DEVELOPING AN ALGORITHM TO ESTIMATE UNIT PRODUCTION COSTS IN A GLASS MANUFACTURING COMPANY

by

MURAT PARLAK

B.S. in I.E., Boğaziçi UNIVERSITY, 1984

Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science
in
Industrial Engineering

Boğaziçi University

1986

DEVELOPING AN ALGORITHM TO ESTIMATE UNIT PRODUCTION COSTS IN A GLASS MANUFACTURING COMPANY

APPROVED BY

Prof. Dr. İbrahim Kavrakoğlu ....

(Thesis Supervisor)

Dr. Gülay Doğu ..G. Doğu.....

Prof. Dr. İ. Özer Ertuna Özer Ertuna

DATE OF APPROVAL

ACKNOWLEDGEMENTS

I would like to express my gratitude to my thesis supervisor Prof. Dr. İbrahim Kavrakoğlu for his invaluable guidance and productive criticisms.

I would like to thank to Dr. Gülay Doğu and Prof. Dr. Özer Ertuna for their interests and evaluations as the members of my thesis committee.

I would also like to thank to the members of Türkiye Şişe Cam Fabrikalari A.Ş. for their contribution and help.

DEVELOPING AN ALGORITHM TO ESTIMATE UNIT PRODUCTION COSTS IN A GLASS MANUFACTURING COMPANY

ABSTRACT

In recent years, cost estimation and cost control have become an important issue in developing countries, especially in industrial sector in Turkey.

In this study an algorithm is developed to estimate unit production costs in a glass manufacturing plant, and some sensitivity analysis are made. The approach is a combination of the accounting approach, statistical approach, and engineering approach. The results of this study may be used in budgeting, pricing, cost control analysis, production planning, and investment planning.

CAM ÜRETEN KURULUŞTA ÜRÜN BAZINDA BİRİM MALİYET BELİRLENMESİ

ÖZET

Gelişmekte olan ülkelerde, özellikle ülkemizde endüstri sektöründe son yıllarda maliyet belirlemesi ve maliyet kontrolunun önemi giderek artmaktadır.

Bu çalışmada cam üreten bir kuruluş için ürün bazında birim maliyet belirleyen ve duyarlılık analizleri yapan bir algoritma geliştirilmiştir. Kullanılan yaklaşim muhasebe, istatistik, ve mühendislik yaklaşımlarının bileşiminden oluşmaktadır. Elde edilen sonuçlar bütçe hazırlanmasında, satış fiatı belirlenmesinde, maliyet kontrolunda, üretim ve yatirim planlamalarında kullanılabılır.

TABLE OF CONTENTS

LIST OF FIGURES

I. INTRODUCTION

1.1. Production Process in a Glass Manufacturing Plant

Basically, the manufacture of glass is the high-temperature conversion of raw materials into a homogeneous melt to be fabricated into useful articles. Some of the raw materials used in production are glass sand, feldspars, soda ash, and dolomitic limestone. Some of the details in the overall process are shown in the flow chart given in Figure 1. Raw materials are mixed in the batch house and then sent into the furnace. After the glass is melted down and conditioned in the furnace, it is drawn from the furnace, where the temperature is about 1500 °C, in desired thickness. Then the glass is entered into bath for cooling process. The temperature in the bath is approximately 1300°C. After bath, the annealing process starts. In this process, the glass is passed along a continuous belt tunnel for 60-90 minutes at a temperature of approximately 500 °C. After annealing the glass is ready for cutting. The glass is

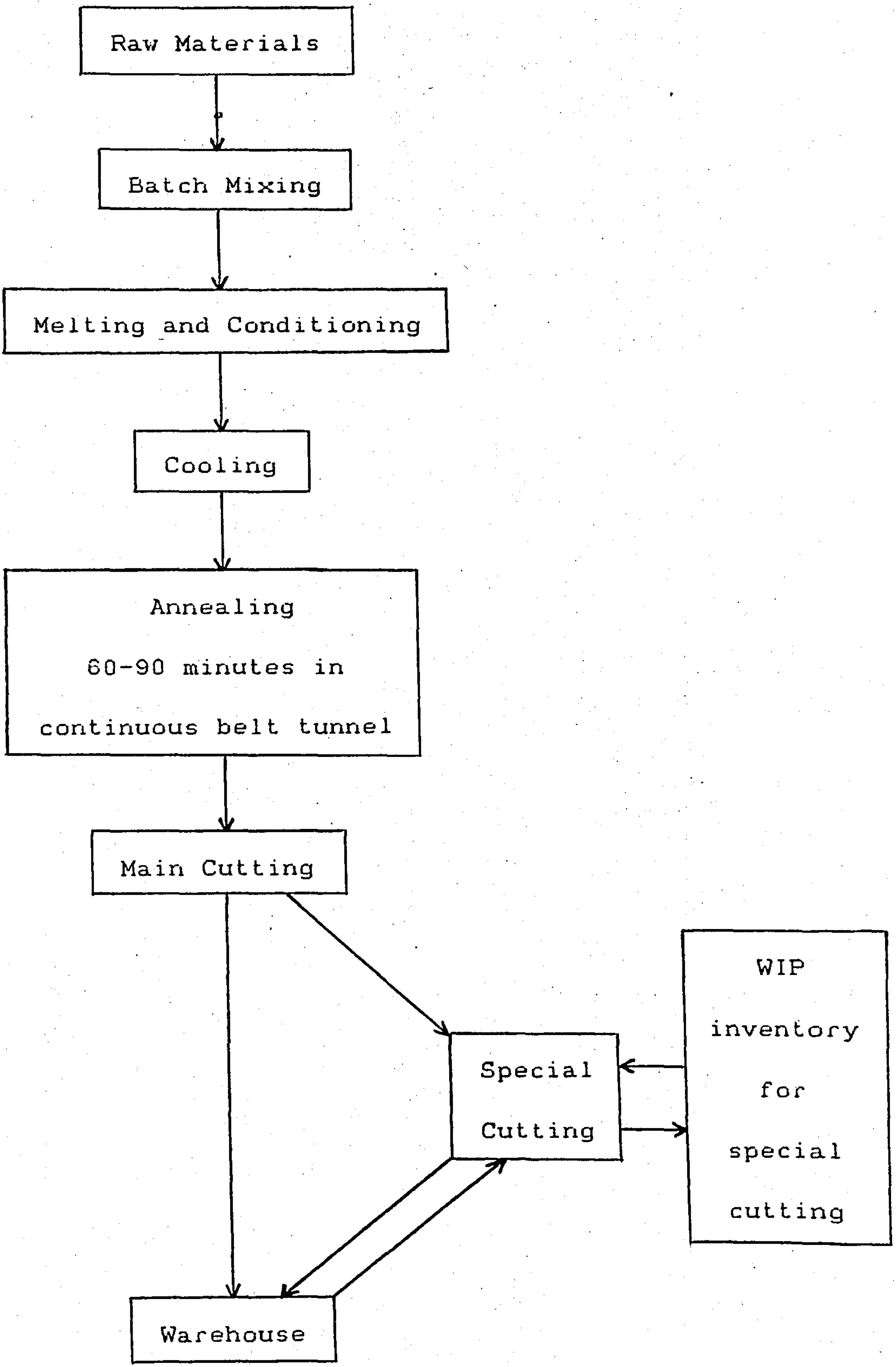


Figure 1. Production Process

first cut and separated on the main cutting line automatically in standard machine-size. At this point the machine-size glass may be sent directly to warehouse, or to special cutting in order to meet special-size glass orders. The special cutting process basically consists of re-cutting, separating and picking operations. Machine-size glass produced in past periods may also be sent to the special cutting department from the warehouse.

In both main cutting and special cutting processes some losses occur, and the production efficiencies are defined in terms of these losses. For example, the production efficiency of three millimeters machine-size glass is defined as the ratio of total net output obtained from main cutting line in the thickness of three millimeters to the amount of total glass drawn from the furnace in the thickness of three millimeters.

1.2. Product Types in the Selected Factory

Glass can be classified either according to its thickness or according to its size. In the selected factory glass is produced in seven different thicknesses which are specifically three millimeters, four millimeters, five millimeters, six millimeters, eight millimeters, ten millimeters and twelve millimeters. Thus in this study the glass production is classified into one of these seven groups. On the other hand, two main groups arise as a result of the attempt to classify glass according to its size. One is the machine-size glass and the other is the special-size glass. Although it may be thought of further classifying the special size glasses into different sizes, such a subclassification is not undertaken in this study because relevant data are not available. Thus in this study we have 14 different products in total, at seven different thicknesses and two different sizes.

1.3. Statement of the Problem

The objective of this study is to develop an algorithm to estimate unit production costs of products which are introduced in the previous section, and also to determine the effects of some decision variables, such as total output, product mix, amount of cullet used in production, and the effects of some exogenous variables such as main cutting line production efficiencies and special cutting line production efficiencies on unit production costs. The unit production cost in this study is defined as TL/ton. The results obtained may then be used in pricing and cost control analysis.

II. EVALUATION OF THE SOLUTION PROCEDURE

2.1. A Review of the Available Approaches in Literature

Most of the studies carried out so far utilize one of the three basic approaches encountered in literature to estimate costs; these are namely the engineering approach, the accounting approach, and the statistical approach. These approaches need not be mutually exclusive. Two or more of them may supplement each other. For example, while using the statistical approach, data can be derived from accounting records and the results can be projected into future by means of engineering estimates.

2.1.1. Engineering Approach

The engineering method consists of systematic guesses about what cost behavior ought to be in the future on the basis of what is known about the rated capacity of equipment, modified by experience with manpower requirements, efficiency factors, and with past cost behavior. Thus it depends upon knowledge of physical relationships, supplemented by pooled judgements of practical operators. It usually makes use of whatever analysis of historical cost behavior are appropriate and available as a means of making the judgement better.

Typically the engineering estimate is built up in terms of physical units and the cost estimates are usually developed at a series of peg points that cover the contemplated or potential output range.

The engineering approach is the only feasible one when experience and records do not provide a sufficient historical basis for measuring cost behavior. Engineering approach is also a needed supplement to statistical or accounting analysis when it is desired to project cost behavior beyond the range of past output experience.(1)*

2.1.2. Accounting Approach

The accounting approach is basically the classification of expenses as fixed, variable, and semi-variable on the basis of inspection and experience. This approach is the simplest and least expensive of the three approaches. Thus it should normally be used whenever feasible as a supplement to the other methods, if it is not used as the principal method.(1)

* Paranthetical references placed superior to the line of text refer to the bibliography.

Fixed costs are those in which total cost takes a constant value over a relevant range of output, while the cost per unit varies with output.

Variable costs are those in which the total cost changes in direct proportion to the changes in volume, or output, while the unit cost remains constant.

Semi-variable costs have both fixed and variable characteristics. They are therefore also called as mixed costs. Semi-variable costs are neither wholly fixed nor wholly variable. They must be separated into fixed and variable components for purposes of planning, estimating and control.(2)

Costs are accumulated by cost centers, which may or may not coincide with operating departments. Cost centers are placed at points in the production process where costs can be measured and recorded as conveniently and accurately as possible. A department may be broken down into several cost centers to obtain more detailed cost data, or several departments may be combined. Each cost center has several numbers of cost components like materials, labor, etc. Each cost component in a cost center is estimated independently and divided into fixed, variable and semi-variable parts.

Since the accounting approach provides no way to correct data explicitly for changes in cost prices or for changes in other conditions that affect cost behavior, a constancy of these cost conditions is essential if accurate results are to be obtained. The statistical method can tolerate more variation in underlying conditions because it possesses a means of dealing with these variations. The accounting method isolates constant cost easily by inspection. It identifies variable cost easily,but determines less accurately the pattern of variation of these and of semi-variable costs. This approach needs to be supplemented by graphical statistical analysis to separate the variable and fixed components of semi-variable cost and to determine the linearity of output relationship for semi-variable and variable costs.

2.1.3. Statistical Approach

Statistical analysis of past behavior of costs deals explicitly with each major problem of determining the cost relationships emprically. The engineering and accounting approaches meet these problems but cope with them less consciously and therefore perhaps less succesfully.(1)

Statistical cost estimation includes sequential observation of costs of the plant over a period of time when it operates at different rates of output. When conditions are favorable, the statistical approach is likely to achieve more reliable measurement of short-run cost relationships than the alternative methods. It is however, more time consuming and expensive. It uses multiple regression analysis to determine a functional relationship between cost and independent variables such as output rate, manufacturing size, and direction of change in output.

At first, statistical approach requires a time unit of observation and time period for collecting data. The time period for collecting data should have the following characteristics.

(a)wide range of output variability and uniform data coverage for the range;

(b)constant size of plant;

(c)little change in technology;

(d)stable managerial methods;

(e)uniform cost records covering changes in volume, cost, and other operating conditions;

(f)number of observations large enough to permit generalization and yet small enough to be manageable in correlation analysis;

Measurement of output is usually the hardest problem in statistical determination of cost. Theoretical cost functions assume that output consists of homogeneous units of a single product. Actually, however, almost all modern plants produce a number of varied products. There are three ways to solve the problem of measuring heterogeneous output. The first solution is to determine the cost-output relationship separately for each product. This approach is available only when products are few, when processing is separable, when records of cost and output for each individual product are available, and when observations of each product are spread over a wide enough range to permit fitting of cost regressions and computing of coefficients of variation. The second way to measure the heterogeneous production is to introduce each significant aspect or dimension of multiproduct output as a separate independent variable in the multiple regression analysis. This solution is particularly useful when different dimensions of output have distinctive cost influences. The third solution for measurement of heterogeneous production is to develop an index of multiproduct output. Although this solution is inherently inadequate because no scheme of product weighting is fully satisfactory, nevertheless it is the only workable solution when the number of products is large, their mix is fluctuating, and their individual costs nonseparable.

Another problem in statistical cost determination is to decide whether the separable components of combined cost should be studied statistically. Analysis of individual elements of expense has several advantages. In the first place individual accounts may require different corrective devices, corresponding to the varying influences which give rise to the need for rectification. Irrelevant influences may differ in kind for different expenses and may also operate with varying intensity on the various categories of cost. The same considerations apply also to the influence of independent variables. An independent variable may affect only certain components of cost.

To obtain empirical cost functions, it is necessary to hold the prices of input factors constant. Two assumptions are made.

(a)Substitution among the input factors does not take place as a result of changes in their relative prices.

(b)Changes in the output rate exert no influence on the prices paid for materials, labor and services.
Because factor prices and other cost distortants affect the individual elements of combined cost differently, elements must be rectified separately.

Once the decision is made to use multiple regression techniques for analyzing the cost items, it is necessary first to choose independent variables as those factors which play the most important role in influencing the cost behavior and secondly to select the most suitable statistical series with which to represent the relationship between these factors. The choice of cost factors is made on the basis of the following criteria.

(a)The factor should have a significant influence upon cost.

(b)The factor should represent a cost influence which is distinct, that is, which is not to any important degree already included in some other independent variable.

(c)The factor should be suspectible to statistical measurement.

Statistical cost estimation applications in some special and small size plants are published by Dean J. in 1976.(1)

An important criticism on statistical cost estimation is that rectification of cost data for changes in wage rates and material prices biases the results of statistical studies toward a linear total cost function. Price-motivated substitution of factors of production, which is an important ingredient in the operation of the law of diminishing returns, is deflated away in the rectification process.

2.2. Analysis of the Studied Approach

The approach used in this study is a combination of the three approaches discussed in the previous section. The cost centers and the cost components are selected and classified as fixed and variable based on accounting records. Accordingly, an algorithm consisting of two main steps is developed to estimate unit production costs of products. The first step is the estimation of total costs for all cost centers independently using statistical analysis of variable input consumptions. The second step is the distribution of these costs to products through an engineering approach.

Each cost component in each cost center is classified as fixed and variable. The fixed cost components are estimated when the annual budget is being prepared and show very small variations during a year. However the variable costs are related to some decision variables such as total output, product mix, and the amount of cullet used in production. Thus each variable cost component must independently be estimated in order to have an estimation of total costs for cost centers.

A two-stage algorithm is applied in order to calculate unit production costs of each product type. In the first stage, the costs of machine-size products are calculated considering the quantity of each product produced, main cutting line efficiencies, and the price of the cullet. In the second stage, the unit costs of special-size products are calculated where the quantities, special cutting line efficiencies, and the price of cullet are taken into account. In addition to these, the flows from main cutting line to special cutting, the flows from warehouse to special cutting, and the work-in-process inventories for special cutting are also considered.

III. ANALYSIS OF THE GENERATED MODEL

3.1. Statistical Estimation of Total Cost

In the process of estimating total cost, as a first step cost centers are identified and cost components are explicitly defined. Then variable cost components are estimated using multiple regression analysis.

3.1.1. Identification of Cost Centers and Cost Components

Six cost centers used in the study are determined from the accounting records kept in the factory. These cost centers where costs are recorded are listed below in the sequential order of the production process.

(i) Batch house
(ii) Furnace
(iii) Bath
(iv) Annealing
(v) Main cutting (Primary cutting)
(vi) Special cutting

Each cost center has several numbers of cost components classified as either fixed or variable. A great portion of fixed costs arises from depreciation expenses. Variable cost components consist of raw materials and energy expenses. Raw material expenses constitute larger portion in variable costs, and consequently in total cost. In the first cost center the variable cost components are raw materials and electric energy expenses. In the second cost center, the variable cost components are fuel-oil expenses in the furnace, and the electric energy expenses. In all other cost centers the variable cost components arise from the electric energy consumptions. The variable cost components are strictly dependent on some decision variables such as total output, product mix, and the amount of cullet used in production. Thus, they need to be estimated for any specific period to estimate total cost.

3.1.2. Estimation of Variable Cost Components

The statistical estimation method developed to estimate variable costs also incorporates the technological changes in production into the model. Instead of expressing cost as a function of variable inputs and thus directly estimating variable costs, it is preferred to estimate the quantity of variable inputs required. This has the advantage of being able to handle with various input prices and prevent one from predicting the price changes in inputs and furthermore rectifying past cost data.

A number of multiple regression models are generated in order to estimate quantities of variable inputs. In total 13 multiple regression models are generated; six of them are for each raw material type, one is for fuel-oil consumption, and the rest are for electrical energy consumptions at each cost center.

In generating each multiple regression model, first, the independent decision variables that affect consumption of the corresponding variable input are tentatively chosen.These independent variables are chosen based upon the experience of personnel in the factory, then statistically tested for their degree of significance upon variable inputs and thus the strong degree of relationship between each independent variable and the chosen variable input is verified. These variables are also tested for independence among themselves. Appropriate independent variables are selected for each variable input using 24 available past observations. The results of these tests can be seen in Appendix A.

In the computer model developed for this study, the coefficients of these multiple regression models are not to remain fixed. Because the number of past observations is not large enough, and new technological changes may change the optimal coefficients, as new observations are made, they are added to the existing list of observations stored and the estimates of coefficients are updated including current data and using Least-squares technique.

Once the quantities of variable inputs are estimated, these are multiplied by current prices, and thus the variable costs are obtained. The estimated total costs for all cost centers become readily available by the inclusion of fixed cost components.

3.2. Distribution of Costs to Products

The products in the factory can be classified into two main groups according to their sizes.

(i) Machine-size products

(ii) Special-size products

Special-size products can only be produced from machine-size products by applying a second cutting procedure. Therefore, the cost of special-size products at any thickness includes the cost of machine-size products at the same thickness and some additional cost of the special cutting procedure. Thus, it is found appropriate to apply a two-stage cost model in order to distribute costs to products. In the first stage, unit production costs of machine-size products are calculated to be used as input for the second stage. In the second stage, where unit production costs of special-size products are calculated, the work-in-process inventory for special cutting at the beginning of period and the flows from warehouse to special cutting are also used as input.

3.2.1. Unit Production Costs of Machine-size Products

Considering the production process given in Figure 1, it can be seen that the costs estimated for the first five cost centers are the costs of total glass drawn from the furnace in the corresponding period. However the total glass drawn from the furnace is not equal to total output of main cutting line because there are some losses during the main cutting procedure. If glass were drawn in only one thickness, unit cost of this product could be calculated easily by subtracting the value of these losses(cullet) from total costs incurred in the first five cost centers and dividing by total net output. On the other hand, when the number of products is more than one, the losses or efficiencies of products differ and their unit production costs also differ. In this case the value of cullet for each product must be considered separately and unit production costs must be calculated separately considering different production efficiencies. The formulae for calculating unit production costs of machine-size products are given in Appendix B.

3.2.2. Unit Production Costs of Special-size Products

In the second stage one can think of the special cutting process as a system with three different types of inputs, and one type of output. The inputs are all machine-size products coming from main cutting line, warehouse, and the work-in-process inventory. These inputs may have been produced in different periods, and thus they have different costs while their quantities also differ. All of these inputs are not necessarily processed in that period, and at the end of the period, there may be still some work-in-process inventory remaining. In calculating unit production costs of special- size products, the weighted average of the costs of these inputs are used. The values of losses which occur in the special cutting process and the efficiencies of products are considered separately. The formulae giving unit production costs of special-size products are given in Appendix B.

3.3. Sensitivity Analysis

In the computer model developed, it is possible to make sensitivity analysis in order to see the net effects of decision variables, and of the production efficiencies on unit production costs. Five types of sensitivity analysis are made available.

(i) Sensitivity analysis for the total amount of production

(ii) Sensitivity analysis for product mix

(iii) Sensitivity analysis for the amount of cullet used in production.

(iv) Sensitivity analysis for production efficiencies on main cutting line

(v) Sensitivity analysis for production efficiencies on special cutting line.

It is also possible to carry out any combination of these five types of sensitivity analysis simultaneously.

IV. EVALUATION AND FUTURE SUGGESTIONS

It can be said that the algorithm is succesfull in estimating costs in the selected factory. The multiple regression models for raw material consumptions explain about 95 per cent of the variations in raw material consumptions. Other variable costs are estimated less accurately but, since the raw material costs are about 60-65 per cent of the total variable costs, the overall accuracy becomes high. Furthermore, the accuracy will become higher when number of observations become higher.

One important advantage of the algorithm is that it makes possible to see the net effects of the decision variables total output, product mix, and the amount of cullet used in production on unit production costs. Thus it provides the chance to design a production planning algorithm considering also the sales costs, the demands, and sales prices of products. Besides, further studies may be carried out for cost control, since the algorithm also makes possible to see the net effects of production efficiencies on unit production costs. That gives the chance of making an investment planning analysis so as to decide how much money can be invested to improve production efficiencies.

On the other hand, one important criticism of the algorithm is that it can be applied only in a sheet glass manufacturing plant. This approach cannot be used even in a plant which produces bottles or other articles made from glass because of the differences between the production processes of the plants.

APPENDIX A

Numerical Results for Tests of Multiple Regression Models

All of the multiple regression models below are linear in terms of parameters and also in terms of variables.

Definition of Independent Variables

X_1: Total amount of melted glass (tons)

X_2: Amount of cullet used in production (tons)

X_3: Average thickness of melted glass (m^2/ton)

Intercorrelations Between Independent Variables

	X_1	X_2	X_3
X_1	1.00	.003	.007
X_2	.003	1.00	.050
X_3	.007	.050	1.00

Number of observations used is 24, and the critical F and t values are listed below.

$1-\alpha$	$F_{1-\alpha,2,21}$	$F_{1-\alpha,3,20}$	$t_{1-\alpha,21}$	$t_{1-\alpha,20}$
.900	2.57	2.38	1.32	1.33
.950	3.47	3.10	1.72	1.73
.975	4.43	3.86	2.08	2.09

Notation :

T_1 : t statistic calculated for independent variable X_1

T_2 : t statistic calculated for independent variable X_2

T_3 : t statistic calculated for independent variable X_3

F : F statistic calculated for overall significance

R^2 : Adjusted R-square value of the model

Multiple Regression Models for Estimating Variable Inputs in Batch House

Variable inputs in batch house are:

Y_1 : Dolomite

Y_2 : Lime stone

Y_3 : Glass sand type 1

Y_4 : Glass sand type 2

Y_5 : Kalker

Y_6 : Soda-ash

Y_7 : Electric consumption in batch house

The models tested for estimating the above variables, and the statistical results are given in the next page. The * sign shows that the corresponding model is selected to use in estimating the corresponding variable input. All of the models are linear in terms of parameters and also in terms of variables.

Tested Model	F	R^2	T_1	T_2	T_3
$Y_1=f(X_1)$	64.71	.74	8.03		
$Y_1=f(X_2)$	7.84	.26		-2.79	
$*Y_1=f(X_1,X_2)$	1475.43	.99	46.85	-27.60	
$Y_2=f(X_1)$	22.87	.51	4.79		
$Y_2=f(X_2)$	5.22	.19		-2.28	
$*Y_2=f(X_1,X_2)$	23.92	.69	5.91	-3.60	
$Y_3=f(X_1)$	64.42	.74	8.02		
$Y_3=f(X_2)$	7.70	.26		-2.77	
$*Y_3=f(X_1,X_2)$	1003.36	.99	38.74	-22.64	
$Y_4=f(X_1)$	63.65	.74	7.99		
$Y_4=f(X_2)$	7.70	.26		-2.77	
$*Y_4=f(X_1,X_2)$	2814.45	.99	64.64	-37.88	
$Y_5=f(X_1)$	63.09	.74	7.95		
$Y_5=f(X_2)$	7.83	.26		-2.79	
$*Y_5=f(X_1,X_2)$	1278.75	.99	43.62	-25.73	
$Y_6=f(X_1)$	81.80	.79	9.06		
$Y_6=f(X_2)$	4.92	.18		-2.20	
$*Y_6=f(X_1,X_2)$	247.19	.97	20.13	-9.51	

Tested Model	F	R^2	T_1	T_2	T_3
$Y_7=f(X_1)$	8.58	.28	2.93		
$Y_7=f(X_2)$	3.12	.12		-1.77	
$Y_7=f(X_3)$	.23	.01			.48
$*Y_7=f(X_1,X_2)$	7.08	.40	3.13	-2.07	
$Y_7=f(X_1,X_3)$	4.16	.28	2.83		.31
$Y_7=f(X_2,X_3)$	1.49	.12		-1.66	.10
$Y_7=f(X_1,X_2,X_3)$	1.49	.12		-1.66	.10

Multiple Regression Models for Estimating Variable Inputs in Furnace

Variable inputs in furnace are:

Y_1: Electric consumption in furnace

Y_2: Fuel-oil consumption in furnace

The statistical results of the models tested for these variable inputs are summarized below.

Tested Model	F	R^2	T_1	T_2	T_3
$Y_1=f(X_1)$	3.97	.15	-2.00		
$Y_1=f(X_2)$	.35	.02		-.60	
$Y_1=f(X_3)$	22.80	.51			4.78
$Y_1=f(X_1,X_2)$	2.16	.17	-1.98	-.64	
$*Y_1=f(X_1,X_3)$	26.18	.71	-3.90		6.42
$Y_1=f(X_2,X_3)$	10.85	.51		.28	4.60
$Y_1=f(X_1,X_2,X_3)$	17.21	.72	-3.86	.42	6.27
$Y_2=f(X_1)$	6.25	.22	2.55		
$Y_2=f(X_2)$	.49	.02		.68	
$Y_2=f(X_3)$	.05	.002			-.29
$*Y_2=f(X_1,X_2)$	3.44	.25	2.54	.77	
$Y_2=f(X_1,X_3)$	3.29	.24	2.56		-.54
$Y_2=f(X_2,X_3)$	.23	.02		.61	-.13
$Y_2=f(X_1,X_2,X_3)$	2.23	.25	2.51	.64	-.36

Multiple Regression Models for Estimating Electric Consumption in Bath

Y : Electric consumption in bath

The statistical results of the multiple regression models tested are summarized below.

Tested Model	F	R^2	T_1	T_2	T_3
$Y=f(X_1)$	.45	.02	.67		
$Y=f(X_2)$	12.86	.37		-3.59	
$Y=f(X_3)$	28.17	.56			5.31
$Y=f(X_1,X_2)$	6.66	.39	.81	-3.55	
$Y=f(X_1,X_3)$	13.75	.57	.54		5.15
$Y=f(X_2,X_3)$	32.87	.76		-4.13	5.81
$*Y=f(X_1,X_2,X_3)$	21.70	.77	.78	-4.10	5.67

Multiple Regression Models for Estimating Electric Consumption in Annealing

Y : Electric consumption in annealing

The statistical results of the multiple regression models are on the next page.

Tested Model	F	R^2	T_1	T_2	T_3
$Y=f(X_1)$	1.39	.06	1.17		
$Y=f(X_2)$	1.36	.06		1.17	
$Y=f(X_3)$	14.60	.40			3.82
$Y=f(X_1,X_2)$	1.32	.11	1.18	1.18	
$Y=f(X_1,X_3)$	8.12	.41	1.15		3.74
$Y=f(X_2,X_3)$	13.27	.56		2.77	4.88
*$Y=f(X_1,X_2,X_3)$	9.75	.59	1.28	2.80	4.84

Multiple Regression Models for Estimating Electric Consumption in Main Cutting

Y : Electric consumption in main cutting

The statistical results are listed below.

Tested Model	F	R^2	T_1	T_2	T_3
$Y=f(X_1)$	.04	.01	.08		
$Y=f(X_2)$	13.48	.38		-3.67	
$Y=f(X_3)$	15.08	.41			3.88
$Y=f(X_1,X_2)$	6.33	.38	.12	-3.60	
$Y=f(X_1,X_3)$	7.27	.41	.43		3.83
$Y=f(X_2,X_3)$	18.37	.64		-3.65	3.85
*$Y=f(X_1,X_2,X_3)$	11.94	.64	.48	-3.60	3.80

APPENDIX B

Equations Developed to Distribute Total Cost to Products

Notation :

C_i :Total cost for cost center i (TL);

ME_j :Main cutting line efficiency for thickness j;

SE_j :Special cutting line efficiency for thicknesss j;

CUL :Unit price of cullet (TL/ton);

TMG_j :Amount of melted glass for thickness j (tons);

TMG :Total amount of melted glass (tons);

$$TMG=\sum TMG_j \qquad (1)$$

TSC_j :Amount of special cut glass for thickness j (tons);

TSC :Total amount of special cut glass (tons);

$$TSC=\sum TSC_j \qquad (2)$$

INS_j :Amount of work-in-process inventory for special cut, for thickness j, at the beginning of the period (tons);

$VINS_j$:Value of work-in-process inventory for special cut, for thickness j, at the beginning of the period (TL);

MS_j :Amount of flow from main cutting line to special cutting, in thickness j (tons);

WS_j :Amount of flow from warehouse to special cutting, in thickness j (tons);

VWS_j :Value of flow from warehouse to special cutting, in thickness j (tons);

$UCMS_j$:Unit production cost of machine-size product in thickness j (TL/ton);

AVC_j :Average unit cost of machine-size products processed in special cutting for thickness j (TL/ton);

TVSC :Total value of machine-size glass processed in special cutting (TL);

$$TVSC=\sum AVC_j*TSC_j \qquad (3)$$

$UCSS_j$:Unit production cost of special-size product in thickness j (TL/ton);

Calculating Unit Production Costs of Machine-size Products

The cost to melt total glass is the summation of total costs for the first five cost centers. The ammount of losses in main cutting process for any thickness j is given by $(1-ME_j)*TMG_j$, and the return of this loss for the plant is just the multiplication of this amount by unit price of cullet. Then the unit production cost of machine-size product j can be calculated as

$$UCMS_j = \frac{(C_1+C_2+C_3+C_4+C_5)}{TMG * ME_j} - \frac{(1-ME_j)*CUL}{ME_j} \qquad (4)$$

Calculating Unit Production Costs of Special-size Products

The average unit costs of machine-size products processed in special cutting for each thickness are the ratio of total values to total quantities.

$$AVC_j = \frac{VINS_j+MS_j*UCMS_j+VWS_j}{INS_j+MS_j+WS_j} \qquad (5)$$

The total cost of special-size products is $TVSC+C_6$, and the ammount of losses in special cutting process for any thickness j is given by $(1-SE_j)*TSC_j$. Then the unit production cost of special-size product j can be calculated as

$$UCSS_j = \frac{TVSC+C_6}{TSC*SE_j} - \frac{(1-SE_j)*CUL}{SE_j} \qquad (6)$$

APPENDIX C

Computer Model Structure

A. Inputs of Computer Model

1. Inputs from files

a. Quantities of variable inputs and production characteristics for past observations;

b. Allocated fixed costs for cost centers;

2. Inputs from keyboard

a. Production characteristics;

b. Current prices for variable inputs estimated;

B. Outputs of Computer Model

1. Outputs to files

a. New set of past observations if changed;

b. New allocated fixed costs for cost centers if changed;

2. Outputs to printer

a. Values of past observations;

b. Values of unit production costs;

c. Values of unit production costs after sensitivity analysis;

3. Outputs to screen

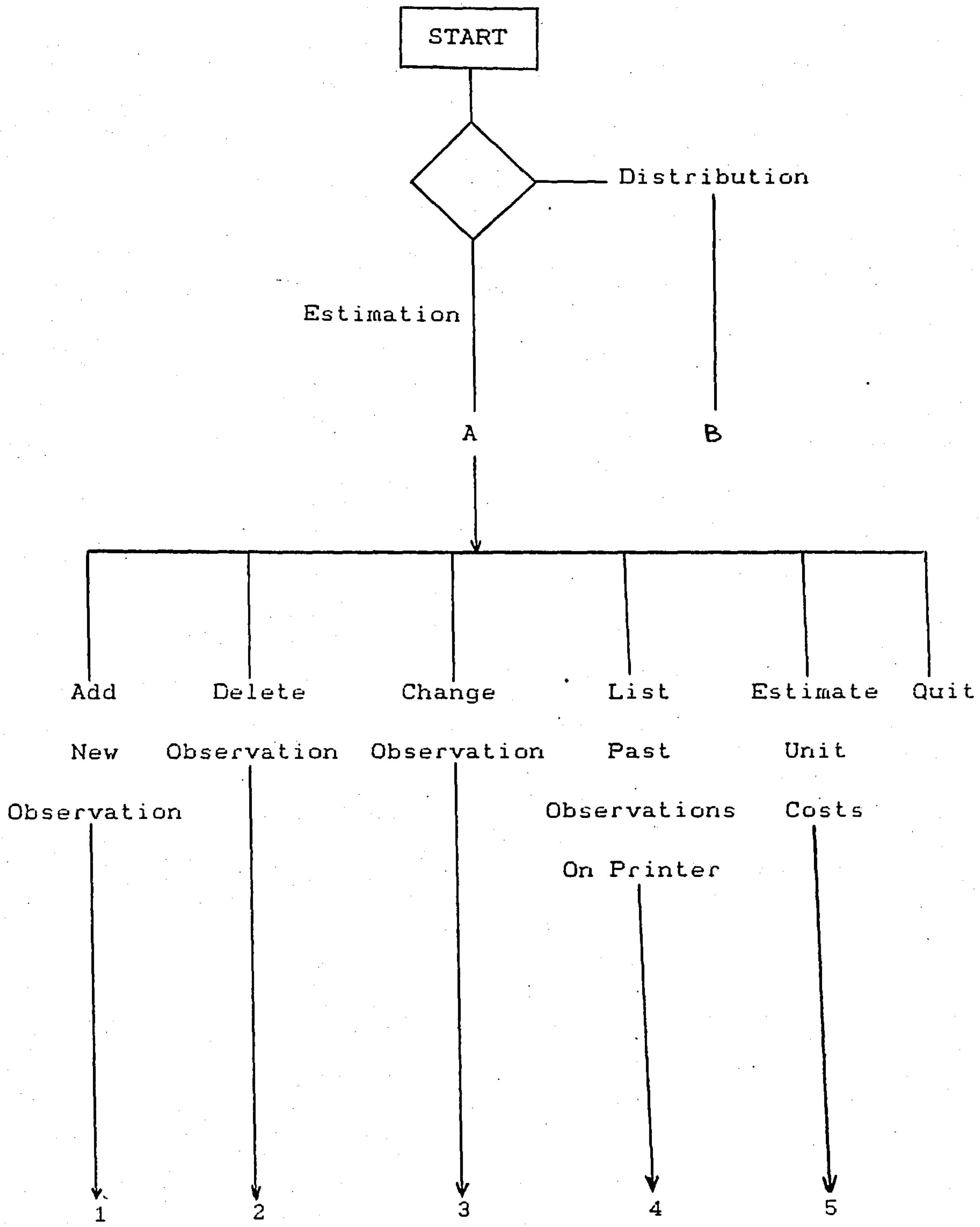
a. Estimated quantities of variable input consumptions;

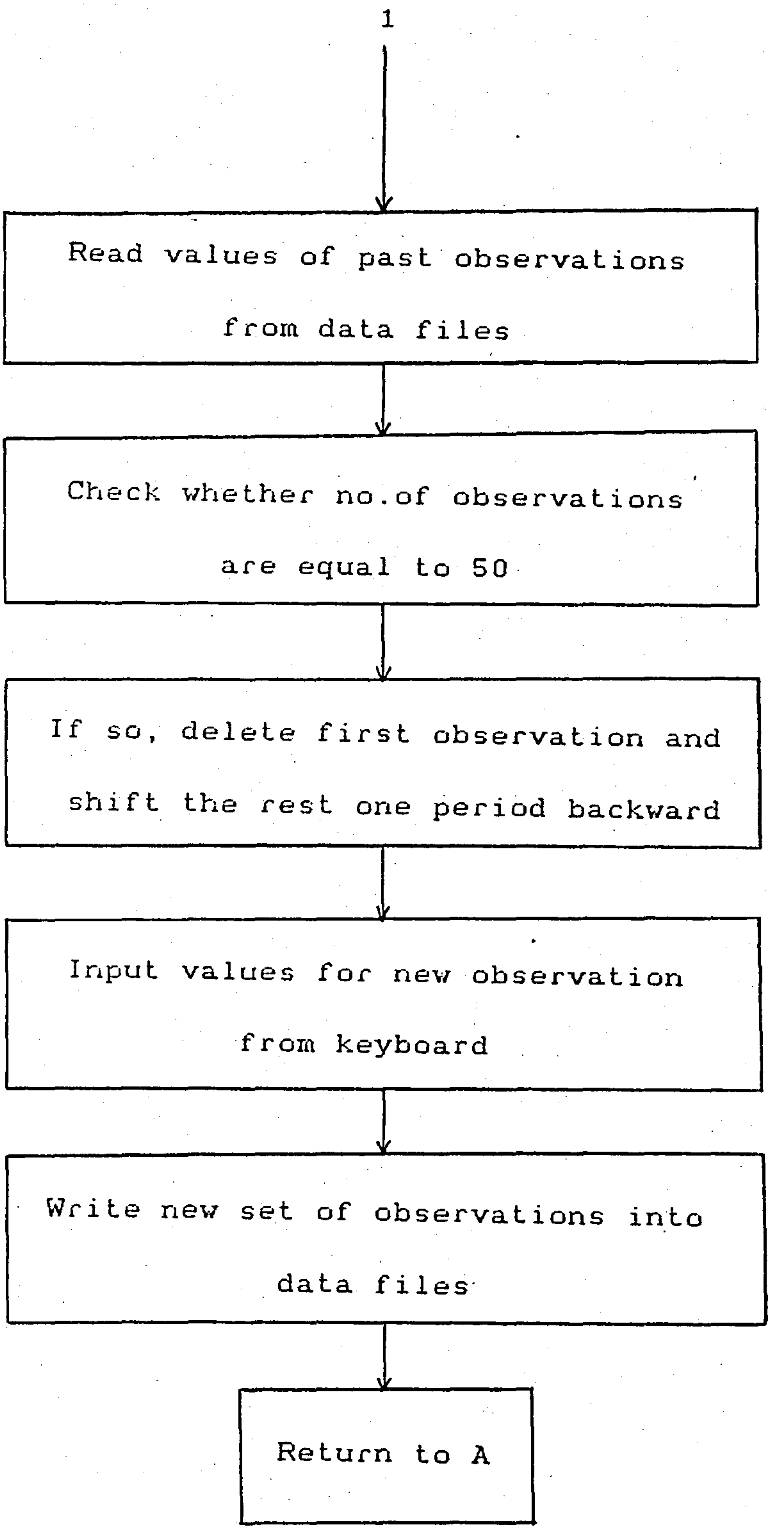
b. Allocated fixed costs for cost centers;

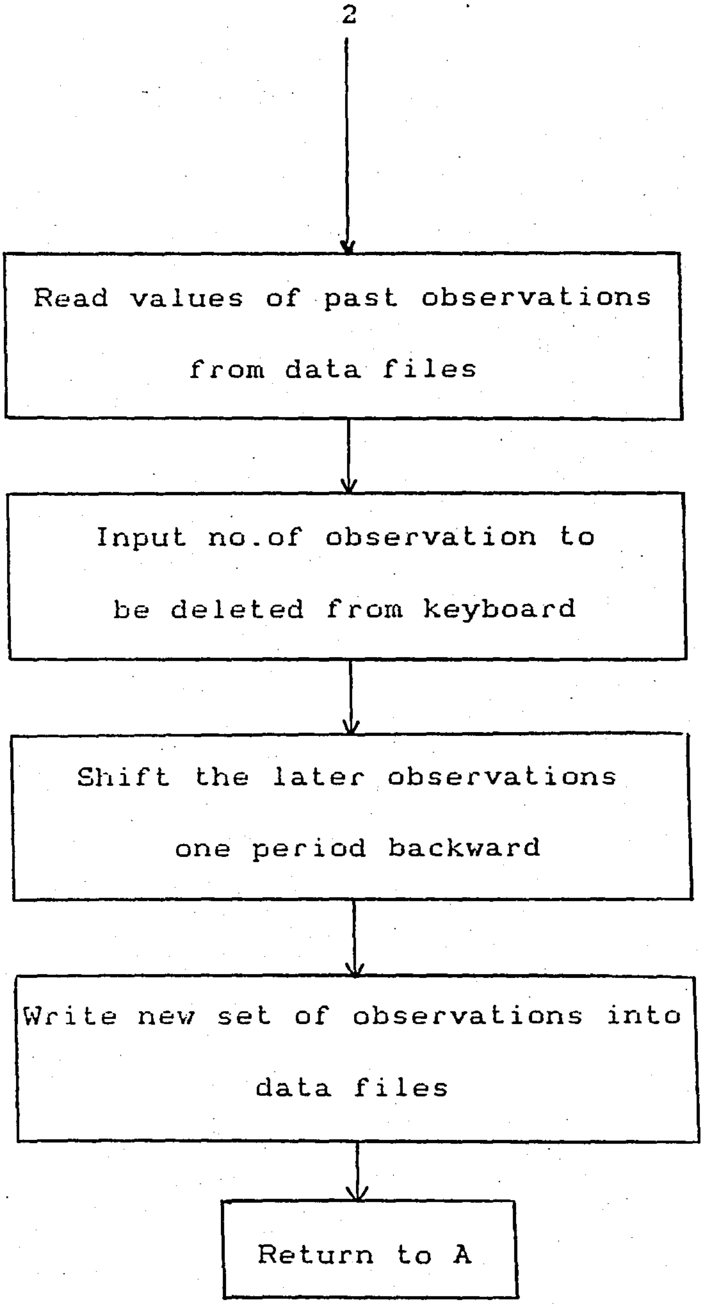
c. Values of unit production costs;

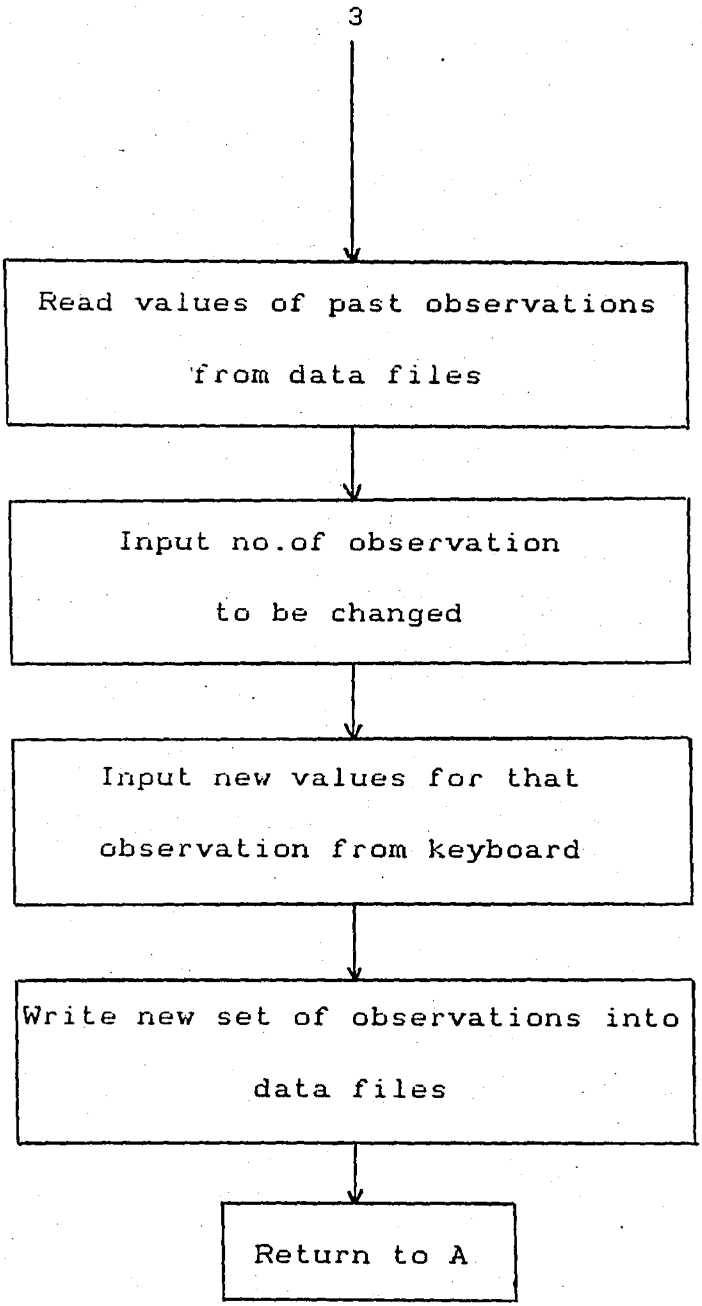
d. Values of unit production costs after sensitivity analysis;

Computer Model Algorithm

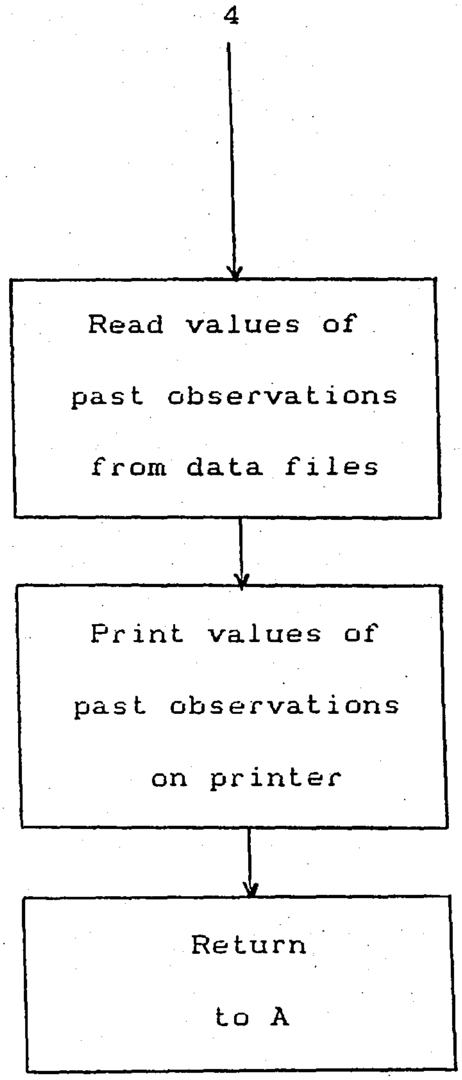


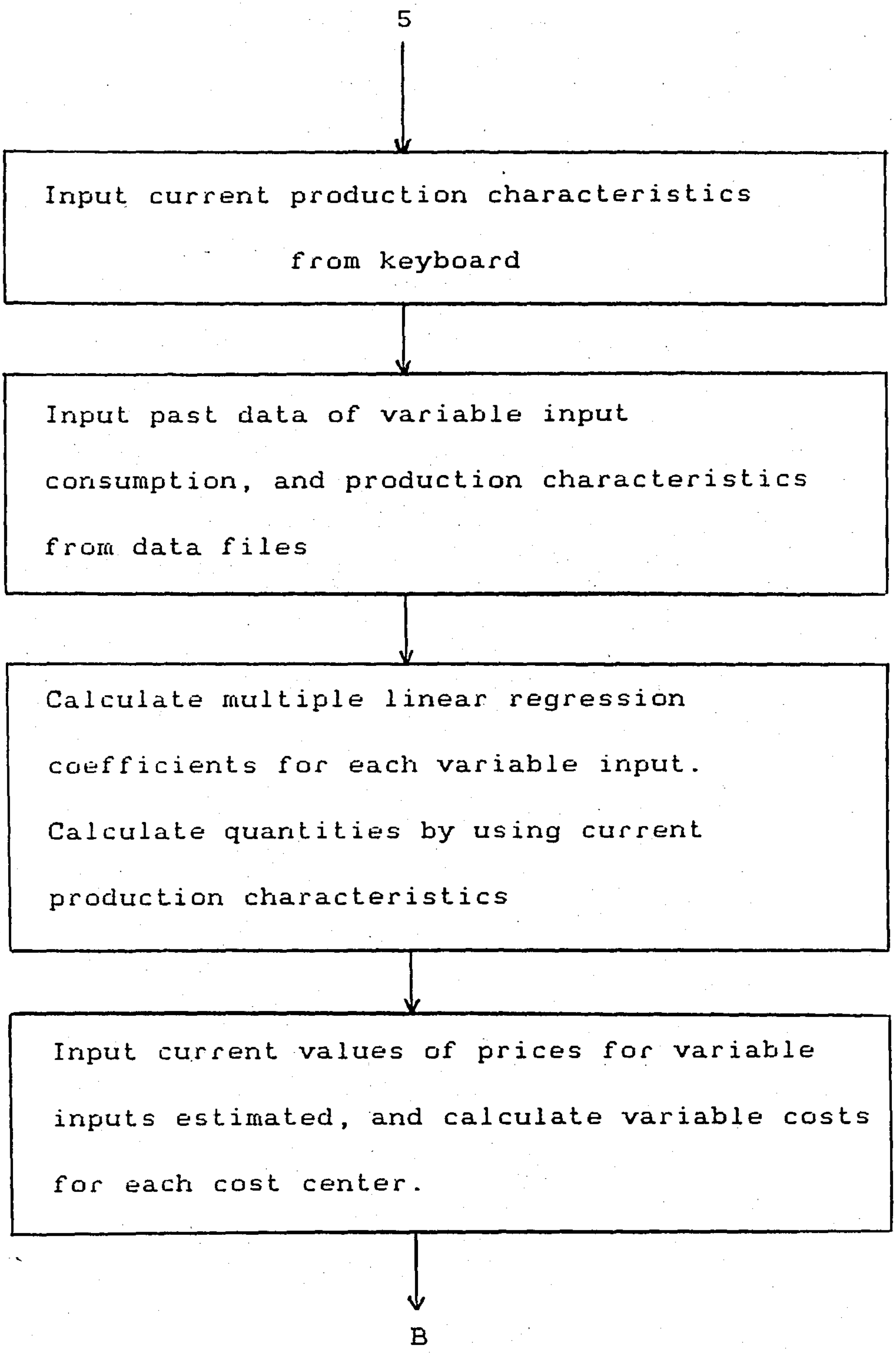

1
Read values of past observations from data files
Check whether no.of observations are equal to 50
If so, delete first observation and shift the rest one period backward
Input values for new observation from keyboard
Write new set of observations into data files
Return to A

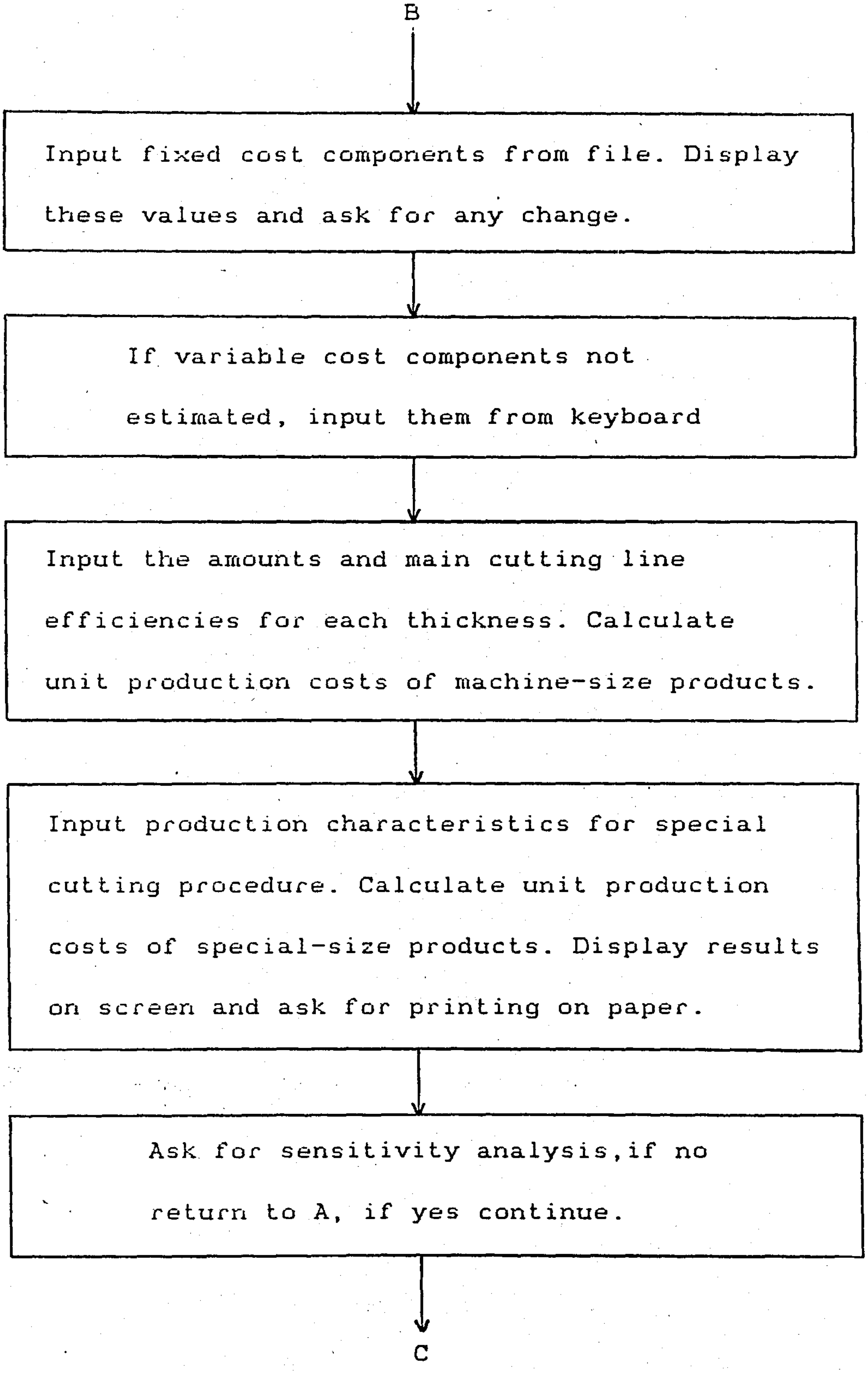

2
Read values of past observations from data files
Input no.of observation to be deleted from keyboard
Shift the later observations one period backward
Write new set of observations into data files
Return to A



3
Read values of past observations from data files
Input no.of observation to be changed
Input new values for that observation from keyboard
Write new set of observations into data files
Return to A


4
Read values of past observations from data files
Print values of past observations on printer
Return to A


5
Input current production characteristics from keyboard
Input past data of variable input consumption, and production characteristics from data files
Calculate multiple linear regression coefficients for each variable input. Calculate quantities by using current production characteristics
Input current values of prices for variable inputs estimated, and calculate variable costs for each cost center.
B



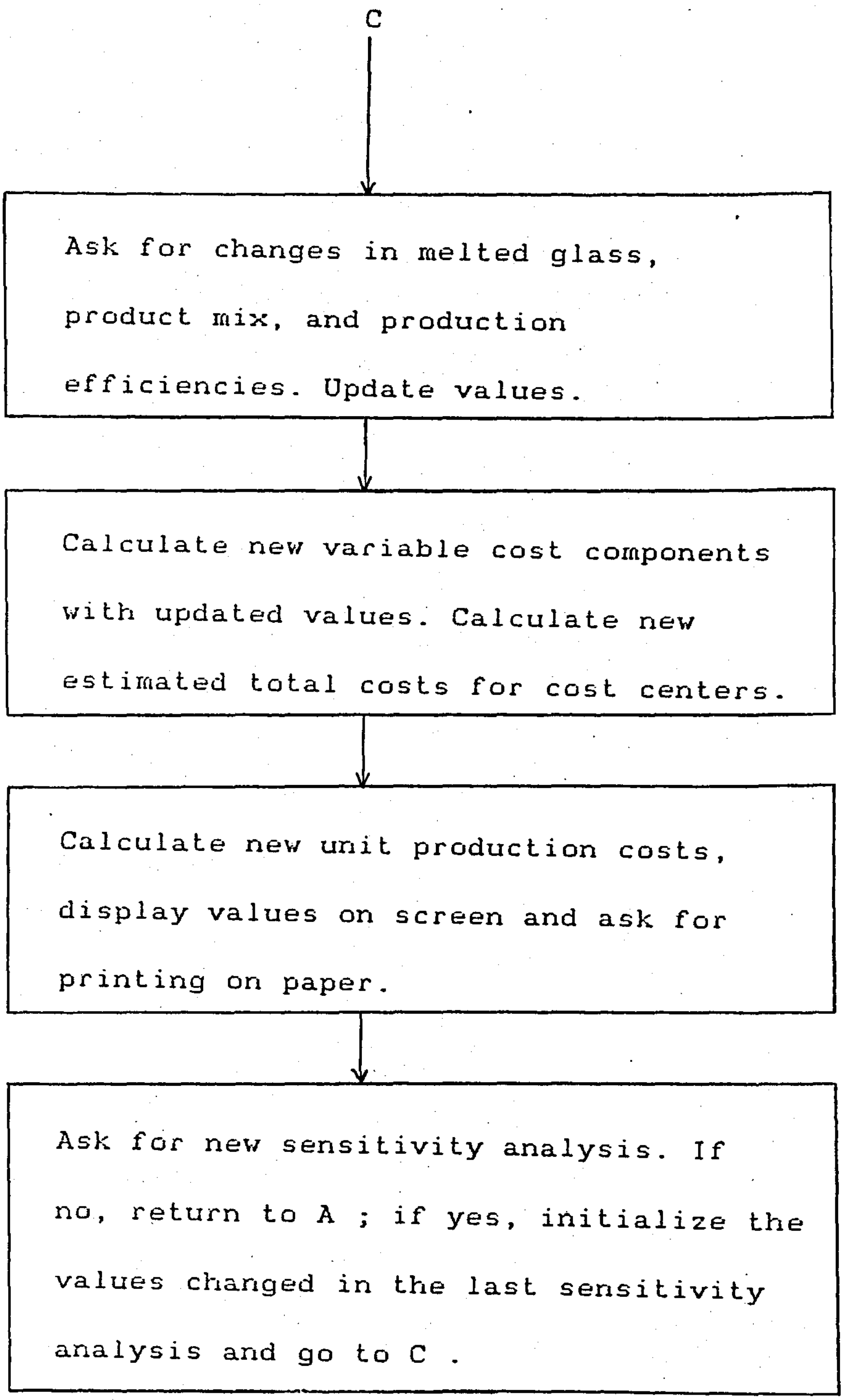
Input fixed cost components from file. Display these values and ask for any change.

If variable cost components not estimated, input them from keyboard

Input the amounts and main cutting line efficiencies for each thickness. Calculate unit production costs of machine-size products.

Input production characteristics for special cutting procedure. Calculate unit production costs of special-size products. Display results on screen and ask for printing on paper.

Ask for sensitivity analysis, if no return to A, if yes continue.



Ask for changes in melted glass, product mix, and production efficiencies. Update values.

Calculate new variable cost components with updated values. Calculate new estimated total costs for cost centers.

Calculate new unit production costs, display values on screen and ask for printing on paper.

Ask for new sensitivity analysis. If no, return to A ; if yes, initialize the values changed in the last sensitivity analysis and go to C .

BIBLIOGRAPHY

1. Dean J., Statistical Cost Estimation , Indiana University Press, 1976.

2. Cashin J.A., Polimeni R.S., Cost Accounting , Mc Graw-Hill International Book Company, 1981.

REFERENCES NOT CITED

Horngren C.T., Cost Accounting:A Managerial Emphasis , Prentice Hall International Inc., 1972.

Jelen F.C., Cost and Optimization Engineering , Mc Graw-Hill Book Company, 1970.

Neter J., Wasserman W., Applied Linear Statistical Models , Richard D. Irwin Inc., 1974.

Chatterjee S., Price B., Regression Analysis By Example , John Wiley & Sons, 1977.