predicted values obtained from applying the dual source model are contained in Appendices A through E.

Referring to Figures V through IX, it is noted that all of the products investigated can be described with a good degree of accuracy by the values computed from the forecasting model. This is even more meaningful when it is considered that these forecasts are for periods of three years or more. The largest discrepancies are found at the end of the forecast period. Had the forecast been made for shorter periods of time (yearly) even closer agreement would be noted. In a normal operating environment an update could be expected to occur at least yearly. Thus, variations between forecasted inputs and actual inputs could be used to adjust future forecasts.

The correlation coefficients calculated for the five products and listed in Appendices A through E are all quite high, in excess of .98. Correlation coefficients of .85 or more are normally considered quite good. The high correlation coefficients can be accounted for in part by the use of cumulative average input per unit. As mentioned earlier, Chapter 2, the cumulative average method of measuring inputs tends to smooth the variations one normally finds when using the input per unit. Even so, the high correlation coefficients found for these five products indicate, assuming normality, a high degree of linearity in the data.

FIGURE V

Product One

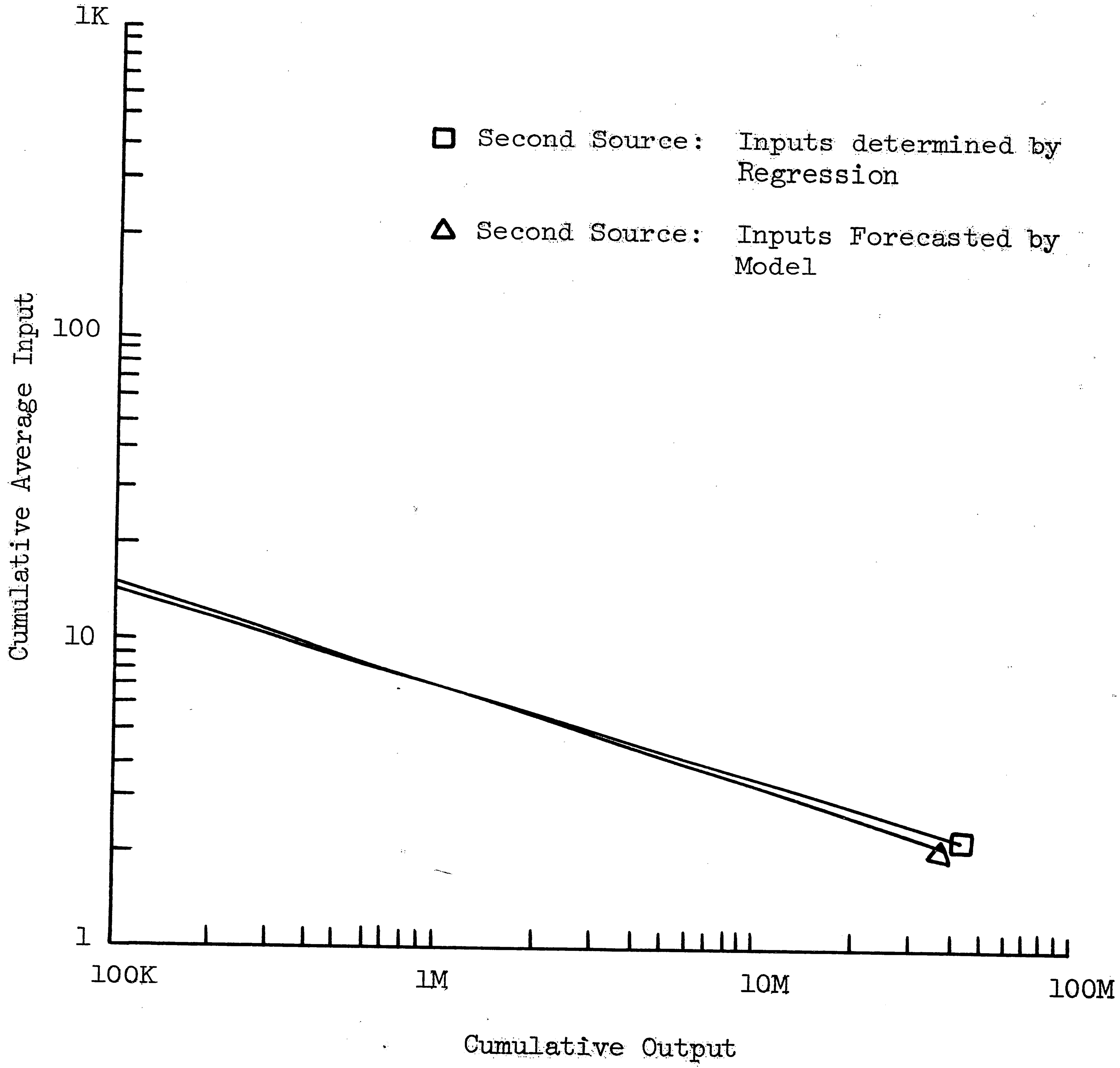


FIGURE VI

Product Two

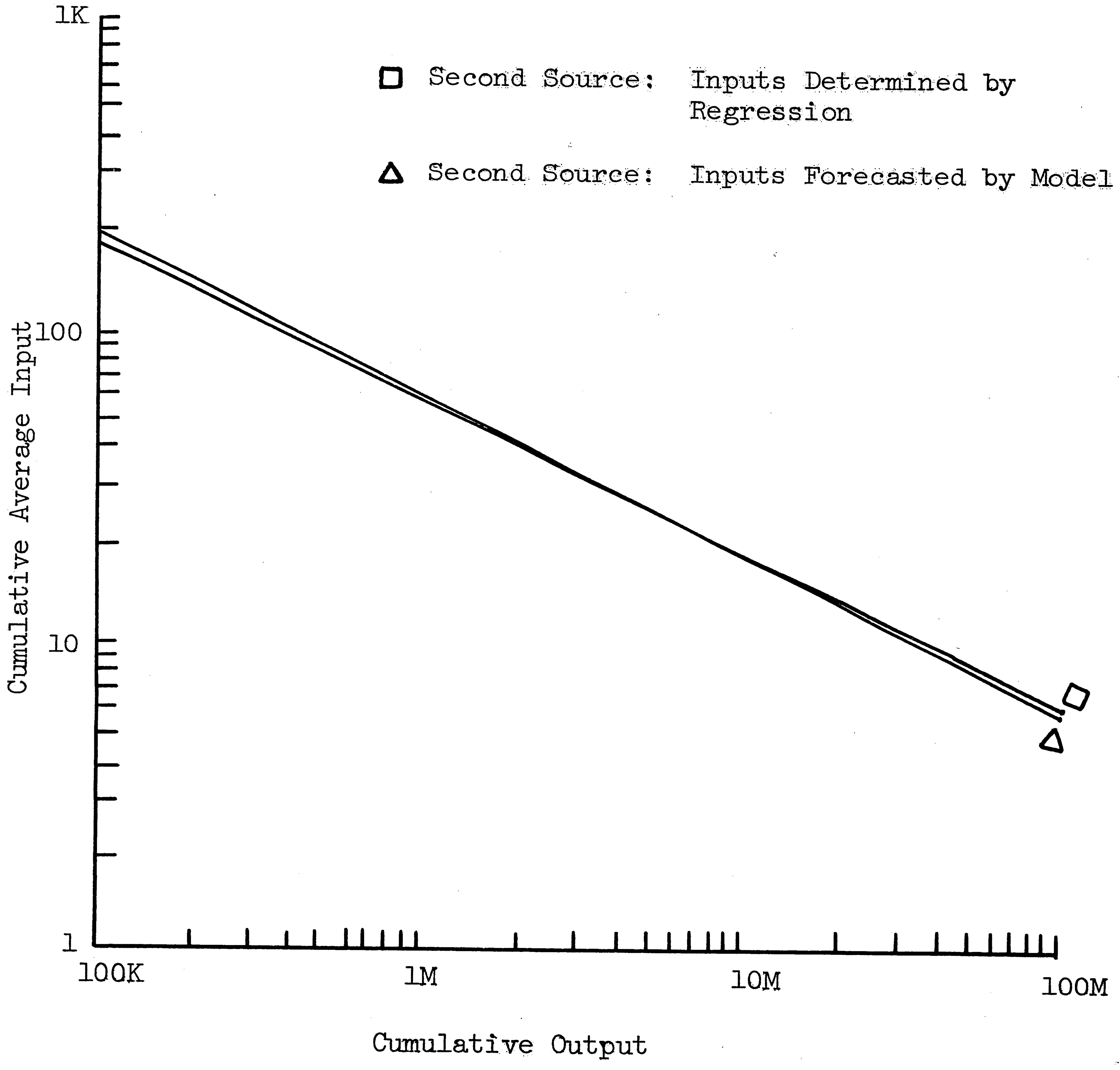


FIGURE VII

Product Three

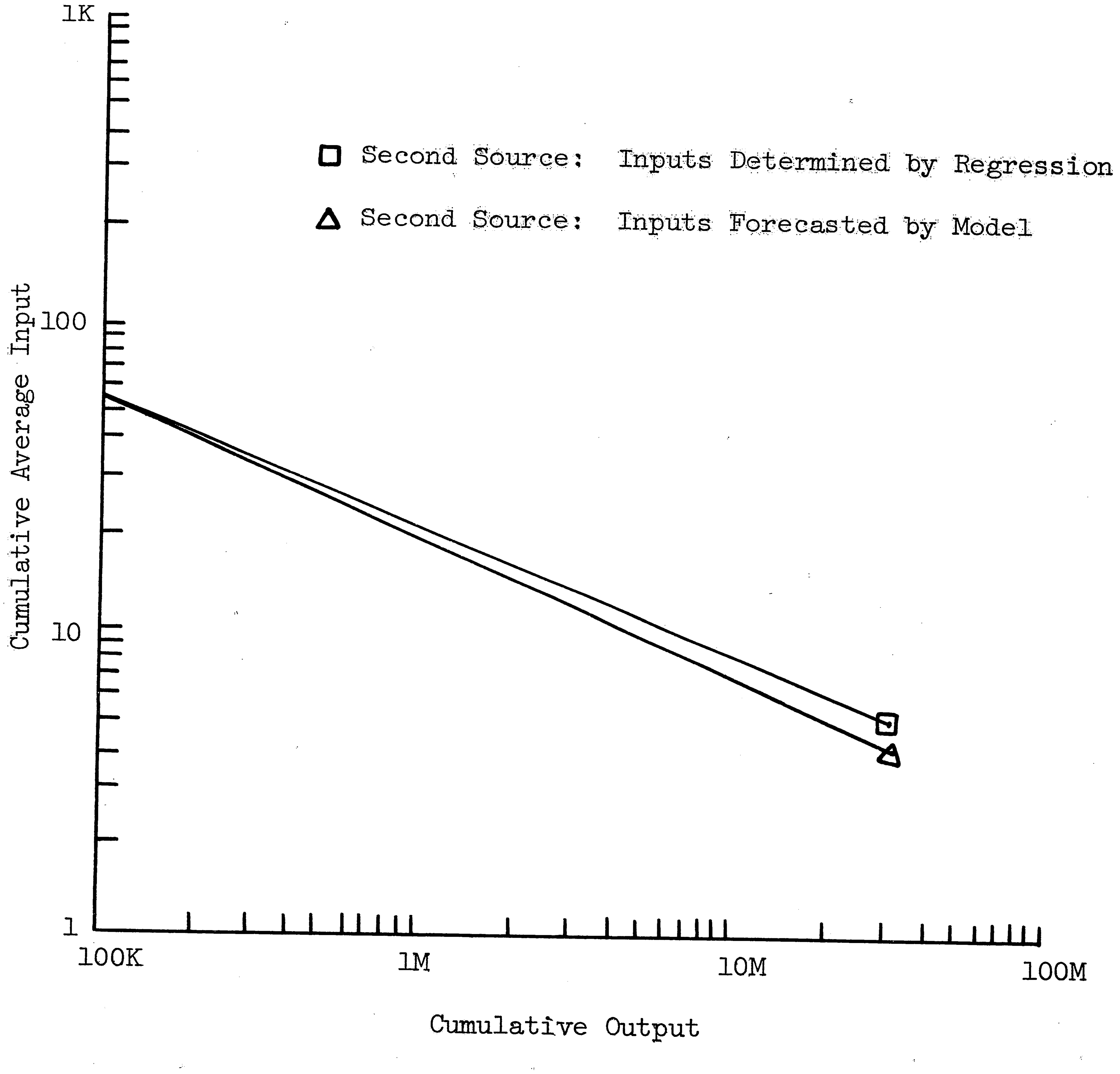


FIGURE VIII

Product Four

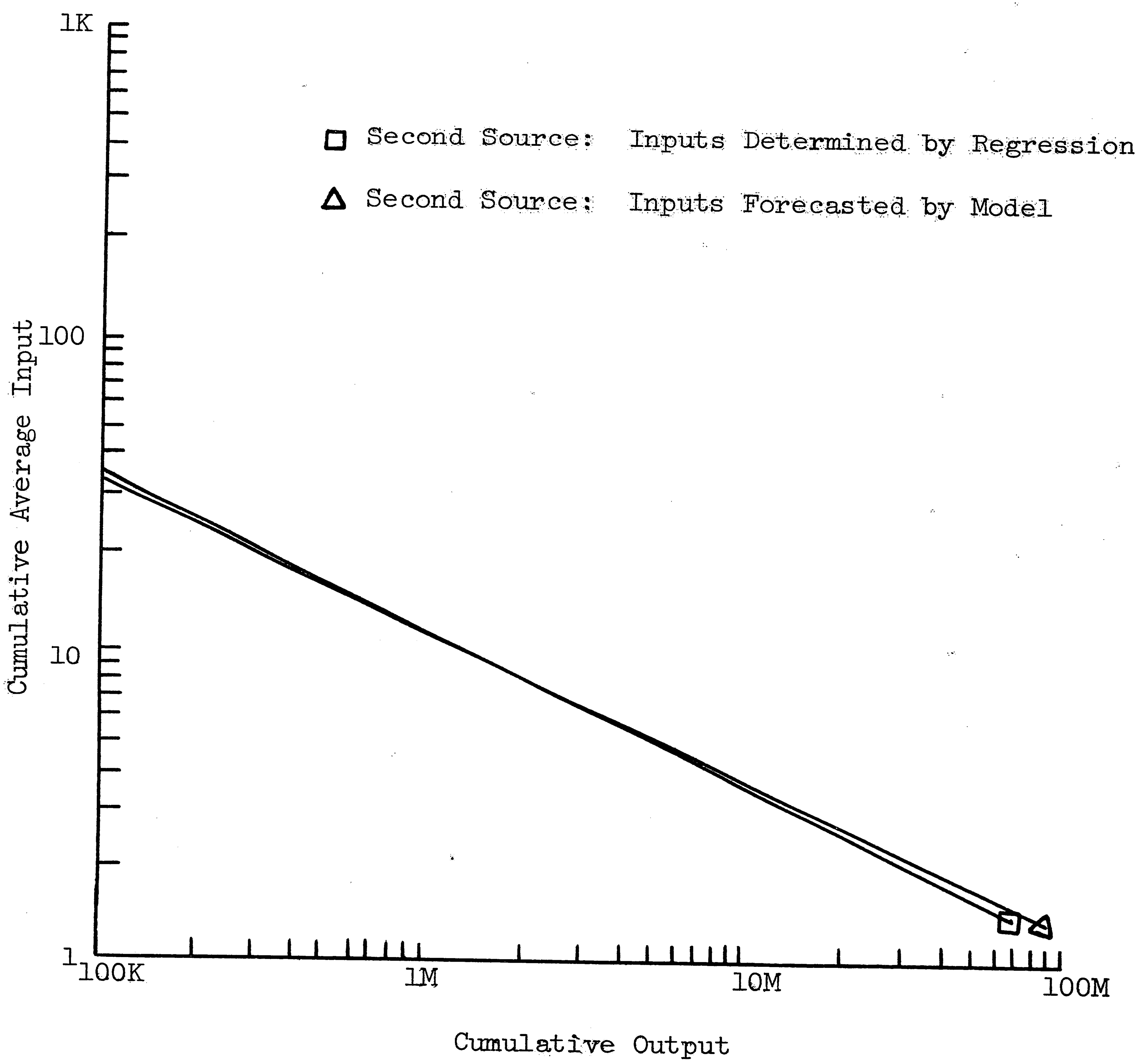
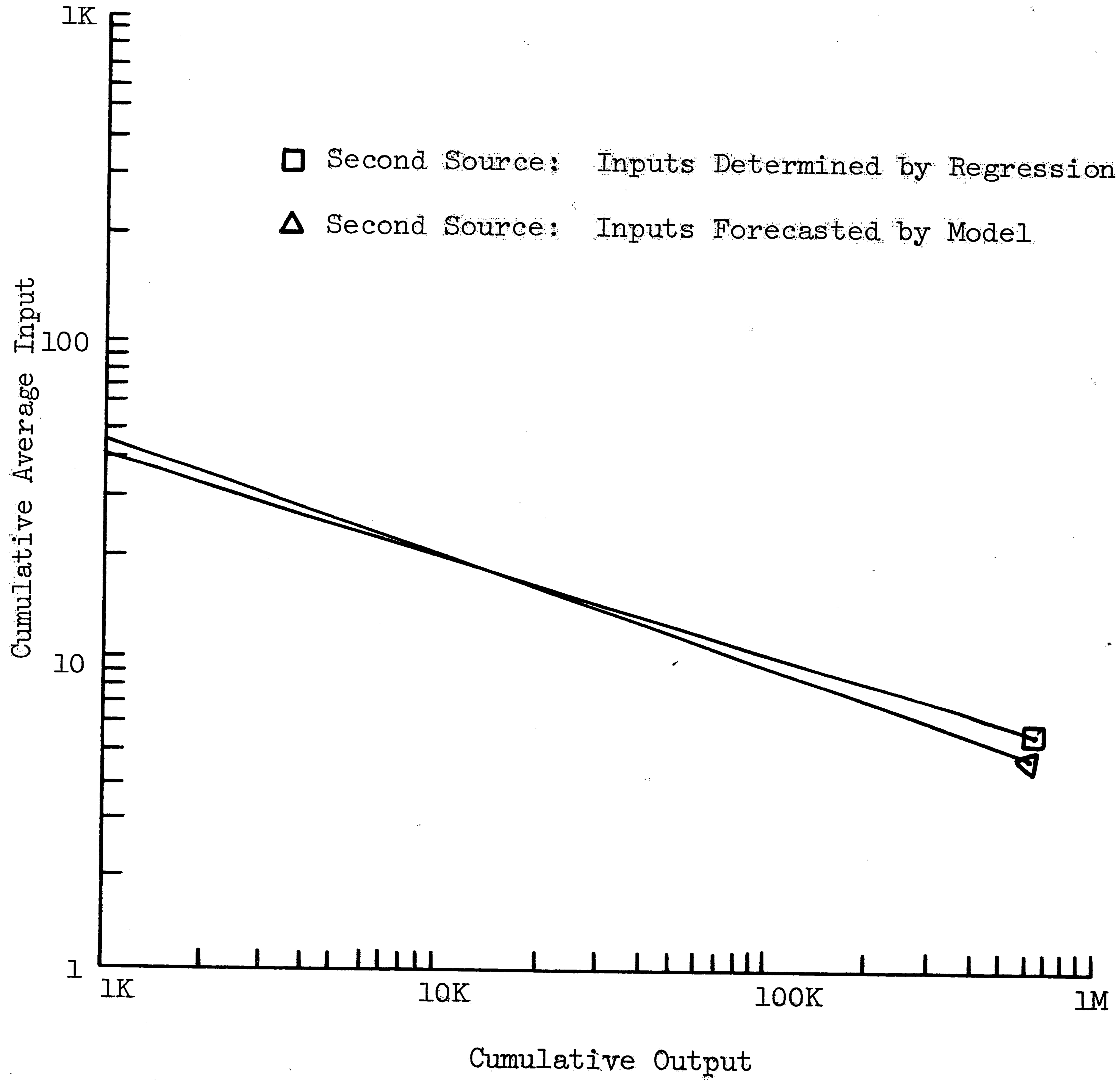


FIGURE IX

Product Five



CHAPTER VI
Conclusions

The application of Progress Function concepts to the area of dual sourcing within a firm has been demonstrated. A model has been developed to account for the transfer of progress from the first source to the second. The model is based on the underlying assumptions that there exists an unconstrained flow of information between the sources and that both sources experience essentially the same rate of progress. Five products dual sourced within the Western Electric Company have been investigated. As a result of this investigation several conclusions can be stated. These conclusions are discussed below.

The first conclusion is that Progress Function concepts are applicable in describing the progress experienced in the high volume manufacture of electron devices within the firm studied. Without exception the processes involving the five products can be described by the function $\overline{Y} = AX^{-b}$.

Secondly, the assumption that two facilities within a firm, producing the same product, experience essentially the same rate of progress has been shown to be valid. The comparison of Progress Indices for two sources producing the same product revealed the existence of little variation. While one cannot conclude that this phenomena exists in all firms or in all areas of manufacturing there is no reason not to expect this condition to prevail in other areas of manufacturing within the particular firm studied.

A third conclusion is that even within a particular area of manufacturing one rate of progress cannot be used to describe all products. This is verified by the range of Progress Indices found for the products studied (70.2% to 81%).

Of more importance however, is the conclusion that, given a dual sourcing program for a firm wherein certain basic conditions prevail, the progress achieved at the original source can be considered transferable to the second source. Further, the amount of progress achieved at the original source is directly related to the cumulative production count at the time of dual sourcing. These facts, when used with a suitable time frame over which the transfer of progress occurs, enables the analyst to make reliable forecasts of the input requirements at the second source through the use of Progress Function concepts. Forecasts, made for one firm, engaged in high volume production of electron devices, were found to be quite reliable for forecast periods exceeding three years and cumulative production exceeding one hundred million units.

The technique of considering the transfer of progress and utilizing Progress Function concepts in dual sourcing applications provides management with a straight forward method for forecasting production requirements. In addition it provides a means for establishing goals. For example, if the transfer of progress is applicable in dual sourcing a product, as it was with the five products studied, then the time frame over which it takes to transfer progress to the second source is of economic importance. Any reduction in this time frame would result in a reduction in the total input requirements at the second source.

CHAPTER VII
Areas for Further Study

The rationale of using Progress Function concepts for dual sourcing has been investigated in only one area, namely, between two facilities within a single firm manufacturing the same product. Indeed, only one general product area (electron devices) has been investigated. The need for additional studies to cover other areas of manufacturing is at once obvious.

Once the utility of the dual sourcing model has been established for manufacturing in general the next area of immediate need would be to extend its application to products which are not identical but similar. This would require an estimate of that portion of the progress achieved on one product that could be considered applicable to the second, similar product. No doubt this would be a function of the similarities between the two products.

Success in the above areas would lead naturally into the area of new products. It is in this area that management expresses the greatest interest, which is not unreasonable considering the number of new products which go into production each year.

The transfer of progress or know-how is an area which deserves considerably more attention. There is a real need to identify those factors which have an impact on the transfer of progress between two manufacturing facilities. Any effort which is successful in increasing the understanding of the transferability of know-how between two manufacturing facilities would represent a major contribution to the field.

The manufacturing Progress Function is a forecasting tool. As with any forecasting technique, it is not an exact science. Because of this and due to its wide applicability to manufacturing processes a better understanding is required of the underlying factors which affect progress. Considering the possible economic applications associated with Progress Functions, they have received far less than their share of study.

APPENDIX A

DATA FOR PRODUCT ONE,
BOTH SOURCES AND
REGRESSION PARAMETERS

PRODUCT ONE, FIRST SOURCE

Cumulative Output, Units	Actual Cumulative Average Input	Input Determined by Regression
100,000	50.0	49.32
2,000,000	17.30	18.66
5,000,000	15.00	13.86
13,000,000	10.00	10.17

Regression parameters, first source

A = 2,065.75

b = -.324

PI = 79.9%

Correlation coefficient -.995

TABLE II

PRODUCT ONE, SECOND SOURCE

X_{1ds} = 10,000,000 units $X_{2,6}$ = 300,000

Cumulative Output, Units	Predicted Input, Dual Source Model	Input Determined by Regression	Actual Input
21,150	25.7	23.26	--
59,005	18.41	17.05	
100,000	15.52	14.53	14.52
229,043	11.86	11.30	--
300,000	10.86	10.41	10.41
500,000*	9.20	8.92	--
1,000,000	7.35	7.22	7.23
10,000,000	3.48	3.60	3.59
20,000,000	2.78	2.91	2.92

Regression parameters, second source

A = 476.10

b = -.303

PI = 81.0%

Correlation coefficient = -.999

*Convenience points for plotting

TABLE III

APPENDIX B

DATA FOR PRODUCT TWO, BOTH SOURCES AND REGRESSION PARAMETERS

PRODUCT TWO, FIRST SOURCE

Cumulative Output, Units	Actual Cumulative Average Input	Input Determined by Regression
81,320	54.35	54.54
1,718,200	11.36	11.49
9,160,800	5.51	4.89
13,080,900	3.67	4.08

Regression parameters, first source

A = 17,482.9

b = -.510

PI = 70.2%

Correlation coefficient = -.997

TABLE IV

PRODUCT TWO, SECOND SOURCE

X_{1ds} = 10,000,000 units $X_{2,6}$ = 2,000,000 units

Cumulative Output, Units	Predicted Input, Dual Source Model	Input Determined by Regression	Actual Input
100,000*	19.67	17.94	--
1,000,000*	6.07	5.76	--
1,378,235	5.15	4.92	--
6,716,400	2.29	2.25	2.12
10,000,000*	1.88	1.84	--
19,592,300	1.33	1.32	1.41
30,377,800	1.06	1.07	1.13
57,525,500	.77	.78	.76
100,000,000*	.58	.59	--
103,053,100	.57	.58	.57
113,069,300	.54	.56	.54

Regression parameters, second source

A = 5,264.6

b = -.494

PI = 71%

Correlation coefficient = -.955

*Convenience points for plotting

TABLE V

APPENDIX C

DATA FOR PRODUCT THREE,
BOTH SOURCES AND
REGRESSION PARAMETERS

PRODUCT THREE, FIRST SOURCE

Cumulative Output, Units	Actual Cumulative Average Input	Input Determined by Regression
100,000	900.	899.9
250,000	600.	600.0
1,000,000	325.	324.9

Regression parameters, first source

A = 14,654.63

b = -.442

PI = 73.6%

Correlation coefficient = -.999

TABLE VI

PRODUCT THREE, SECOND SOURCE

X_{1ds} = 600,000 units $X_{2,6}$ = 300,000 units

Cumulative Output, Units	Predicted Input, Dual Source Model	Input Determined by Regression	Actual Input
100,000	55.36	55.01	51.57
300,000	34.05	35.25	33.56
500,000	27.16	28.66	27.48
1,000,000	19.99	21.65	--
1,300,000	17.80	19.46	18.91
4,000,000	10.83	12.35	12.19
10,000,000	7.22	8.52	8.51

Regression parameters, second source

A = 5,831.78

b = -.405

PI = 75.5%

Correlation coefficient = -.996

*Convenience points for plotting

TABLE VII

APPENDIX D

DATA FOR PRODUCT FOUR, BOTH SOURCES AND REGRESSION PARAMETERS

PRODUCT FOUR, FIRST SOURCE

Cumulative Output, Units	Actual Cumulative Average Input	Input Determined by Regression
100,000	75.0	76.33
200,000	56.0	54.85
1,250,000	22.5	22.89
4,500,000	14.1	12.43
5,700,000	10.1	11.10

Regression parameters, first source

A = 18,482.87

b = -.477

PI = 71.9%

Correlation coefficient = -.995

TABLE VIII

PRODUCT FOUR, SECOND SOURCE

X_{1ds} = 4,000,000 units $X_{2,6}$ = 1,000,000 units

Cumulative Output, Units	Predicted Input, Dual Source Model	Input Determined by Regression	Actual Input
32,559	60.51	61.68	--
100,000	35.44	35.58	40.0
122,476	32.17	32.22	--
265,843	22.23	20.77	--
300,000	--	16.83	20.0
500,000*	16.45	16.17	--
1,000,000	11.82	11.51	9.50
10,000,000	3.94	3.72	4.38
20,000,000	2.83	2.65	2.52

Regression parameters, second source

A = 10,055.12

b = -.490

PI = 71.2%

Correlation coefficient = .991

*Convenience points for plotting

TABLE IX

APPENDIX E

DATA FOR PRODUCT FIVE
BOTH SOURCES AND
REGRESSION PARAMETERS

PRODUCT FIVE, FIRST SOURCE

Cumulative Output, Units	Actual Cumulative Average Input	Input Determined by Regression
36,562	26.43	26.57
117,286	17.99	17.58
254,280	12.97	13.36
447,286	11.08	10.94

Regression parameters, first source

A = 1,100.31

b = .354

PI = 78.2%

Correlation coefficient = -.998

TABLE X

PRODUCT FIVE, SECOND SOURCE

X_{1ds} = 200,000 units $X_{2,6}$ = 31,000 units

Cumulative Output, Units	Predicted Input, Dual Source Model	Input Determined by Regression	Actual Input
1,000*	46.63	41.28	--
2,010	36.41	33.27	37.31
10,000*	20.62	20.27	--
15,640	17.60	17.65	16.30
30,853	13.83	14.32	13.93
50,000*	11.66	12.33	--
53,389	11.39	12.08	11.14
100,000*	9.12	9.96	--
128,895	8.33	9.20	8.61
200,000*	7.13	8.04	--
286,000	7.19	6.28	7.23
500,000*	5.15	6.05	--
604,707	4.82	5.71	6.76

Regression parameters, second source

A = 348.42

b = -.309

PI = 80.7%

Correlation coefficient = -.986

*Convenience points for plotting

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