AN ABSTRACT OF THE THESIS OF

SALAHUDDIN FARUQUI for the degree of MASTER OF SCIENCE
(Name) (Degree)

in Industrial Engineering presented on March 13, 1975
(Major Department) (Date)

Title: REGRESSION BASED TIME STANDARDS FOR FISH FILLETING

Abstract approved: Redacted for privacy
Dr. Stephen F. Love

In this study the ability of establishing time standards using the technique of regression analysis is demonstrated. Numerical standards are developed for fish filleting operations which are satisfactory for practical use by the seafood processing management.

For the analysis non-experimental or historical fillet data was obtained from two seafood processors on the Oregon coast. The fillet data was then analyzed statistically and a linear model developed. This model reflects the relationship between the total man-hours (the dependent variable) and the number of pounds of fillet produced for each specie of fish (the independent variables). Regression coefficients of this model then represent the standard time for producing a pound of fillet for different species of fish filleted. This represents a departure from previously reported applications of regression analysis to standards development. While developing the model a main problem which had to be resolved was the identification and reduction of the

variation present in the historical data. Thus the study gives primary consideration to the reduction of the variance of the model and the regression coefficients.

Results obtained from this analysis are satisfactory to the management of both the plants. The methods used for reducing the variance were encouraging. The feasibility of regression analysis as a technique to determine time standards, as compared to the traditional methods is demonstrated.

Comparisons are made between and within plants for the overall production rates, standards developed for various species (regression coefficients) and delays and other unproductive time. Possible causes for the variations are identified which could be used as starting points for the extension of this study.

Regression Based Time Standards for Fish Filleting

by

Salahuddin Faruqui

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1975

APPROVED:

Redacted for privacy

Assistant Professor of Industrial Engineering
in charge of major

Redacted for privacy

Head of Department of Industrial Engineering

Redacted for privacy

Dean of Graduate School

Date thesis is presented March 13, 1975

Typed by Susie Kozlik for Salahuddin Faruqui

ACKNOWLEDGEMENTS

I am deeply indebted to Dr. Stephen F. Love for his most friendly academic assistance, guidance and suggestions during the preparation of this study.

I also wish to express my gratitude to Professor William F. Engesser for the opportunity given to me to work for him and for the financial help provided.

I extend my appreciation and thanks to the management of the two seafood processors for their help and suggestions during the course of this study.

At last, but by no means the least, special thanks are due to Mrs. Susie Kozlik for typing this thesis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

REGRESSION BASED TIME STANDARDS FOR FISH FILLETING

I. INTRODUCTION AND SUMMARY

This study is directed towards demonstrating the feasibility of establishing time standards with the help of regression analysis. Although the general idea of using this statistical tool toward this end is not new, the way in which it is used here is different from most of the previously reported applications. The concept of standards has been defined by Buffa (3) as follows:

> Production standards state either how many parts, assemblies, etc. should be produced per minute, hour or day, or they may indicate the amount of time allowed as standard for producing a unit of work. Whether standards are expressed in terms of pieces per unit of time or time per piece is quite irrelevant; however, they are often called 'time standards' when expressed in time units. Although production standards are designed to determine how much output is expected of an employee, they include more than just work.

Various techniques have been developed for establishing time standards, such as traditional time study (using stop watches), motion pictures, video tape, work sampling, standard data and predetermined motion time. These techniques are further reviewed briefly in Chapter 3.

In this study a statistical technique for measuring and quantifying relationships between two or more variables, known as multiple regression analysis is used. This technique has been applied by industrial engineers to various aspects of their fields, including forecasting, sales analysis and process control.

Problem Description

The problem can be viewed generally on two planes. On the broader level, it is to establish the feasibility of multiple regression analysis as a technique to determine time standards in seafood industry, as compared to the traditional methods On a more specific level, numerical standards are sought for filleting operations which are satisfactory for practical use by fish processing management.

Working with 'non-experimental' or historical data, a linear model is developed which reflects the relationship between the total man-hours (the dependent variable) and the number of pounds of fillet produced for each species of fish (the independent variables). In the model, the coefficients of the independent variables are equivalent to the standard times for producing a pound of fillet for different species of fish filleted. The development of this model, together with a discussion of the difficulties which were encountered and resolved are explained in Chapter 4. The possible causes for variations are given in Chapter 5.

Review of Literature

In comparison with the literature which coveres the theory of regression analysis and the associated statistical properties of such models (1), (2), relatively little has been written on the use of regression analysis as applied to work measurement. Draper and Smith (1) talk of "predictive models" which need not be useful for control purposes but certainly do describe the linear relationships between the dependent and independent variables. Some articles have been written (6), (7), (8), (9), (10), (11), (12) and (13), regarding the application of regression analysis to various aspects of work measurement. Jelinek and Steffy (7), in their article show the use of linear and non-linear regression models for predicting the total cycle time for an operation such as drilling holes in a part. The dependent variable being the normal time to drill one part and the independent variables; the number of holes drilled, diameter of holes drilled, depth of cut, etc.

Similarly, Salem (8) in his article describes the use of predictive models for determining the indirect labor time for packing a finished product. Here the dependent variable is the time per pallet load of material packed and the independent variables are the number of cases packed, orders, weight and volume.

Another example is that of a turning operation given by Doney and Gelb (12). Again the object is to obtain the cycle time of the whole turning operation using the given specifications such as the over-all length, stock outer diameter, bore diameter, finished outer diameter, etc.

All of these articles and their examples use the regression model to predict standards by breaking down the total operation into various sub-operations. The times for these sub-operations are then obtained or are already available. With these times and the total cycle time, a linear or non-linear relationship is then obtained so as to predict the total cycle time. In contrast, this study is not directed towards predicting the total cycle time for one operation, but rather to obtain the standard times for a number of different operations by determining the relationship between the total man-hours per day and the number of items produced of each product. (The actual model is developed in Chapter 3). In fact, the standard time is not the dependent variable, but rather the coefficients of the independent variables comprise a set of standards for a group of mutually exclusive operations. In this study the main objective is therefore to try and reduce the variability of the regression coefficients.

An article by Martin (9) came close to the object of this study. Standard times for the manufacture of different kinds of trailers and campers was required. Data available was total man-hours per week and the total number of the ten products produced for that period. A linear relation was established which accounted for 80% of the variation in man-hours per week, but two of the coefficients were negative. To eliminate this, two products were dropped and a new relationship obtained. No doubt this time there were no negative coefficients but the time spent making these two products was not being accounted for. Moreover, the problem of high variance of the regression coefficient was completely ignored and no effort was taken to get a better estimate of the time standards. In contrast, this study has been carried out keeping in view the object of reducing the variability of the regression coefficients, which are the time standards, and to account for all the items produced and consequently the time taken to produce them.

On the subject of fish filleting, much information is provided in the unpublished thesis of Peterson (15). Standard and normal times for filleting different species were obtained by micromotion study of above average and average workers. Some of these standards were used in this study for comparison purposes.

This study was carried out with the help and cooperation of two seafood processors on the Oregon coast. They provided the fillet data on the condition that their identities not be revealed. Thus, throughout this study they shall be referred to as Plants A and B. The form in which the data was provided and the way that it was analyzed is explained in Chapter 4. In Chapter 5, the results of the analysis are given and discussed.

Obtaining data from two different sources provided the opportunity to compare the results of the analysis and discuss the various factors which create inter-plant differences. The two plants are described in Chapter 2, in which a comparison is made between their operations and working conditions.

II. DESCRIPTION OF PARTICIPATING PLANTS

Organizational Structure

The two seafood processors who were interested in this study and agreed to provide data for the analysis, are located on the Oregon coast. As already mentioned, these plants will be referred to as Plants A and B, because of the request by management to remain anonymous. In general, these plants have a similar organizational structure.

Plant A is one of the larger plants belonging to a parent seafood organization which owns a number of other plants on the Pacific Northwest coast. In this plant the primary types of seafood processed are bottom fish, crabs, salmon and occasionally shrimp. The raw material is brought in directly from the sea by boats, most of which are externally owned. A contract arrangement with the plant insures a steady supply of fish, weather permitting. Bottom fish is filleted mainly in the Spring and the Summer months. The fish are usually processed that same day they are landed and most of the fillets are then frozen, packed and distributed to various parts of Oregon, Washington and California for consumption. The filleting operation in this plant is totally manual, although at the time the data was obtained, there were plans of installing a skinning machine and redesigning the whole layout of the fillet room. New conveyor belts were also to be installed with the new working area to increase the efficiency of the plant. These changes would greatly affect the time standards to be established for filleting. After such modifications it would be necessary to develop a new model and revised time standards. The procedure for doing this is straightforward, following the guidelines of this study.

Plant B started off in the early fifties as a mink food producer. The fish caught was minced and shipped to the mink farms of the plant owner. Later on, as the demand for seafood increased, it was decided by management to fillet the fish and use the leftovers as mink food while selling the fillets separately. At present Plant B processes bottomfish, salmon, crabs and shrimp, during their respective seasons. The raw material is supplied to the plant by one company boat and other regular privately owned boats which have agreements with the management to insure a steady supply. Similar to Plant A, the fish supplied are filleted the same day and most of the fillets are frozen, packed and shipped by refrigerated trucks to the consumers. The operation of filleting is sometimes manual and sometimes semi-mechanized using a skinning machine, which was installed in the Spring of 1974. This machine is installed in an area separate from that of the filleting room. The fillets are then carried to the skinning machine by an operator's helper. Thus the introduction of the skinning machine did not have a significant effect on the overall filleting methods as such, and the environment of the filleting area. The total number of different species filleted by Plant B during the period over which the data was analyzed was more than 14, whereas that for Plant A was 9. The physical facilities of Plant B are fairly small and have not been significantly changed since it was built in the fifties. The working area is not well organized compared to that of Plant A.

Working Conditions and Filleting Methods

The environment of the working area has a significant effect on the productivity, quality level, delays and the physiological well being of the workers. Factors included in the assessment of the working area environment include: temperature, humidity, lighting, noise, congestion and other factors affecting the normal operation of the worker. The management of Plant A has taken cognizance of these factors to ensure proper and efficient operation of the system, except for the knife sharpening procedure. Knives used by the workers are sharpened by a filleter who takes time off from the regular job and sharpens the knives. This sometimes introduces a certain amount of delay in the regular working cycle of a filleter who has to wait for her knives to be sharpened. Apart from this there is a steady supply of fish to the workers.

In contrast, the work area in Plant B is not well-equipped. There is a slight congestion among the workers due to the lack of sufficient work space; lighting is not adequate; and there is sometimes an inch or two of water on the floor of the fillet room showing the absence of proper drainage system. The inconveniences caused to the workers due to these factors might tend to influence the overall model of the system and the time standards. However, a worker is always available to supply sharpened knives to the filleters, thus avoiding any delay for that reason.

The filleting methods used by the filleters in both plants have a certain amount of variation. These differences are caused because of the individual working capabilities of the filleters. Workers basically follow similar cutting actions for filleting, but there seems to be a lot of variation in the manner in which the worker picks up the fish from the conveyor belt, positions it on the working table, discards the left-overs and places the fillet in a container. The only time the worker handles the product is at the work place. Also in Plant B there is a difference in tables on which the filleting operation takes place.

The basic cuts made for filleting bottomfish can be categorized into four groups: skin-on, skin-off, dressed and miscellaneous. The majority of the filleting is done using the skin-off cut; where the whole operation is done manually by first cutting into the side of the fish and then removing the skin from the fillet. The skin-on cut is usually made when the fillets are to be passed through a skinning machine which will remove the skin. In the category of dressed fish, the operation of filleting consists of removing the insides of the fish, its head and sometimes its tail. Apart from these three categories, there are some special cuts which are not common and are made only on special orders. These cuts include skin-off one side only and skin-off-tail-on.

The time standards developed for these different cuts and species take into account the variations and other avoidable and unavoidable delays due to the factors mentioned earlier in this section. These avoidable delays and the time lost in the actions pertaining to the operation of filleting decrease as the workers gain experience and perfect their methods of filleting.

Quality and Yield

The quality of fillets can be determined by their physical characteristics, texture of the meat and the bacteriological content. At present these characteristics are checked at the plants, and a thorough check is made to see if any skin still remains on the fillet or not. This operation is known in the fish industry as 'removing the feather.' Apart from this check, the Food and Drug Administration does perform a regular inspection of the working conditions of the plant. Without any formal quality control on the physical characteristics of the fillets, the yield can vary consierably among the workers, which in effect reduces the overall productivity of the system. But at the same time stringent yield requirements would increase processing time. Thus a balance has to be made between these two important factors. Table 1 gives the present average yield percentages for various species being filleted in Plant B (as provided by management). The management of Plant A declined to provide similar figures.

Table 1. Plant B Yield Figures.

Fish Specie	Average Percentage Yield*
1. Perch	22.0
2. Dover	25.5
3. English	24.5
4. Petrale	29.0
5. Rock	30.0
6. Ling	28.0
7. Sand-Dabs	25.0
8. Butter Fish	31.0
9. Rex	33.0
10. Cats - skin off tail on	25.0

$$\text{Average Percentage Yield} = \frac{\sum_{i=1}^{n} \frac{(\text{weight of fillet})}{(\text{weight of fish})} \times 100}{n}$$

The quality is further deteriorated by excessive handling while being prepared to be frozen and the inefficient manner in which the frozen fillets are transferred from the freezers of the company to the wholesale supplier. Thus in this study it had to be assumed that the quality had already been established and that the present production conformed to it.

III. REGRESSION ANALYSIS AS A METHOD FOR ESTABLISHING TIME STANDARDS

Need for Time Standards

Time standards provide a methodology and rationale for determining a fair days' work for different jobs. Generally there are two basic classes of uses for time standards in an industry: planning, and evaluation and control. Under planning, the uses include scheduling, bidding, pricing, anticipation of labor needs and those decisions which are concerned with the future course of action of the company: decisions as to what to do, how to do it and when to do it. As for evaluation and control, these time standards can be used for establishing incentive methods of wage payment, establishing a standard cost system or deciding how effectively the worker, machine or department is operating. Uses in this category include monitoring of operating performance, comparison of alternative system designs, and appraisal of the learning effect. Time standards are useful in so many ways in designing, planning, operating and evaluating a production system, that they should be regarded as truly basic data.

Methods for Establishing Time Standards

Since the time when Taylor originated time study, numerous techniques have been developed for establishing time standards.

Generally all of these techniques can be classified under two distinctly different categories: direct observation and measurement, and synthesis. A description of most of the techniques falling under these two categories is given below:

1. Observation and measurement. This requires direct observation of the operation as it is performed and appropriate measurements of that operation. Due to this there is always some tendency among the operators being observed to perform their tasks extra carefully, which of course, does not provide the true time standards. The two basically different methods of direct observation use are time study and work sampling.

Traditional time study using stop-watch, motion pictures, video tapes and other time measurement devices - the most prevalent of these techniques being the stop-watch time study. Techniques using motion pictures, video tapes, etc., differ from stop-watch study in that the operation is recorded and then later analyzed by either using a variable speed projector or having the time dubbed on to the tapes. General procedures have been specified by many authors suggesting how the study should be carried out. Generally a normal time is then computed by the following formula:

$$\text{Normal time} = \frac{\text{averaged observed actual time}}{(\text{average rating factors})/100}$$

To this normal time are then added allowances for fatigue, delay, personal time, etc., to determine the standard time. Thus:

$$\text{Standard time} = \text{Normal time} + \text{Allowances}$$

There is no doubt that the stop-watch technique is rather simple, but it has a number of inherent drawbacks, apart from the error of watch-reading itself. Some of these errors can be attributed to the difficulty of estimating allowances, and overlapping in consideration of certain factors, etc.

Work sampling. Briefly, it involves estimation of the proportion of time devoted to given types of activities over a certain period of time by means of intermittant, randomly spaced observations. This method is usually used where it is required to estimate the time cycle of two or more activities and where it is inconvenient, expensive or impossible to obtain this information from records or other techniques. In this case normal time can be calculated according to the relation:

$$\text{Normal time} = \frac{T \times WP \times R}{U}$$

where

T = total time period over which the observations were made

WP = the fraction of time devoted to that particular operation

R = rating of the operator in fractions, and

U = the total number of units produced during the time period T.

Standard time is then computed as before. The number of observations required depends mainly on the accuracy required.

2. Synthesis. Using specially derived tables, formulas and graphs, it is possible to 'build' or synthesize the time standards for operations without the necessity of actually making direct measurement of an operation or even observing it. This gives a more accurate estimate of the overall time standards since it takes into consideration the effects of the environment on the operation too. This method can be subdivided into two different techniques, predetermined time and standard data.

The predetermined motion time approach involves establishing the expected performance time for a basic sub-division of manual activities by averaging the times required by a number of persons to perform the given motion. This system of times is then used to synthesize performance times for a large variety of manual operations. The sum of these predetermined times gives the normal time for an operation, to which are added the allowances to obtain estimates of the time standards. Methods-time measurement is one such system of predetermined motion time currently available. These systems eliminate the need for the very troublesome performance rating required in the direct observation and measurement methods.

Using the standard data technique, a relationship is developed between the normal time required to perform a task and certain pertinent characteristics of the task in a form that permits synthesis of the former from the latter. The most common form of standard data in use is referred to as the elemental type. Here the normal time for various elements E1, E2, E3, etc., of the task being performed are individually determined as functions of certain significant variables affecting these variables. The total normal time of the whole operation is then obtained by summing up the normal times of the elements. Again, by adding the allowances to the normal time of the operation, the time standards can be established.

To determine a relationship between a dependent variable, the normal time, and independent variables is not an easy matter for an ordinary time study practitioner. Statistical analysts have been effectively dealing with problems of this type for decades. The technique used by them to relate a dependent variable with a number of independent variables using empirical data is commonly referred to as regression analysis. As already mentioned in Chapter 1, this technique has not been widely used in the field of time study. In the remaining sections of this chapter, are described briefly what regression analysis is and how this technique can be effectively used for determining time standards by using only historical or 'non experimental' data.

Regression Analysis Applied to Determine Time Standards

Regression analysis is an objective and very useful method of fitting an equation form to empirical data. This procedure yields an estimating model (equation) ordinarily referred to as a regression equation. Within limits of the basic equation form selected and the empirical input data given, the least squares regression equation is the best estimate of the relationship between a dependent and one or more independent variables.

After going through a curve fitting process, a linear relationship is established which yields the 'best' linear fit to the empirical data provided, in the sense that the sum of the squares of the deviations between the original values of the dependent variable and the values predicted by the model is a minimum. Thus the process utilized is known as the 'least squares' method.

As more independent variables are introduced, the procedures for determining such a relationship becomes more difficult. At this point it becomes essential to develop the linear model from the data on an electronic computer. Otherwise the economics do not favor its implementation.

The ability of regression analysis to establish a relationship between dependent and independent variables makes the method suitable for developing time standards. The techniques involved in determining the regression equation for the empirical data also provide related information which helps determine when the analysis should be terminated, what other factors related to the process might be helpful, how well the present equation conform to the data, which days are upsetting the analysis, which independent variables are significant and what the variability of the regression coefficients is.

The ability of regression analysis to establish time standards can be best realized by a simple illustrative example. (The details of the model are discussed in the next section. This example was developed to give the processors a simple view of how their data will be used and analyzed.)

EXAMPLE:

Suppose that two different species of fish, X and Y, are being filleted in a plant. The only data available is the total pounds of fillet produced for each specie and the total time involved in doing so. This time does not include the lunch hour and other breaks taken by the employee.

Day	Fish Fillet		Total Processing
	Specie X	Specie Y	Time in Minutes
1	200 lbs.	600 lbs.	1440
2	300 lbs.	400 lbs.	1210

To the above data the following equation can be fitted:

Total min. = (min/lb for specie X) (pounds of X fillet) +

(min/lb for specie Y) (pounds of Y fillet)

Substituting the above data in the given equation, the following two relationships are obtained for the two days.

1440 = (min/lb for specie X)200 + (min/lb for specie Y)600

and 1210 = (min/lb for specie X)300 + (min/lb for specie Y)400

Solving these two equations yields values for the two coefficients, which in fact are the time standards for producing a pound of fillet of specie X and Y. Thus, time standard for specie X is 1.5 min/lb and that for Y is 1.9 min/lb. And the model becomes: Total min. = 1.5 (pounds of X fillet) + 1.9 (pounds of Y fillet).

Thus using only the fillet data currently available, it is possible to estimate the time standards for each specie of fish, the processing of which may be two completely different operations. From this example it can be observed that it is possible to develop time standards from historical or non-experimental data, without considering the different elements of each operation. This is obviously not the end of the analysis, since the model was developed from the data of only two days.

Supposing on the third day the following data was recorded:

Day	Fish Fillet		Total Processing
	Specie X	Specie Y	Time in Minutes
3	400 lbs.	200 lbs.	1100

Substituting this data in the model developed, the time required for producing the given amount of fillet should have been only 980 minutes. This gives a residual (or actual production time) - (model time) of 300 minutes. This discrepancy between the actual time and the model time might be attributed to a number of reasons. It could be that on the third day the workers did not work up to their full capacity, or there was an unavoidable delay in the supply of fish or perhaps there was an error in recording the data. Thus there could be a number of similar reasons which could explain the variation. To be able to establish reasonable standards it is essential to try and reduce the variability of the model and that of the regression coefficients.

Causes for Variation

Systems in general do not perform with perfect uniformity with respect to timing or quality. Variation is always present in the time required to perform an operation, especially if human beings partially or completely control the rate of work. There is variation in the timing and type of interruptions of the production activity of man and machine. Variation can also be observed in the timing and type of demands for auxiliary service, such as services of knife sharpener, material handler, repairman, inspector and the like. The variation in these and many other cases is the cause of a multitude of difficult problems faced while attempting to establish time standards.

To partially or completely eliminate the effect of variation on the estimates of the time standards, it is useful to distinguish the causes for such variations in the system. Following are some of the causes of variation in fillet rates in a seafood industry. Sources of variation:

1. Different species of fish being filleted
2. Set-up time, idle time and other delays not related to the operation of filleting
3. Ability among workers
4. Differences in filleting methods
5. Environmental and tool differences
6. Daily performance of each worker
7. Different sizes of fish being filleted by the workers
8. Quality of fillet being produced
9. Percentage yield being obtained for each specie of fish
10. Fatigue
11. Data errors being made while recording, decoding and handling it at different points of the analysis

Once the causes for variations have been identified, it is desirable to account for them in the model being developed. This step in the analysis is fairly critical. Unfortunately it is not always possible to incorporate all the causes for variation while developing the model. The main reasons for this being (I) that it is impossible to measure the effect of the cause of variation on the model in advance of the complete analysis, or (II) not possible at all with the available historical data.

Thus, one of the objects of this study has been to identify the various causes for variation and then account for them in the final model. This has been done to quite an extent by using various techniques which are explained in detail in Chapter 5, where the results of this study are analyzed statistically.

One of the major causes for variation in the model is different types of fish being filleted by the workers. All workers are supposed to fillet almost all kinds of fish which are available, except for few exceptionally high skilled operators who prefer to work on the fish which are readily available, such as English, Dover, Perch, etc. By doing so they keep a constant pace and are able to process a large number of fish while keeping the quality of the fillet at a reasonable level. Switching from one kind of fish to another often disrupts the regular pattern of the work, which, to a certain extent, has an effect on productivity of the worker as well as the quality of the fillet produced. Moreover, the fact that in the typical fish processing plant at least two to three different kinds of fish are simultaneously being filleted on the same table, but by different workers, produces interrelationships between the independent variables, which are difficult to determine. To rectify the variability caused by these phenomena, and to account for the fish which were not very regularly filleted or which were filleted in small quantities, similar kinds of fish were grouped together to form a single independent variable.

These groupings were based on the fact that fish filleted in a similar manner could be categorized together. These fish would have similar time standards if treated separately. Those species for which there was not enough data were grouped to form large categories such as dressed miscellaneous, skin-off miscellaneous and skin-on miscellaneous. Most of these groups were suggested by the processors themselves. The groupings finally made are discussed in Chapter 5.

Regression Model Development

The model to be used to express the relationship between the total man hours and the number of pounds of fillet produced for each specie of fish is

$$Y = b_0 + b_1X_1 + b_2X_2 + \dots\dots\dots + b_nX_n$$

Y, being the dependent variable, will represent the total man-hours per day required to fillet all the different species of fish available. X_1, X_2, ... X_n are the independent variables, which in this model represent the number of pounds of fillet produced daily for the 'n' different (possibly grouped) species of fish. The regression coefficients, b_1, b_2, b_3, ...b_n, give the average or the expected change in Y when X_1, X_2,......X_n, are respectively changed by one unit, one at a time, while the other independent variables remain the same. These regression coefficients in this study represent the time standards sought for each specie of fish. The constant term of the regression model, b_0, includes lost time and other work which is not related to the operation, and which cannot be accounted for by the normal allowances. It is possible to segregate these individual elements unless some measureable variable is present. In other words, for a particular observation (one day) the summation of number of pounds of fillet produced for all species of fish multiplied by their time standards plus this constant (which includes lost and nonproductive time) will equal the total direct labor time in man-hours.

In the model thus described, interest generally lies in obtaining estimates of the regression coefficients based on the simultaneous observations of the independent variables included in the equation. As explained in the Regression Analysis Section, the most commonly used technique is the well known method of least-squares, the object of which is to minimize the sum of the difference between the actual and the predicted value of Y, which can be represented as follows:

$$\min \sum_{i=1}^{n} (Y_i - \hat{Y}_i)$$

where $\hat{Y}_i$ is the value of Y_i predicted by the model.

A nonlinear model might have been used to predict the dependent variable, Y, quite accurately, but this would not provide the time standards in terms of minutes per pound of fish filleted. The regression coefficients would be expressing the quantitative effect of a change in one of the independent variables, such as X_j^2, X_jX_k, $\log(X_j)$, or any other non-linear combinations of the independent variables. These non-linear models are generally useful for obtaining predicting equations, but have no physical basis in this model.

All the mechanics of calculations are done by SIPS on the OS-3 system, which generally follows the following linear regression methods in matrix terms.

The model consideration can be written more succinctly in the form

$$Y = X\beta + \epsilon$$

where Y is an (n x 1) vector of observations of the dependent variable,

X is an (n x p) matrix of known independent variables,

β is a (p x 1) vector of regression coefficients,

ϵ is an (n x 1) vector of errors and is normally distributed,

and where the expected value of ϵ, written as $E(\epsilon)$, is zero.

Also the variance of ϵ, follows the relation

$$V(\epsilon) = I\sigma^2$$

where σ^2 is the variance of the model.

Therefore the model can be written as

$$E(Y) = X\beta$$

The error sum of squares is then

$$\epsilon'\epsilon = Y'Y - 2\beta'X'Y + \beta'X'X\beta$$

The estimate of β is the value b, which when substituted in the above equation minimizes $\epsilon'\epsilon$. By differentiating this equation with respect to β and setting the resulting matrix equation equal to zero, the normal equations are obtained. At the same time β is replaced by b. The normal equations can be written as follows in the matrix form

$$(X'X)b = X'Y$$

From these normal equations the value of b can be obtained from the equation

$$b = (X'X)^{-1}X'Y$$

The vector b, gives the regression coefficients, which are the time standards for filleting different species of fish.

Confidence intervals for the different elements of the vector b can be computed from the following formula

$$b_i \pm t\,(v, 1 - 1/2\alpha)\ (\text{estimated s. e. } (b_i))$$

where the 'estimated s. e. (b_i)' is the square root of the ith diagonal term of the matrix $(X'X)^{-1}s^2$, and s^2 is the estimate of the overall variance of the model. For more details, refer to (Applied Regression Analysis by Draper and Smith) (1) and Statistical Methods (2).

IV. DATA COLLECTION AND REFINEMENT

Data Required for Analysis

As mentioned in Chapter 1 and the model developed in Chapter 3, data required for establishing time standards using regression analysis exists as historical data. Such data might be called 'non-experimental' or 'clinical.' The particular data required for this study consisted of number of pounds of each specie of fish fillet produced by each employee each day and the total time consumed by them in doing so. This kind of data is routinely collected by the processors for wage payments and other production records. In contrast, the data required for traditional time study analysis techniques is obtained from specially designed experiments, where each individual element of the operation is observed carefully, while the time required to execute it is recorded.

The main drawback in this experimental approach is the danger of a material effect on the performance of the worker being observed by the analyst. Another drawback is that the workers selected must be rated, because they may not be 'average' workers.

The fact that the phenomenon being measured may affect appreciably the very act of measurement, is one of the factors that inhibit the routineness in this process. Once a standard is set it cannot be easily changed if the company learns that the standard does not apply, for example, due to the fact that the method has been changed. If the standards are to be changed, new experiments have to be designed before the appropriate data is collected. In the case of non-experimental data there is no fear of the workers not performing normally. The data collection is done in a routine manner, and the workers do not have the feeling of being observed as part of an experiment. Moreover, if the standards are proved incorrect or the method of operation is changed, all that is required to do is to let the system perform normally and collect the data as usual for a sufficient period of time and then determine the standards by fitting a regression equation to it.

Regression analysis can handle experimental data as well as non-experimental data. A difficulty which arises with the non-experimental data is the interrelationship among the independent variables. These unwanted intercorrelations can be suppressed in controlled experiments by using 'balance designs,' where such independent variables are controlled so that they are orthogonal to each other, which means that the intercorrelation is made to be zero. In certain cases, such as in this study, the interrelationship between the independent variables was decreased by grouping some of the highly intercorrelated variables together. The need for these groupings have already been discussed in Chapter 3, and the final groupings used for analyzing the data from both the plants is given in Chapter 5.

Raw Data Source

The data provided by the management of Plant A, was in the form of a so-called 'fillet sheet.' A typical fillet sheet measures about 36" x 28". Across the top of the sheet are written the names of the workers. Rows are included for each specie of fish filleted on a given day. On the last row at the bottom of the sheet, are recorded the time at which the worker arrives, leaves the plant, the duration of the lunch break and the number and duration of any extra breaks taken during the working period.

The production record is kept as follows. Each time a worker fills a container with fillets, the floor lady replaces these containers with an empty one, and then weighs the filled containers so as to determine the weight of the fillets produced by the worker. This information is then recorded on the fillet sheet in that particular worker's column and in the appropriate row for that particular specie. At the end of the day, these individual entries are added separately for each specie of fish filleted by each worker. These sums are then multiplied by the rate per pound for the respective specie to obtain the earnings of the employees.

A beginner, or apprentice filleter is paid according to the number of hours worked until the time the floor lady is satisfied that his production rate has reached a certain minimum level. From then on he is paid according to the number of pounds of fillet produced by him. Thus the workers are paid on a 'piece-rate' basis. This is the only incentive scheme employed by the management. The rate at which the employees are paid depends on the specie and is derived by negotiations with union, not by reference to any standard.

From this fillet sheets the total production of fillet for each specie of fish per employee and the net working time was transferred on to appropriate forms. These forms provided the data in a compact and versatile manner. Moreover the fillet sheets had to be returned to the processors.

The raw data source for Plant B was a set of 'employee earning reports.' Although initially the data was recorded on fillet sheets, similar to the one kept by Plant A, it was then transferred on to punched cards which were later processed by a Portland-based computer firm to compute the earnings for all employees. These employee earning reports were made after every two weeks. A sample of this report is given on Figure 1. The explanations of the various items on this report are given in Table 2. Because of the simple, concise and compact form in which the information was provided, it was deemed unnecessary to transfer it into a simpler form. These computer outputs were xeroxed so as to keep a complete record of the information for the duration of the analysis.

Figure 1. Sample Raw Data Source from Plant B

[redacted]

EMPLOYEE EARNINGS REPORT 3/31/74

EMPLOYEE NUMBER & NAME	DATE	HOURS WORKED	RATE	AMT.	TIME CODE	DIST	PROD CODE	PRODUCTN (LBS.)	RATE PER LB.	AMT.
4550 [redacted]	3/15/74	.00	2.1000	2.10	1.0	44	ADDITION			
		.00 *		2.10 *						.00 *
		.00 **								
	3/19/74	5.25	2.1500	11.29	1.0	31				
					1.0	31	140	61.50	.1700	10.46
		5.25 *		11.29 *						10.46 *
		5.25 **								
	3/20/74	8.00	2.1500	17.20	1.0	44				
		5.00	3.2250	16.13	1.5	44				
					1.0	44	S108	284.00	.0725	20.59
					1.0	44	S106	52.50	.0450	2.36
					1.0	44	S118	3.00	.0900	.27
					1.0	44	S119	3.00	.1150	.35
					1.0	44	S111	2.00	.0600	.12
					1.5	44	S212	5.00	.1275	.64
					1.5	44	S206	66.50	.0675	4.49
					1.5	44	S204	28.00	.0563	1.58
					1.5	44	S208	55.00	.1088	5.98
					1.5	44	S222	2.50	.0638	.16
					1.5	44	S219	5.00	.1725	.86
					1.5	44	S211	46.00	.0900	4.14
		13.00 *		33.33 *						41.54 *
		13.00 **								
	3/25/74	8.00	2.1500	17.20	1.0	44				
					1.0	44	S108	223.00	.0725	16.17
					1.0	44	S120	5.50	.0750	.41
					1.0	44	S106	80.50	.0450	3.62
					1.0	44	S118	6.00	.0900	.54
					1.0	44	S111	31.00	.0600	1.86
					1.0	44	S112	5.00	.0850	.43
					1.0	44	S119	3.00	.1150	.35
					1.0	44	S104	7.80	.0375	.29
		8.00 *		17.20 *						23.67 *
		8.00 **								
	3/26/74	8.00	2.1500	17.20	1.0	44				

Table 2. Key to the Information Provided in Figure 1 the Sample Raw Data Source from Plant - B.

No.	Information
1.	Name of employee
2.	Code number of employee
3.	Total normal hours worked
4.	Total over time hours
5.	Normal hourly rate ($/hr)
6.	Overtime hourly rate ($/hr)
7.	Total time worked (3 + 4)
8.	Code for normal working time
9.	Code for overtime
10.	Total amount earned as calculated from number of hours worked (13 + 14)
11.	Code for filleting during normal working hours (S1) or during overtime (S2)
12.	Code for specie of fish filleted
13.	Total normal hours earnings (5 x 3)
14.	Total overtime earnings (6 x 4)
15.	Code for type of work done by employee (e.g. 44 = filleting)
16.	Production of fillet (in pounds) per specie
17.	Rate per pound for each specie
18.	Earnings according to the number of pounds of fillet produced (16 x 17)
19.	Total earnings according to the number of pounds of fillet produced (sum of 18)

Table 3. Comparison of Information Provided in the Raw Data Source by Plants 'A' and 'B.'

No.	Information	Plant - A	Plant - B
1.	Name of employee	Yes	Yes
2.	Number code of employee	No	Yes
3.	Type of work done	Yes	Yes
4.	Pounds of fillet produced per employee per specie of fish	Yes	Yes
5.	Normal working time	Yes	Yes
6.	Over time	Yes	Yes
7.	Number and duration of breaks	Yes	No
8.	Hourly earnings	No	Yes
9.	Pound wise earnings	Yes	Yes
10.	Hourly rate	No	Yes
11.	Rate per pound for each specie	Yes	Yes
12.	Quality of fillet produced	No	No

The employee earning reports (for Plant B) give wages earned by the workers based on both their productivity and the hours worked. The workers are then paid the amount which is greater of the two. This relieves the floor lady or the supervisor of making a decision as to when a worker should be paid according to the number of hours worked or at piece-rate.

In Table 3, a comparison is made between the information provided on the raw data sources from Plants A and B. It will be observed that neither of the plants keep any record of the quality of the fillets produced.

Data Refinement

Having obtained the raw data from the processors, it was transformed into three main forms. This was done so as to reduce the variability present in the data, which as already mentioned in previous chapters, is one of the main objectives of this study. These three different forms and their purposes are described as follows.

1. Production Rate Charts -- For both plants, charts were developed giving the production rates for each employee per day. To obtain these figures, the total amount of fillets produced per day by each employee was divided by the number of hours worked that day.

These figures were then averaged over the total working days to be considered for the analysis and then an overall average production rate was calculated for both plants. At the same time, these figures were also averaged over each day worked to determine the average production rate for each day. From these charts it was possible to separate the very high and low skilled workers. It was necessary to distinguish these workers from the normal workers so that the variability among the workers could be reduced, since no rating factor was being used to normalize the performance of all the workers.

Similarly, these charts enabled the reduction of variability among the working days considered by making it possible to distinguish the days when the average production rate was too high or too low. The reason for these above and below average production rate days could not be established in all cases because the data was historical. Apparently on these days some exogenous factors affected the performance of the workers, such as weather, impending holiday, etc., as shown in Appendix I.

2. Daily Production Charts -- This chart shows the total production of fillets for different species of fish per day, irrespective of the employees. Also the total man-hours utilized for the production per day are recorded. It is this data which is analyzed statistically to determine the relationship between the independent variables (i. e.

the number of pounds of fillet produced for each specie per day), and the dependent variable (i. e. the total working time for each day, in man-hours). This working time does not include the lunch breaks, coffee breaks and other major irregular breaks like disruption in the supply of fish, power failures, etc. However it does include minor irregular breaks which are not associated with the operation of filleting, such as personal time, coming in a few minutes late from lunch or coffee breaks, etc. Moreover, this data does not include the fillets produced by the very high and low skilled workers and their working time, which are identified in the Production Rate Charts. Also the days having above and below average production rates were excluded. The balance of days excluded for both the plants is shown in Table 4.

The data from these charts was then transferred on to computer files of the OS-3 system and analyzed using Statistical Interactive Programming System (SIPS), a system developed at the Oregon State University Computer Center for statistical analysis. The results of this analysis are given in Chapter 5. The Production Rate and the Daily Production Charts for both Plants A and B are given in Appendix I.

3. Grouping -- The need for grouping various species of fish together, as already discussed in Chapter 3, arises because some of them do not have enough data. Also the interrelationship present among the different species filleted, compliments the need for

grouping the fish being filleted in a similar manner into different categories.

Table 4 compares the information provided by these charts for both the plants, and the action taken on the bases of this information.

After making a number of runs for the data of both the plants, the overall variance and the standard errors of the regression coefficients were reduced considerably. This was made possible by examining the residuals and excluding the outliers, and by trying a number of grouping schemes, as suggested by the management of the seafood plants. The final model and the results of the analysis are given and discussed in Chapter 5.

Table 4. A Summary of Information Provided by the Production Rate and the Daily Production Charts.

No.	Information	Plant A	Plant B
1.	Total number of working days for which the data was provided	30	43
2.	Total number of working days considered for analysis	27	39
3.	Total number of employees working during that period	42	43
4.	Number of employees not considered for analysis	7	2
5.	Overall average production rate for all employees	34.04 lbs/hr	40.95 lbs/hr
6.	Total number of species filleted	17	24
7.	Total number of groups in final model	8	11
8.	Average number of workers per day	16	26
9.	Average man-hours per day	107.20	156.34
10.	Average working time per employee	6.70 hrs.	6.01 hrs.

V. ANALYSIS OF THE RESULTS

Introduction

To fulfill the objectives of this study, the data obtained from the two plants was refined as described in Chapter 4. This refinement, in short consisted of transferring the data on to forms which provided it in a simple and compact form; transforming the data to obtain daily production rate of employees and the daily production of fillets of different species; and developing grouping schemes for these species. The statistical analysis was then performed on the OS-3 system using Statistical Interactive Programming System, by making several runs for both the plants.

The analysis was carried out keeping in view the objective of reducing the variability of the regression coefficients and that of the model as a whole so as to obtain reliable estimates of the time standards for filleting different species of fish. The techniques used for this purpose proved to be quite successful and the results of the final runs proved to be far more realistic than those obtained in the initial runs. The assumption was made that the quality of the fillets being produced, had already been established at both the plants at certain levels by the management.

During the period over which the fillet data was analyzed, there was no significant change in the methods of filleting. The introduction of a skinning machine in the production system of Plant B, did not affect the overall methods of filleting nor did it change the work environment. The only change resulted in filleting a certain amount of fish with their skin on. In fact the model developed for Plant B determines fairly accurate time standards for both skin-off and skin-on fillets.

Having obtained the time standards, it became possible to compare the results between and within the plants so as to identify some of the possible sources of variation which cause the difference in the results of the two plants. The production rates for Plants A and B were determined from the Production Rate Charts given in Appendix I. The comparisons of the standards between the plants and with the previously established standards are given in this chapter. An example is also included as to how actual allowances can be determined using standards developed by regression analysis and the normal times obtained from micro-motion studies having given the percentage yield and the average weight of the different species. The possible causes for variation are listed in this chapter and in Chapter 3.

Results of Plant A

The data available for Plant A consisted of only 27 days, after excluding those days which had exceptionally high or low average production rates. Moreover these days were not continuous, in the sense that six days were from January, seven from May, eleven from June and three from July, as it can be seen from the daily production chart in Appendix I. This reflects the way the data was provided by the management; they were in fact not very enthusiastic about parting with their fillet data. Apparently, partially due to this discontinuity in the data the results obtained were not devoid from variation and it was not possible to obtain accurate estimates of the time standards.

The grouping of different species was based on three major procedures by which the fish were commonly being filleted: skin-off dressed and miscellaneous. The majority of fish were being filleted skin-off while two species Rex and Cata were filleted in a special manner in which either the skin was removed from only one side or the skin was being removed completely and the tail was left on. The final grouping scheme used for determining the standards and the model is shown in Table 5. In variable 28, six different species were grouped together because of lack of data; although some of them may not be filleted in a similar manner. For variable 25, English was lumped with Dover, at the suggestion of the processors, because of the inconsistency and the scarcity of the days during which English was being filleted. For similar reason, dressed Petrale and Rock were grouped together to form variable 24.

Table 5. Final Grouping for Plant A.

Variable No.	Fish Species
21	Skin-off Petrale
25	Skin-off English and Skin-off Dover
28	Skin-off Perch Skin-off Sand Dabs Skin-off Ling Skin-off Rock Skin-off Butterfish Skin-off Misc.
9	Rex - Skin Off One Side
14	Cats - Skin Off Tail On
24	Dressed Petrale and Dressed Rock

On analyzing the data, the regression model obtained had a fairly good fit to the existing data, as indicated by the square of the multiple correlation coefficient, R^2, which has a value of .9113. This model is given in Figure 2. In all the model contains six variables, which are fillets produced from different groups of fish species. Along with these independent variables is a constant term of 7.64 man-hours. The presence of this constant does not indicate that when no fillets are produced, the total man-hours utilized will be 7.64; on the contrary, when there is no production, the model will not come into effect. As already explained in the previous chapters, this constant term represents the average man-hours spent on irregular activities and delays. It may not necessarily be the same for each day, when there is a large difference in the number of hours worked. On dividing this figure by the average number of employees per day, (i.e., 16) it can be seen that on an average each employee wastes approximately half an hour per working day. These delays and irregular activities may or may not be under the employees control.

The time standards computed from the model and the standard errors of the regression coefficients are given in Table 6. The limits on the mean time standards are calculated according to the formula given in Chapter 3, and are the 95 percent confidence intervals. The results of the analysis show that three groups i.e., variables 9, 14 and 24 have a relatively high standard deviation, and in the case of

Total Man-Hours = 7.635 + .0229 (Rex - Skin-Off One Side) + .120 (Cats - Skin-Off Tail On)

+ .0614 (Skin-Off Petrale) + .0059 (Dressed Petrale)

+ .0290 (Skin-Off English and Dover)

+ .0090 (Skin-Off Perch, Sand Dabs, Ling, Rock, Butterfish and Misc.)

Standard Deviation of Model = 12.29 Man-Hours R Squared = .9113

Figure 2. Final Model for Plant A.

Table 6. Time Standards for Plant A.

Variable No.	Fish Species	Mean Mins/Lb	Standard Deviation Mins/Lb	Upper* Limit Mins/Lb	Lower* Limit Mins/Lb
21	✓ Skin-Off Petrale	3.682	0.493	4.668	2.696
25	Skin-Off English	1.737	0.231	2.199	1.275
	Skin-Off Dover				
28	Skin-Off Perch	0.537	0.216	0.970	0.105
	Skin-Off Sand Dabs				
	Skin-Off Ling				
	Skin-Off Rock				
	Skin-Off Butterfish				
	Skin-Off Misc.				
9	Rex - Skin-Off One Side	1.374	1.308	3.990	0
14	Cats - Skin-Off Tail On	7.219	2.150	11.519	2.920
24	✓ Dressed Petrale	0.354	0.903	2.160	0
	Dressed Rock				

*95% confidence limits.

variables 9 and 24, the lower limits are zero, indicating large variation in the time taken for processing the fish in those groups. This could also be due to the different methods used for filleting these fish by the employees, lack of data for these fish and possibly that these fish are difficult to fillet. On the other hand, fairly accurate results have been obtained for the variables 21, 25 and 28.

Results of Plant B

The management of this plant, being more interested in this study, provided the data which represented a fairly good cross section of their regular working periods. The total number of days considered for the analysis was 39 days ranging from May to July during which a skinning machine was purchased and put to use. With the addition of this machine, the procedures for filleting fish was categorized into four major groups: skin-off skin-on, dressed and miscellaneous.

The procedures for filleting differ significantly for the four groups. This of course, rules out the possibility of lumping the fish which are filleted according to the different procedures. Sub-groups were created within these major groups for the statistical analysis. The final grouping scheme used for obtaining the regression model are shown in Table 7. In all, eleven groups were formed, six of which contained a single specie. The other combinations were made with the approval of the management of Plant B.

Table 7. Final Grouping for Plant B.

Variable No.	Fish Species
2	Skin-Off Dover
3	Skin-Off English
4	Skin-Off Petrale
5	Skin-Off Perch
9	Skin-Off Cats
28	Skin-Off Ling and Rock
31	Dressed Petrale, Black-Cod, Sand Dabs and Misc.
33	Skin-Off Black-Cod, Sand Dabs and Misc.
34	Skin-On English and Dover
35	Skin-On Petrale, Ling, Perch, Rock, Black-Cod and Misc.
36	Skin-Off Rex

As can be seen from Table 7, the majority of the groups developed were for the skin-off fillets and only two groups are of skin-on fillets. Dressed fish was not produced in large quantity which resulted in only one group, i.e. variable 31. These groups provided fairly accurate time standards, having low variation.

The final model for Plant B is given in Figure 3. The square of the multiple correlation coefficient has a value of .94888 which in statistical terms is considered to indicate a close relationship between the independent variables and the dependent variable. Using the Student-t test to determine the faith in the relationship, the value of the multiple correlation coefficient was found to be significant at the 99% confidence level.

The model in Figure 3 has a constant term of 21.838 man-hours, which when divided over the average number of workers (i.e. 26), gives a value of .84 hours as delay per employee per day. This delay again is unrelated to the process of filleting and is an average value. Delays would differ from day to day and are generally not in the control of the employee.

The time standards for the different groups were obtained from the regression coefficients of the model. These standards, their standard errors and their upper and lower 95% confidence intervals are given in Table 8. For most of the species, the time standards thus obtained have low variations, except for the variables 5, 9, 28, 31

Total Man-Hours = 21.838 + .0230 (Skin-Off Dover) + 0.242 (Skin-Off English)
+ .0271 (Skin-Off Petrale) + .0162 (Skin-Off Perch)
+ .1009 (Skin-Off Cats) + .0069 (Skin-Off Ling and Rock)
+ .0147 (Skin-Off Black-Cod, Sand Dabs and Misc.)
+ .0960 (Skin-Off Rex) + .0130 (Skin-On English & Dover)
+ .0067 (Skin-On Petrale, Ling, Perch, Rock, Black-Cod and Misc.)
+ .0171 (Dressed Petrale, Black-Cod, Sand Dabs and Misc.)

Standard Deviation of Model = 13.03 Man-Hours R Squared = .94888

Figure 3. Final Model for Plant B.

Table 8. Time Standards for Plant B.

Variable No.	Fish Species	Mean Mins/Lb	Standard Deviation Mins/Lb	Upper* Limit Mins/Lb	Lower* Limit Mins/Lb
2	Skin-Off Dover	1.380	0.191	1.762	0.998
3	Skin-Off English	1.450	0.120	1.690	1.211
4	Skin-Off Petrale	1.623	0.165	1.952	1.293
5	Skin-Off Perch	0.973	0.562	2.097	0
9	Skin-Off Cats	6.055	1.753	9.560	2.549
28	Skin-Off Ling	0.414	0.221	0.857	0
	Skin-Off Rock				
31	Dressed Petrale	1.023	0.572	2.167	0
	Dressed Black-Cod				
	Dressed Sand Dabs				
	Dressed Misc.				
33	Skin-Off Black-Cod	0.879	0.322	1.522	0.236
	Skin-Off Sand Dabs				
	Skin-Off Misc.				
34	Skin-On English	0.778	0.086	0.949	0.606
	Skin-On Dover				
35	Skin-On Petrale	0.402	0.199	0.800	0.005
	Skin-On Ling				
	Skin-On Perch				
	Skin-On Rock				
	Skin-On Black-Cod				
	Skin-On Misc.				
36	Skin-Off Rex	5.759	0.322	1.522	0.236

* 95% confidence limits.

and 36. The large variation for these variables may be attributed to lack of sufficient data, difficulty in filleting or employees using significantly different methods for filleting these species.

Variables 9 and 36, i. e. Cats and Rex respectively, have fairly high mean time standards. This is due to the fact that these two species are relatively small and it takes a large number of fish to be filleted before a pound of fillet can be produced. This could also be a reason for the large variation in the time taken for producing a pound of fillet of these species.

In contrast, the time standards obtained for variables 2, 3, 4, 33, 34 and 35 have low variation and are quite accurate. These are the species which are filleted in large quantities and the methods for filleting them are relatively simple. Also it is these species which are significant in determining the time to be spent in producing a certain amount of fillets of the different species of fish.

Inter-Plant Comparison

While comparing the results obtained for these two plants, it should be kept in mind that these plants function in a rather different manner. The differences which might influence the results of the regression analysis can be listed as follows:

1. Layout of the working area,
2. Working conditions in the plant,
3. Size of fish,

4. Quality of the fillets established by the management,

5. Quality and supply of fish,

6. Conditions of the working tools, i.e. the type of knives used,

7. Rate at which the knives are sharpened,

8. Types of workers and the worker ability,

9. Data recording procedures, etc.

These differences could be quite significant, but the main factors whose influence would be reflected in the comparison, are the sample size (i.e. the number of days for which the data was analyzed) and the average production rate of the employees.

The models for predicting the man-hours required for producing a certain amount of fillets of different species for both the plants indicate a very close relationship between the total man-hours per day and the independent variables. This can be ascertained by observing the multiple correlation coefficients of the models and their standards deviations, which do not show much variation. The standard deviation for Plant A (12.29 man-hours) is slightly lower than that of Plant B (13.03 man-hours) mainly because of the difference in the number of working days for which the data was analyzed and the fact that Plant B incorporated a skinning machine in its system during this period, which raised the daily production rate. The model also shows that the delay time for Plant A (7.635 man-hours) is much less than that of Plant B (21.838 man-hours). This difference can be attributed to the difference between the average number of employees working per day in the plants and the fact that Plant A has a more efficient system for supplying the raw material to the workers. At the same time the working conditions in Plant A are much better than those of Plant B, which affect the desire of the employee to work without any interruptions.

While comparing the time standards developed for the different species being filleted in these two plants, it can be seen that there is a close agreement between those of skin-off English and Dover as shown in Figure 4. The standards for both these species in the two plants have low variation and their means do not differ much. However, there is a marked difference in the mean standard for skin-off Petrale and also it's standard deviation is higher in Plant A than in Plant B. This may be because of a difference in the methods of filleting Petrale in the two plants and a possible difference in the size and quality of the fish obtained at the two plants. Apart from these comparisons it would not be appropriate to compare the time standards of the other groups, as they do not include the same species.

These standards developed by regression analysis, are for each particular plant. It would be unjustifiable to apply them to another enviornment producing the same products. Moreover, after a major change in the methodology of filleting, capacity of the plant, layout of working area, etc., these standards should not continue to be used

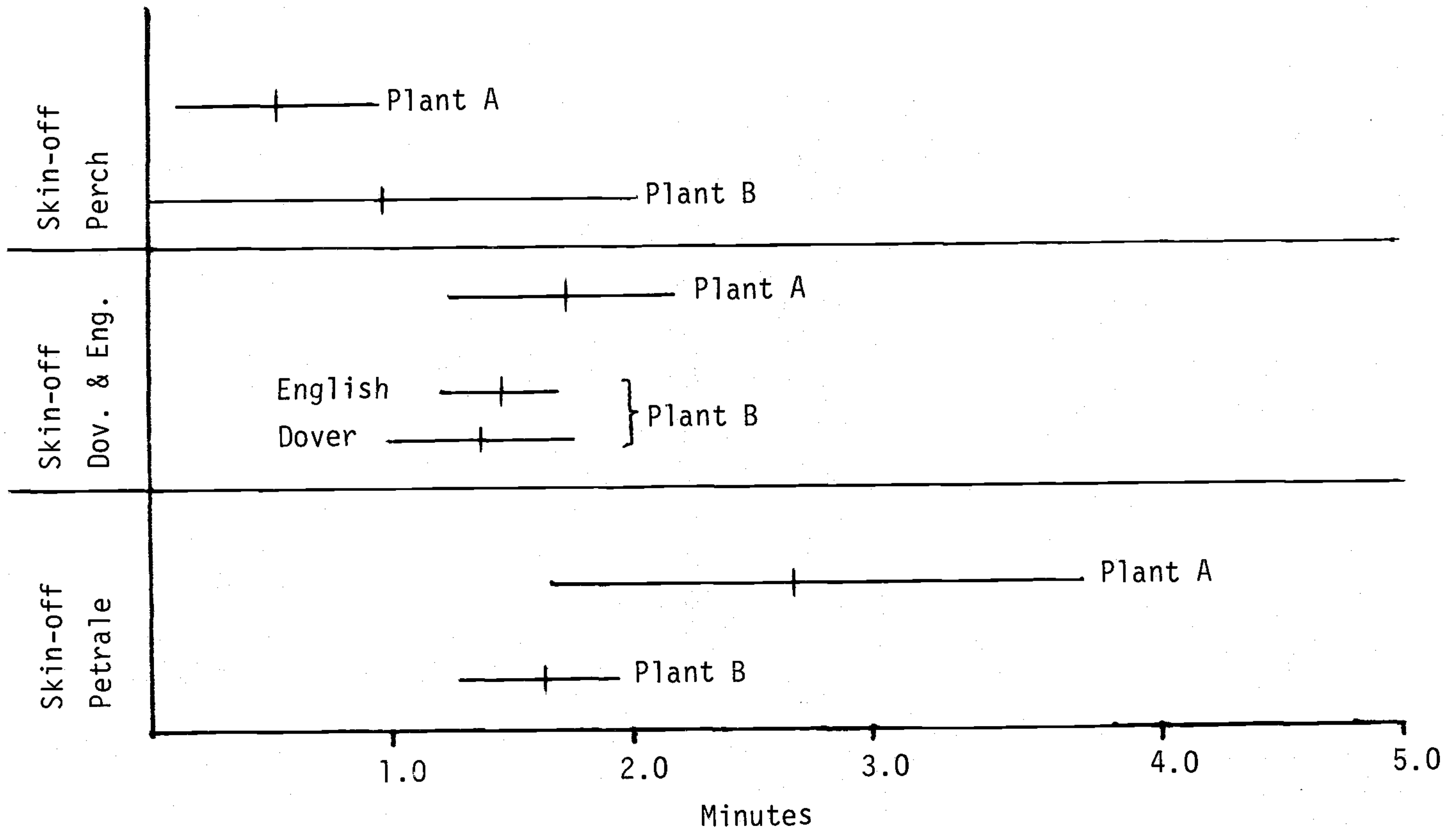

Figure 4. Standard Time Comparisons Between Plants

since in that case the present models would not represent the true relationship. This is particularly true for Plant A, where there has been a complete renovation of the working area, as already described in Chapter 2.

Comparison With Previous Standards

During a study in 1972, a graduate student (15) developed time standards for fish filleting for three different species: skin-off Petrale, skin-off Dover and skin-off English. The standards presented in that study were established after developing a new method of filleting based on the analysis of low, average and high skilled workers at Plant B. This new technique for filleting, was used by an above average worker for filleting small samples of the three species mentioned above. Standards from this experiment were then derived by first weighing the fish, recording the time it took to fillet and then weighing the fillets produced. From these figures the yield and the time standards were determined.

Table 9 shows the standard time established by this new method and by regression analysis for Plant B. Also are given the standard deviations of these mean times and the sample sizes used by the worker filleting in the new manner.

In comparing the results of these two techniques, the following facts concerning these two studies should be kept in mind: (I) there is

Table 9. A Comparison of Results.

Fish	Traditional Method*			Regression Technique - Plant B	
	Mean mins/lb	Standard Deviation mins/lb	Sample Size	Mean mins/lb	Standard Deviation mins/lb
Petrale	0.896	0.217	18	1.623	0.165
Dover	1.080	0.398	16	1.380	0.191
English	1.827	0.310	15	1.450	0.120

*Using stopwatch time study on an above average worker.

a difference of two years between these analysis; (II) only one worker was observed for the traditional method, while the regression analysis technique takes into account almost all the workers; and (III) the sample sizes used during the motion picture analysis are rather small and possibly do not represent the process of filleting in its best manner.

The above mentioned facts would tend to create a significant difference among the results of these two studies. Even so, the time standards obtained for skin-off Dover and skin-off English, are quite similar; but there is a large difference in their standard deviations. For skin-off Petrale it seems that the time required to produce a pound of fillet has gone up since the last study was done. This could be due to the change in the size and quality of Petrale now being processed. Moreover the filleter observed in the earlier study could be exceptionally good in filleting Petrale.

The comparisons in Table 9 confirm that the time standards developed by using regression analysis are reasonably accurate, considering the differences among the two analysis.

Determination of Allowances

When comparing the time standards established by regression analysis and those developed by micro-motion study, the actual allowance for that particular process can be observed. As an example such a comparison is made here in this section for the manual production of skin-off Dover in Plant A and B. The standard obtained by micro-motion study had the units of minutes per fish. For comparison, the regression analysis standard which has the units of hours per pound of fillet produced, is converted to minutes per fish. For this conversion an average yield of 25.5% is assumed for skin-off Dover and the average weight of Dover is taken to be 1.5 lbs/fish. Table 10 gives the comparison and the allowance observed.

Table 10. Allowance Determination

Source	Standard time hr/lb of fillet	Normal min/fish	Allowance min/fish
Plant A	0.029	0.44	0.226
Plant B	0.023	0.44	0.090

With the data provided it is not possible to determine what the actual cause is for the large difference in the allowances for the two plants. Of course it should be kept in view that the average yield and weight figures have a certain amount of variability.

VI. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this thesis was to determine the feasibility of using regression analysis as a technique for establishing time standards. To accomplish this, historical or non-experimental data for fish filleting was obtained and then analyzed statistically to develop time standards for filleting different species of fish. The methodology used and the results obtained have been discussed in the previous chapters. In this chapter some applications of these results are discussed; the study carried out is evaluated and some recommendations are given for further research and for implementation.

Applications of Results

In general the time standards established by regression analysis and the regression model developed can be effectively used for the following purposes:

a. Establishing Incentive Schemes--Simple incentive schemes can be established for wage payment. A standard rate of work can be determined (between the mean time standard and its lower limit) which will permit the average worker to exceed the standard by, say, 30%, and thus earn a bonus over the guaranteed pay. Many different schemes are available which can be utilized to satisfy both the management and the workers.

b. Evaluation of Operators--The overall production rate for employees obtained from the past data can be used as a measure of evaluating new employees under training. The time standards established can also be used for the purpose of evaluation and can be very helpful in determining which employees should fillet a specific specie so as to optimize output.

c. Pricing and Bidding--Due to the availability of time standards and the overall production model, the companies can estimate satisfactorily the time it would require to produce a certain amount of fillets as demanded by the customers. Moreover management can quote a competitive price for that order once the time for production and the number of filleters to be used are determined.

d. Anticipation of Labor Needs--As already mentioned, once the time to complete a job is determined, labor needs can be computed according to the length of an average working day, assuming that the production volume for that day has been ascertained.

e. Process Control--Using the concept of control charts the residuals of actual production time and the model (predicted) production time can be plotted to determine whether the process is under control or not. For this purpose, confidence limits can be computed on the basis of the standard deviation of the residuals. These limits and the concept of control charts are explained briefly in Appendix II.

The effectiveness of these applications depends on the accuracy of the model and that of the time standards. Thus whenever there is a change in the production processes or in the labor capability, a new model can be developed to obtain a reliable picture of the system.

Evaluation of the Study

The objectives of this study, as mentioned in Chapter 1, have been accomplished. It has been demonstrated that regression analysis can be successfully used as a technique for establishing time standards by using historical or non-experimental data. This technique has previously been used for developing time standards in some areas of production; the models previously developed were used to predict the overall cycle time, using the elements of the process as independent variables depicting the time standard for that particular process. The regression model, as utilized in this study, differs from the previous applications to work measurement in the sense that time standards are established for a number of products by the same model by considering only the quantity of these products produced and the total time taken for their production. The necessity of an elemental approach has been eliminated for existing systems. When applied to the determination of time standards for fish filleting, this study can be considered unique.

The standards established in this study provide the standard time for producing a pound of fillet for several different species of fish. These standards include the allowances for fatigue, personal time and other unavoidable delays related to the process of filleting. These standards when compared to those established by other work measurement techniques, such as stop-watch study using video tapes, show the actual allowances for that particular process. One such comparison is made for the production of skin-off Dover fillet, as shown in Appendix III. The results of this analysis indicates that approximately 0.09 min/fish is taken up as allowance and delays by the workers of Plant B while filleting Dover. Other comparisons are made in Chapter 5 for three different species filleted in Plant B. The results obtained in this study are quite realistic considering that all employees have been accounted for over a certain period of time.

Advantages and Disadvantages of Using Regression Analysis

Regression analysis can be considered as one of the most significant and promising tools to be introduced to the field of time study. The main advantage this technique has over the other traditional methods for establishing time standards is the relatively short time in which the standards can be developed. Once the data has been collected and transferred onto computer files, it does not take much time to analyze it statistically. In summary the advantages accruing from the technique of regression analysis can be stated as follows:

1. Rapid establishment of time standards and process model.
2. Ability to handle a large quantity of historical data, and thus represent reliably the actual plant operating conditions.
3. Removal of the necessity of breaking a process down into its elements.
4. Provision of not only the standards, but a measure of variability of the standards.
5. Reduction of the cost of establishing these standards as compared to other traditional methods.
6. Less manpower required for the analysis.

Of course this approach is not without its drawbacks. The technique can become rather complex if there are too many variables to be considered. In a case like this, similar or related products should be separated and sets of regression models should be developed, one for each group. Moreover it is not advisable to use this technique where there are constant changes in capacity, technology and employees. This would tend to incorporate a large amount of variation in the model and the time standards. It would be uneconomical to use regression analysis where the type, quality and availability of the data cannot be relied on. Economically, regression analysis can be best justified in a situation where a number of similar operations are being performed on a substantial number of different raw materials; also where major changes in methods are infrequent, such as in the fish filleting plants studied.

Most of the features of regression analysis when applied to work measurement, can be easily comprehended by persons familiar with these systems. But the conomic feasibility of this technique over that of stop-watch study is usually not appreciated. Although no economic analysis has been conducted between these two techniques, it can be seen that as the volume of standards to be established increases, a point is eventually reached where the saving in time required to set the standards can justify the use of regression analysis. The costfor setting standards as a function of the total number of standards to be set for both stop-watch study and regression analysis can be graphically represented as in Figure 5

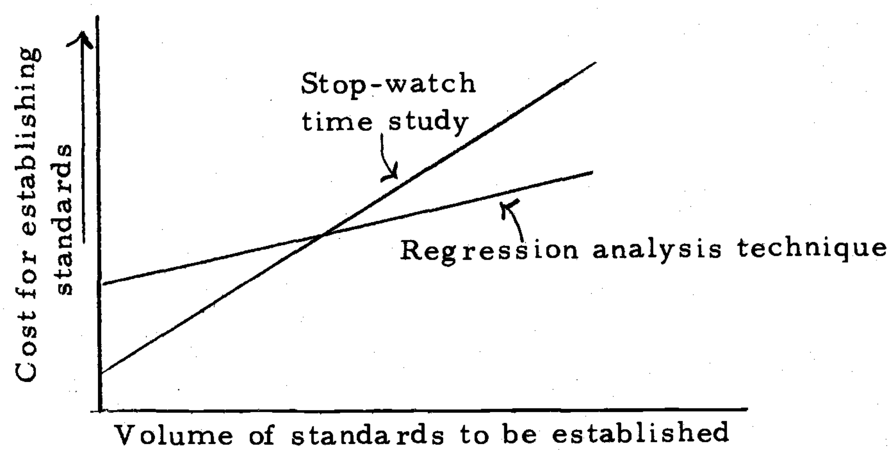

Figure 5 Cost Comparison.

Recommendations for Implementation

To the fish-processing management it is recommended that an incentive wage payment scheme based on these standards be considered. No doubt they have incentive schemes now, but the problem is that they are not based on standards, instead they have evolved due to labor negotiations, etc. Incentive schemes based on actual operating data, such as the time standards developed in this study, will have verifiability. Both the union and management should welcome such a scheme. As discussed above it is suggested that quality control programs should be incorporated by the management in the system of fish filleting.

Recommendations for Further Research

An important problem faced during this study was the lack of a measure with which to judge the effect of quality of the fillet and size of the fish on the variation present in the model and consequently on the standards (regression coefficients). The data provided by the management of both the plants did not contain information pertaining to these two factors. A method for introducing these subjective factors directly in the development of the regression model would greatly reduce the present uncertainty (variation) in the time standards. No doubt, the problem of obtaining the sizes of fish being filleted is rather complex and cumbersome, but if suitable sample sizes are obtained and are accounted for in the model, the variation can be further reduced.

Having identified the possible causes for the variations in the production rates and the standards between the plants, a detailed study should be carried out which would pin-point the main causes for the variations. At the same time normal times for filleting different species of fish should be obtained by micro-motion studies that they may be compared with the standards already developed in this study so as to determine the actual allowances. The use of achievement charts for filleting could also be used at the same time for finding these allowances.

To determine the daily efficiency of the plant and the workers, the regression analysis model developed should be kept in a tabular form along with the daily performance. The difference in the two results would then indicate the plant efficiency.

BIBLIOGRAPHY

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

2. Snedecor, G. W. and W. G. Cochran. "Statistical Methods." The Iowa State University Press, Ames, Iowa. 1967.

3. Buffa, E. S. "Modern Production Management." John Wiley & Sons, Inc., New York. 1965.

4. Krick, E. V. "Methods Engineering." John Wiley & Sons, Inc., New York. 1962.

5. Barnes, R. M. "Motion & Time Study." John Wiley & Sons, Inc., New York. 1968.

6. Secor, H. W. "The Use of Regression Analysis Techniques to Increase Standards Application Efficiency." The Journal of Industrial Engineering. Vol. XVII, No. 1. Jan., 1966.

7. Jelinek, R. G. and W. Steffy. "The Use of Multi-Variate Techniques for the Analysis of Work Measurement Data." The Journal of Industrial Engineering. Vol. XVII. No. 2. Feb., 1966.

8. Salem, M. D. "Multiple Linear Regression Analysis for Work Management of Indirect Labor." The Journal of Industrial Engineering. Vol. XVIII. No. 5. May, 1967.

9. Martin, D. D. "Instant Time Standards." Industrial Engineering. Nov., 1971.

10. Figler, R. B. "Regression and Correlation Analysis." Industrial Engineering. Oct., 1974.

11. Ballard, C. and R. Hichkend. "An Equation to Estimate Assembly Time." Industrial Engineering. Aug., 1969.

12. Doney, L. and T. Gelb. "Regression Short-cuts Cycle-time Estimating." Industrial Engineering. Feb., 1971.

13. Crocker, D. C. "Intercorrelation and the Utility of Multiple Regression in Industrial Engineering." Industrial Engineering.

14. Engesser, W.F., R. Conrads, P. Willis, C. Cheung, R. Peterson and W.G. Mercer. "Profit by Cameras". Circular No. 47, Engineering Experiment Station, Sea Grant College No. ORESU-R-73-023. O.S.U.

15. Peterson, R.H. "Systems Design for Bottomfish Processing". Unpublished M.S. thesis in the Dept. of Industrial Engineering at O.S.U.

APPENDICES

APPENDIX I

The charts developed for the refinement of the raw data provided by the management of the two seafood processors are given in this appendix. The summary of the information provided by these charts is in Table 4.

Appendix IA and IC are the Production Rate Charts for Plants A and B respectively. Similarly Appendix IB and ID are the Daily Production Charts showing the total production of fillets for different species of fish per day, irrespective of the employees.

Appendix IA. Production Rate (lbs/hr) per Employee per Day for Plant A

EMPLOYEE #	DATE	104	105	106	108	109	114	115	128	516	520	521	522	523	524	528	529	531
100		38.67	23.55	21.73	63.10	42.90	47.38	47.79	37.79	37.47	52.10	45.43	60.81	46.63	31.93	82.37	38.33	61.82
110		24.47			51.42	37.83	47.61	41.45	39.29									
120		37.56	15.86	28.34	61.20	44.39	77.88	52.99	72.79	43.35	35.00	51.03	68.13	47.76	35.25	75.78	37.67	67.59
130		26.94	19.32	18.32	52.09	35.84	62.19	42.76		40.35								
140		11.32	13.75	12.06	29.61	25.10	49.58	29.75	36.71		24.40	24.93						
150		14.58	19.77	17.03	52.51	32.06	71.00	26.25	54.29	33.35	34.81	48.50	55.19		25.23	37.72		59.69
160		12.60		11.50	41.57	34.67	62.55	40.06	53.83					31.23				
170		25.30	15.40		33.57	40.00	45.00	38.98	42.29	39.59	41.41	40.81			31.17	29.78	36.44	50.03
180		14.30	19.23		45.79	40.19	55.46	41.60	47.07	26.94	37.48	43.34		37.65	26.93	31.75	33.17	54.41
190		28.81		17.71	73.35		79.88	48.78	42.00	44.00	30.72	47.31	35.50	38.44	30.93	65.22	36.61	
200		7.0	10.38	19.98	16.20									37.78				
210		26.97	20.91	25.27						35.47								
220		41.92	27.70							46.94	56.77	62.70			41.83	83.07	30.72 44.61	
230		16.22	15.23	13.08	40.20	27.06	32.97	31.77	45.50	27.12	38.42	27.13	38.75	58.30	24.60	27.53	25.61	37.47
240		13.19	15.32	12.87	45.97	23.87	45.84	32.24	66.00		41.88			26.38				
250		32.47			50.74	33.26	68.80	36.48	49.36	32.35	26.44	39.06				26.88	30.22	47.26
260		40.34												23.69				
270		10.06	9.37	8.24	25.23	10.72	21.82					12.65			9.25			
280		8.26	10.64	8.34	32.50	14.55	22.74	14.94	11.50			13.10		30.38	13.50	22.83		
290		57.90	26.30		73.94	47.57	106.73	59.30	58.93	41.12	46.03	60.70		18.72	35.38	89.73	44.50	75.38
300		6.38												46.23				
310					3.36	4.35		10.76										
320					34.19	20.61	34.28	27.56	16.36	20.06	32.09						23.06	
330					6.2		14.34	13.94	7.00	13.35	16.84	16.06	18.31		16.03	15.34	18.94	30.41
340						26.16	31.03	32.50	38.71	27.41	31.13	26.16		23.25	22.87	25.88	24.50	35.75
350						12.65	17.41	23.78						26.41				
360						6.13												
370						3.42												
380						4.35	12.26	11.75	8.21		15.63	14.19			14.33	16.66		
390										45.35	53.97			18.60				
400											43.72				39.63	50.13	49.67	78.47
410												13.09		53.56	12.77	13.88	17.83	33.84
420										27.00				13.34				
430																		
440																		
450																		
460																		
470																		
480																		
490																		
500																		
510																		
MEAN		22.68	17.45	16.35	41.65	25.78	45.00	33.44	39.33	33.79	36.05	34.48	52.78	34.21	25.09	40.32	31.95	50.62
S. D.		14.03	5.46	6.17	19.63	14.32	24.67	13.60	19.05	9.46	11.67	17.20	21.01	13.16	10.13	26.84	9.58	16.36

Appendix IA. (continued)

EMPLOYEE #	DATE	601	603	604	613	614	617	618	621	625	627	701	708	709	MEAN	S.D.
100		60.87	50.50	56.53	49.50	45.22	41.47	45.55	51.50	56.65	54.00	58.15	57.40	31.94	49.31	10.98
110															40.27	9.37
120		57.35	50.79	48.80	61.78	37.17	43.72	47.30		64.00	57.12	65.83	63.91	55.41	53.57	12.67
130															43.36	12.38
140															28.93	11.02
150		38.95	42.32	52.73	58.88	42.11	28.88	33.30	62.30	39.35	45.39	82.38	59.34	28.66	44.18	15.89
160															39.51	16.11
170		45.22	42.11		54.31	[illegible]	50.84	39.45	44.50	37.25	48.94	71.15	60.13	41.25	42.90	9.85
180		49.26	36.61	57.60	54.66	34.17	45.31	34.75	58.80	32.35	47.24	80.46	46.39	43.09	48.84	12.89
190			46.43	55.20	69.31	41.61	62.50	40.55	81.43	48.00	64.91	81.46	46.92	54.78	52.46	16.28
200															20.33	15.80
210															31.05	4.26
220															53.97	15.06
230		43.43	28.29		30.03	30.06			49.50	41.25	30.00	54.31	40.92	41.53	35.62	10.36
240				71.33											40.74	19.20
250		44.26	33.79	46.40	43.91	42.94	32.46		57.30					38.41	40.64	10.72
260															32.02	11.77
270															14.96	6.82
280							5.19	11.45		18.80					16.90	8.19
290		67.22	60.89		70.23		43.32	41.65		44.15	46.42	88.92	59.61		57.86	15.51
300															26.31	28.18
310															6.16	4.02
320					35.89	28.17	30.72			33.60	35.70	37.08	33.56	22.44	29.09	6.62
330		26.39	20.75	27.40	20.63	22.89	20.44	24.50	43.61	37.75	35.30	33.08	36.81	26.63	22.69	9.78
340			31.00	34.80	28.28	29.74	36.31	28.90	34.00	40.25	27.09	27.15	37.75	31.50	30.51	4.93
350															20.06	6.22
360															6.13	0.00
370															3.42	0.00
380															12.17	4.10
390															39.31	18.44
400		63.87	63.50		46.47	59.00				61.30	46.12				54.72	11.51
410		25.57	22.25	29.47	30.59	24.39	30.75	23.20	29.40	40.21		46.15	30.97		28.11	11.25
420												39.77	35.14	35.34	30.12	10.45
430		33.50	43.61	50.33	40.06	50.06	51.56	41.60	62.00	65.85	56.73	54.85	64.17	48.09	51.01	9.82
440			49.86		64.72	67.50	78.03	73.20	64.41	64.68	59.39	55.62			64.16	8.56
450			4.11					10.75							7.43	4.70
460			7.83	9.27	9.44		11.28	11.65	21.00	22.30	20.39	13.85	16.19	16.25	14.45	5.16
470					5.56		17.16	14.45	11.43	17.72	19.67	14.08			14.29	4.72
480						21.67	27.59	20.15	39.75	23.80	27.42	55.31	27.56	30.91	30.47	10.95
490							11.97	17.40	15.31	22.60	21.91	16.92		17.69	17.69	3.69
500										46.00	35.15	64.15	45.81	59.78	50.16	11.17
510										24.00		28.62			26.31	3.27
MEAN		44.23	37.13	44.99	39.95	36.37	30.19	28.04	42.84	37.22	39.59	48.64	43.95	38.77	34.04	13.26
S. D.		13.97	16.83	16.86	20.83	13.31	18.35	16.20	19.49	15.31	14.14	24.22	14.21	15.25		

Appendix IB Daily Production Chart for Plant A

Date \ Variable No.*	9	14	21	24	25	28	Total Man-hrs
1 04	141.50	0	1223.75	104.75	1360.25	508.25	151.50
1 08	69.75	45.25	1415.50	438.75	88.00	3601.75	135.00
1 15	288.75	0	1243.50	69.50	1866.25	1854.75	158.15
1 28	371.50	0	20.00	129.25	840.67	830.25	57.25
5 16	57.00	38.50	149.75	0	1734.50	262.75	68.00
5 20	193.50	0	180.00	54.00	2137.50	1943.00	124.00
5 21	89.75	0	0	0	4013.50	27.75	126.00
5 23	355.00	67.25	388.00	0	2400.75	993.00	126.00
5 28	141.25	0	845.25	956.50	1414.50	1016.75	114.00
5 29	10.50	0	0	0	1825.00	177.75	63.00
5 31	363.00	0	492.50	0	1437.00	2124.00	87.25
6 01	0	0	19.75	0	1896.25	859.00	62.25
6 03	103.75	5.50	430.50	53.00	1935.75	955.25	86.50
6 04	7.25	0	13.50	0	1132.25	871.50	45.00
6 13	222.50	0	617.00	64.00	2617.75	1397.50	126.00
6 14	7.75	0	12.25	0	1831.25	441.00	63.00
6 17	238.50	27.75	298.25	78.50	1887.25	1757.00	129.50
6 18	0	0	0	0	2131.50	41.50	75.00
6 21	31.50	10.75	23.25	0	1872.75	1302.00	71.25
6 24	256.75	441.75	18.50	73.75	2004.25	3091.50	149.00
6 25	0	129.50	0	0	2115.25	1614.50	99.50
6 27	165.50	175.25	0	0	2821.75	2267.00	137.75
7 01	23.50	63.75	37.00	70.75	830.00	1938.50	61.75
7 03	254.00	27.50	497.75	0	2519.00	2911.50	144.00
7 09	0	125.50	351.75	169.25	1997.75	2775.00	139.50

* For explanation of variables see Table 5

Appendix IC. Production Rate (lbs/hr) per Employee per day for Plant B

EMPLOYEE #	DATE	501	502	509	513	514	516	520	521	522	523	524	528	529	530	531
315		31.94	50.0	33.2	43.03	55.52			42.36	58.91	35.43	36.13	38.77	42.65	40.67	44.67
600									37.13	42.09	28.91	36.69	37.13	37.87	32.5	28.5
650		46.58	47.03	46.47	53.94	56.45	51.47	53.44	59.25	66.55	48.91	46.31	48.84	53.61	41.17	
1200					46.95	40.91			53.63	76.73	43.64	56.54	47.74	50.31	41.83	36.62
1800									38.31	49.18	32.73	38.77	39.29	37.74	33.83	35.33
2060		12.45	13.59	16.2	13.45	16.38	13.1	17.30	17.56	23.45	16.48	18.69	17.6	20.45	16.17	20.77
2075		9.61	10.48	9.8	10.3	13.33	9.7	12.7	12.44	17.73		16.46	11.75	12.65	10.83	
2150																
2350																
3300		36.97	30.69	44.82	48.85	68.0	46.63	60.5	46.25	112.36	47.64	35.69	46.97	32.26		31.14
3700		33.03	29.79	45.18	38.97	48.73	44.32	43.58	51.31	64.73	55.09	25.54	52.39	32.39	24.0	
4050		39.0	39.21	33.56	38.24	50.36			38.06	54.45	27.91	38.24	32.71	37.16	30.67	38.0
4075		40.13		40.94		52.0										
4100							43.68	44.16	43.0	52.55	35.45	41.12	39.48	41.03	38.67	
4200													37.73	38.26	43.33	39.67
4550		51.23	59.52	43.41	57.21	65.18	47.47		59.44	83.09	46.73	58.77	50.71	59.81	58.67	47.33
5000		21.10	25.72	15.8	18.12	22.64	25.40		28.75	35.36	16.64	29.69	22.32	30.45	23.17	37.0
5305					26.91	29.82	26.7	25.12	29.88	38.55	24.55	30.38	25.81	28.71	27.0	33.33
5350				24.1		40.36			34.69	42.45	24.91	37.62		31.87	26.17	
5430		22.75	29.0	22.15	20.94	15.33		15.04	22.43	31.45	19.0	24.64	21.94	25.81	19.67	23.5
6650			26.48	24.3	29.03	29.73	37.05	27.68	29.19	41.64	25.36	36.54	28.07	39.61	28.67	32.33
6785																
7900		39.87	43.1		56.0	62.18	44.0						47.1	48.71	35.83	
8175									31.13	42.18	24.64	31.62	26.97	27.35	27.17	24.0
8320		8.52	8.41	9.8	11.7	12.19	14.0		17.25	26.36	16.64	20.92	16.52	23.94	21.83	27.33
8925		9.55	13.31	11.5	16.42	19.81	16.4	20.4	18.88	25.27	18.67	21.69	15.68	21.1	19.0	17.5
9925											43.55	30.77	46.65	41.23	23.0	38.67
10000		29.61	33.38	23.3	29.15	43.91	34.8	32.16	36.75	46.75	21.45		28.65	31.35	26.67	20.83
10075					11.0	13.81	19.0		20.13	30.64	17.45	22.36	17.75	23.23		
10175																
10200		35.1		38.71	42.73	45.64	37.16	39.36	41.0	52.82	34.67	39.12	36.06	39.1	33.5	
10500		34.52	40.9	30.2	39.63	54.73	39.89		40.5		34.73	46.56	40.0	45.68	38.67	
11425		17.1	17.52	15.0			18.10	18.56	23.19	31.18	17.82	16.67	17.29	23.91	18.5	21.5
11500		37.23	39.03	31.1	40.12	55.9	46.53	37.36	36.0	55.64	30.0	38.38				
7400		30.45	33.31	25.8	38.18	37.09	40.0	33.84	37.88	50.45	33.36	34.23	32.19	45.23	27.0	46.0
7925																
9900		31.42	30.97	44.94	50.06	69.55	41.05		46.63	57.73	37.91		35.74	39.48	34.5	38.15
2500		45.87	47.93	31.29	41.64	48.27	37.68	46.0	50.44	58.18	37.82	48.08	44.45	48.84	39.5	39.0
7140		9.61	6.63	8.8	12.73	16.4	16.0	14.18				12.67	17.13			
200		22.45	21.52	19.5	25.27	28.36	21.40	22.0	30.33							
2225					34.25	38.45					26.73	30.48	29.29		26.67	32.0
4800																
8400																
MEAN		34.96	36.92	34.32	40.21	47.45	39.13	37.35	38.76	47.59	34.92	36.03	37.48	36.64	33.15	33.44
S.D.		8.29	10.17	8.73	10.39	13.18	8.28	12.12	10.6	15.46	9.22	9.74	9.06	10.12	8.77	8.06

Appendix IC. (continued)

EMPLOYEE #	DATE	603	604	605	606	607	610	611	617	619	621	622	624	625	626	627	628	629
315		57.61	59.75	37.71	57.5	28.8	61.64	44.0	57.44									
600		42.78	41.88	44.86	41.5	33.0	44.92	34.25	33.75		53.13	54.34	67.61	36.63	47.88		43.5	
650		52.0	57.75	51.14	67.0	34.40	51.56	45.88	51.88	44.10	49.44	43.73	59.88	44.31	44.75	48.13	33.69	44.13
1200		55.61	42.63	48.0	53.0	46.0	56.07	43.25	43.75		47.63	44.8	61.55	39.88	44.75	53.5		
1800		50.67			45.25	34.20	45.08	44.0	36.94		40.81						31.44	44.25
2060		35.56		28.29	47.75	31.40	40.44	35.29	38.44		42.13	33.67	42.97	40.13		41.13	33.25	46.0
2075		53.11	22.38	18.86	34.5	21.8		26.35	26.38		29.47	24.0	31.45	30.25	24.25	30.0	22.38	35.5
2150		68.41	67.0		82.75		82.15	57.33	60.38		70.63		84.26	73.25	71.25	73.19	56.75	
2350						25.20	47.23	36.53	43.13		31.44		54.45	44.69	33.81		28.94	
3300		44.83	32.88	32.22	54.0	46.38	63.78		45.87	41.73	43.44	68.13						
3700			24.38	32.0	44.75	55.88	59.85	40.12	41.06	49.6	49.38	36.13	89.70	57.0	82.50	60.88	32.0	57.25
4050		79.13	68.06	65.71	83.0	48.20	73.45	57.65	67.0		57.19		78.95	64.38	60.69	76.94	48.13	
4075																		
4100		43.0	39.25	60.29	45.25	30.6	46.15		37.0		36.38	37.55	42.19	55.0	53.50	60.0	45.0	
4200		54.33	40.63	58.57	58.5		52.15	41.6	49.13		41.75	45.79	57.68	50.43	81.88	68.69	42.25	
4550		63.72	52.63	57.14	83.75	33.2	58.38	44.71	54.94		44.19		69.29	51.0	65.0	83.13	60.88	
5000		56.67	49.25	40.57	67.75	31.8	48.77	42.12	56.13		42.58		56.52	41.38	37.14		40.88	
5305		53.67	57.63	38.57	72.25	40.5	52.31	48.5	48.19		42.88							
5350							54.96	44.0										
5430			45.71	45.14	62.0	37.80	51.23	32.75	51.06			39.73			38.75	48.75	37.38	46.5
6650		51.67	45.88	21.71	73.25	51.4	60.33	60.0	57.0	55.3	42.38	40.93	55.35	48.75	42.56		33.19	48.0
6785																34.31	28.88	38.25
7900		54.13	46.88	83.71		37.0	60.85	59.87	48.5		57.13		86.25	68.38	67.25	85.69	49.75	
8175		42.78	52.53		54.75		36.31	19.87	25.88		26.5						35.69	34.0
8320		54.17	41.38	36.86	63.5	40.0	54.77	42.5	52.63		47.13	38.73	86.32	49.0	40.5	51.88	35.43	
8925		47.33	37.5	28.29	62.5	32.2	54.22	32.71	43.38			39.38	61.68	45.63	43.38	41.25	34.0	35.25
9925		39.17	35.81	30.43	61.25	43.13						38.34	50.0	63.75		62.5	38.06	51.5
10000		62.78	57.25	35.43	78.0	53.4	60.74	54.83	60.63		58.13	48.0	69.55	56.25	49.63	56.25	41.0	49.63
10075			41.13	26.0	63.75	72.0	55.7	54.12										
10175																		
10200		40.0	37.88	37.43	56.5	24.0	39.54	40.71	40.88	41.2	35.13	36.25	43.43	32.13	60.0	66.69	43.0	49.5
10500				59.43	53.75	26.0	48.92	35.07	37.56		35.94		47.48	57.75	52.5	57.13	44.88	
11425			37.83	46.57	39.75	32.2		26.94	41.25		39.19	24.93						
11500		73.0	61.63	77.71	100.25	32.8	47.23	33.88			74.88		86.97	69.25	73.88	83.25	56.38	
7400		48.33	63.13	42.29	89.0	73.25	67.62	65.75	57.81	72.5	61.63	59.13	85.87	62.0	54.0			
7925						19.6	35.85	33.87	37.75		27.63			39.63	30.13	33.5	22.75	
9900		35.56	38.75	35.71	56.75	28.8	50.77	47.41			44.62	56.21						
2500		44.78	46.81	46.86	51.0	28.44	43.85	28.63										
7140		28.33	36.75			21.50												
200																		
2225																		
4800																		
8400																		
MEAN		51.18	46.38	43.67	61.44	37.34	53.34	42.02	46.3	50.74	45.46	42.62	63.89	50.87	52.17	58.18	39.21	44.53
S.D.		11.49	11.76	15.7	15.59	13.13	10.2	11.36	10.19	11.93	11.89	11.04	17.22	11.97	15.98	17.15	9.83	7.0

Appendix IC. (continued)

EMPLOYEE #	DATE	701	702	703	705	708	709	711	712	713	715	MEAN	S.D.		Ji
315												45.82	10.6		27
600		46.91	51.2	64.93	83.57	70.44					48.40	44.78	12.73		31
650		48.85	58.1	64.13	53.66	53.13	48.19	59.30	55.24	53.82		50.72	7.9		51
1200		37.33	43.5	47.47	49.57	46.69	45.81	68.0	50.82	62.51	45.68	50.19	8.58		38
1800		34.79	45.7	56.93	52.0		51.35				46.07	42.41	6.76		29
2060		41.21	38.9	48.93		47.38	37.09	41.29	42.24	49.22	37.35	30.76	12.6		38
2075		28.36	24.4	31.73	37.14		25.45	24.71	30.24	33.22		22.88	10.05		36
2150		63.27	61.5	84.8	95.71	95.63						65.65	18.38		22
2350						47.0	40.0	42.86	45.63			40.01	7.89		14
3300					62.71	83.0		59.50	47.37	51.85		49.08	15.68		41
3700		42.79	40.6	58.0	65.57	48.75	40.91	27.64	46.35	47.65		44.31	13.34		50
4050		57.71	52.2	66.92		64.38	58.06	69.71	71.88			51.93	16.41		45
4075		23.24		23.54											
4100		63.87	54.7	65.73		73.63		70.29	55.13			46.76	10.53		37
4200						52.25	46.79	52.14	61.58			50.34	10.63		28
4550		68.0	66.8	85.73	101.08	95.63	78.19	116.87	73.88	83.48		63.5	16.36		48
5000		42.0	31.3		66.0	57.25	41.45	50.71	33.5	35.83		35.0	13.63		46
5305						57.63	37.09	43.0	45.33	48.52		42.05	11.55		32
5350						67.38	41.09	53.21	42.0			40.38	11.96		21
5430		37.82	29.4	44.13	56.25	44.0	40.63		32.17			32.76	11.56		44
6650		41.45	38.2	49.47	52.69	46.25	42.5	55.0	55.65	54.78		40.39	12.81		50
6785		39.88	41.9	44.27		49.43						39.56	6.69		7
7900							77.55	101.91	62.25			57.25	15.53		33
8175		39.76		36.67	44.43	36.0	33.70	35.57	45.09			34.29	9.39		29
8320		49.45	43.0	53.33	60.67	61.13	48.0	60.14	48.48			37.3	18.79		38
8925						44.75	36.73	36.57	44.35	47.0		31.7	14.42		37
9925		38.30	37.5	48.27					37.70			42.33	10.26		26
10000		52.24	44.3	52.53	61.14	52.63	47.39	56.71	63.06	57.22		44.19	13.88		50
10075												33.58	19.5		16
10175			23.65	37.47											
10200		49.27	49.0	57.73	67.2		40.0	47.57	54.47	64.0		43.32	9.3		48
10500		70.19	59.1			47.25			56.25			43.59	11.89		37
11425		35.75					24.97	25.5	27.29	50.78		26.75	9.2		38
11500						85.25	62.05	68.29				56.81	20.35		27
7400												46.99	16.67		37
7925							38.42	38.5				29.31	6.74		18
9900												42.67	9.53		33
2500												44.64	7.78		33
7140												16.73	8.6		12
200												25.52	4.84		17
2225												31.83	5.18		13
4800												23.93	4.38		6
8400												34.24	5.73		4
												38.35	9.04		6
												46.05	5.19		4
MEAN		45.76	45.57	52.03	63.09	59.45	45.11	54.37	49.13	52.85	45.71	40.95		ΣJi	1297
S.D.		12.25	11.11	17.21	17.4	16.68	12.13	21.84	12.11	12.26	12.75	10.47			

Appendix ID. Daily Production Chart for Plant B

Date \ Variable* No.	2	3	4	5	9	28	31	33	34	35	36	Total Man-hrs
715	758.0	0	40.0	1178.0	329.5	817.0	82.0	39.5	2912.5	2057.5	90.5	172.0
713	175.0	48.0	291.0	0	0	271.0	0	366.0	2678.0	320.0	12.0	70.3
712	610.0	283.0	907.0	0	194.0	562.0	281.0	216.0	4959.0	1696.0	217.6	187.8
711	1141.0	19.0	80.0	37.0	120.0	139.5	0	238.0	4478.0	2231.0	216.0	153.5
709	921.5	300.0	701.0	0	36.0	710.0	78.5	807.0	3839.0	981.0	261.0	180.5
708	1255.5	77.5	509.0	8.0	0	284.0	0	0	8190.0	1083.0	36.0	187.5
705	502.0	27.5	5.0	0	0	138.0	421.5	108.0	4476.0	266.0	164.3	101.8
703	746.0	128.0	39.0	0	87.0	22.0	13.0	121.0	3904.0	3450.0	284.0	145.5
702	72.0	571.5	709.0	32.0	85.0	19.0	80.0	576.0	4372.0	2546.0	119.0	195.3
701	805.5	571.0	748.0	83.0	42.0	84.0	77.0	291.0	4037.0	1111.0	227.0	163.8
629	59.0	13.0	564.5	0	0	345.5	720.0	10.0	160.0	442.0	0	48.8
627	551.5	141.5	1599.0	131.5	16.0	532.0	0	1013.5	4574.0	910.0	39.5	153.8
626	900.5	397.5	37.0	483.0	20.0	231.0	0	999.0	4905.0	1180.0	144.0	169.8
625	957.5	315.0	831.0	0	0	554.0	699.0	4.0	5367.0	676.0	83.5	175.3
624	1755.0	26.0	382.0	357.0	37.0	719.0	404.0	642.0	3468.0	2890.0	172.5	165.0
621	2911.0	2.0	124.5	70.0	104.0	46.0	95.0	536.0	4849.0	965.0	126.6	216.0
617	2648.0	404.0	356.0	230.0	252.5	463.0	10.0	331.0	4012.5	1408.0	196.5	213.5
614	2902.5	192.0	557.5	336.5	18.5	460.5	243.0	1315.0	3629.5	3316.0	137.0	222.5
611	933.0	127.0	251.0	3.0	57.0	115.0	698.0	917.0	1756.0	553.0	51.0	122.0
610	2104.0	125.0	399.0	1239.0	64.0	655.0	488.0	13.0	2908.0	2651.0	173.0	197.3
606	1418.5	96.0	24.0	303.0	8.0	685.5	0	633.0	2325.0	1812.0	49.5	116.3
605	350.0	172.0	496.0	17.0	12.0	303.0	0	1905.0	679.0	563.0	21.5	95.3
604	2044.5	52.0	1087.0	158.0	52.0	669.5	879.0	28.0	3634.0	2106.0	99.0	218.0
603	3370.5	165.5	312.0	486.0	157.0	1513.0	0	19.0	3624.0	2193.0	332.0	232.5
531	1085.0	56.0	55.5	2.5	0	131.5	364.0	535.5	0	0	34.5	62.0
530	1439.0	5.5	249.0	47.5	0	242.0	64.0	576.5	0	15.0	8.0	79.8
529	0	5304.0	4.0	117.5	75.5	1379.0	41.0	755.5	0	345.0	252.5	211.3
528	0	5709.5	3.0	43.5	145.5	310.5	203.5	720.5	0	212.0	167.3	205.5
524	0	4058.0	29.5	470.0	187.0	56.0	118.5	1034.5	0	0	35.3	168.8
523	33.0	2613.0	0	12.0	19.5	413.0	0	1206.0	0	0	283.9	144.8
522	0	2343.0	0	69.0	294.5	3004.5	0	1340.0	0	0	6.0	147.0
521	136.0	5026.5	18.0	494.5	337.5	239.5	357.0	1511.0	0	0	52.0	210.5
520	3.0	2720.0	0	71.5	0	0	0	390.5	0	0	0	92.3
516	0	2095.5	13.5	28.5	75.5	689.5	10.0	617.5	32.0	0	54.5	110.0
514	0	2217.0	0	55.5	136.5	2601.5	212.0	574.5	0	0	92.0	137.0
513	35.5	4983.0	0	67.5	186.5	509.5	0	555.0	0	0	126.4	187.8
509	190.5	0	1761.0	0	0	84.5	13.0	508.0	0	0	206.1	110.8
502	47.0	337.5	2919.5	3.0	93.5	377.5	38.5	586.5	0	0	198.0	150.5
501	402.0	93.5	4678.5	14.0	25.0	331.5	0	126.5	0	0	123.5	175.3

* For explanation of variables see Table 7

APPENDIX II

PROCESS CONTROL

The model developed for the two plants can also be used for the process control. Considering the residual (i. e. [actual time] - [model time]) as an attribute, control charts can be used for measuring the stability of the process. Upper and lower limits are calculated about the mean of the residuals, which help determine whether the variation in the process is due to chance or it has an assignable cause. The limits are calculated according to the following formula

$$\text{Upper Control Limit} = \bar{X} + 3s$$

and $$\text{Lower Control Limit} = \bar{X} - 3s$$

where

$\bar{X}$ = mean of the residuals

s = standard deviation of the residuals.

The control limits calculated for the two plants, based on the data provided are:

Plant A

$\bar{X}$ = 0.0

s = 10.73 man-hours

UCL = 32.18 " "

and LCL = -32.18 " "

Plant B

$\overline{X}$ = 0.0 man-hours

s = 10.98 " "

UCL = 32.95 " "

and LCL = -32.95 " "