SOME ECONOMIC ASPECTS OF
CELLULAR MANUFACTURE.

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DECLARATION

No part of the work described in this Thesis has been submitted in support of an application for another degree or other qualification of this or any other institution.

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SUMMARY

The concept of Group Technology (GT) has been used in European industries for many years, firstly as a possible cure to certain problems such as those associated with machine shop operation, but now it is thought of more in terms of a total manufacturing system covering all aspects and sections of the company, and not only the section where the problems appeared to originate.

The idea of suggesting GT as a possible solution for many problems associated with the engineering industry have usually formed an attractive proposition, but due to the different peculiarity of these problems, it is very important to evaluate each case individually so that maximum benefit could be obtained.

Component families and machine groupings have always been at the core of the GT philosophy for manufacturing systems and many disagreements have been voiced in the literature over how this process should best be carried through. The formation of cells has not been widely reported and it would seem that the most common criteria of grouping is machine utilization which has not been adequately defined as to what is meant by an acceptable level of machine utilization in a cell. In this thesis unit cost of items produced in a cell is put forward as a viable

and attractive method of assessing cell design and operation. However to be truly effective it must be possible to consider a range of cell designs for unit cost comparison purposes, and a technique based on (P.F.A.) using the Clustan computer analysis has been successfully developed for this purpose.

Hence it is possible to consider a large number of cell designs ranging from each machine as one cell to all machines as one cell together with various family groupings. This provides a very powerful analytical tool for manufacturing system design which is fully illustrated by its application to a case study from the engineering industry.

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CHAPTER 1

Introduction

Introduction

Prior to the introduction of Group Technology (GT) there were four main basic types of production systems. Firstly the continuous production system which is defined by its very high volume of production and very small variety of products, such as petroleum, steel, electricity, etc. Secondly the mass/flow production system which has small variety of products with large quantities but does not normally run continuously. Thirdly the system which is concerned with a large variety of products and relatively small quantities of each products is batch production. Repetition of the manufacture of the same product is the main characteristic of this system. Fourthly the jobbing production system which is also concerned with large variety and small quantity products but is characterized by the almost elimination of product repetition.

From a production efficiency stand point there is no doubt that the continuous (mass/flow) production system, with the facilities laid out in accordance to the sequence of operation demanded by the product, is by far superior to the batch and jobbing production system were similar facilities are grouped together. The benefits of mass production have become apparent since the beginning of the motor car industry and any technology which will bring mass production principles into batch production must have a considerable influence on the improvement of a great number of engineering companies. Group technology could be looked on as a method of achieving some of the benefits of mass production in the batch production industry.

Group technology was developed to provide an acceptable bridge between high volume, low variety flow production and low volume, high variety batch production. Component classification and production data analysis appear to be the most effective techniques currently used to set up the data base fo GT applications but production flow analysis is considered by many to be an acceptable alternative. The main aim of component classification is to describe a component by a meaningful code number using its shape and design features. Using this code number, families of components can be formed either manually or by automatic sorting.

Production data analysis is divided into three separate but linked phases; Production flow which is concerned with the type the number and the sequence of each operation carried out; Production demand is concerned with the establishment of the demand for individual components for the purpose of machine loading; Production technology is concerned with the detailed method of manufacture but the specification of this information is generally best considered after decisions have been made on the establishment of the actual production system. Production flow analysis as suggested by Burbidge (1) finds families and their associated groups by analysing the information given on the component route cards. It finds a devision based on the existing methods and the existing allocation of operations to machines. Rather than to create families and groups of machines the task is to find them from the existing data. The technique is to manipulate the data given in a form of component to machine matrix to define families and groups of machines.

Different types of group technology manufacturing systems have emerged from the consideration given to the change and improvement upon conventional manufacturing methods. Families of components with high degree of similarities can be considered, in a flow line, having fixed sequence of processing. All components need not however pass through every machine in the group technology flow line, and balance is achieved by labour movement. The cell layout system on the other hand consists of a number of machines which are all needed to complete the manufacture of a given component or family and possible repetition of machines should be expected. The components or families considered for this system do not have the same process sequence, and some operator flexibility is also required. The other possible system is the machine centre, where the components or family is produced on one machine tool. Generally a machine centre when used, forms a part of the normal conventional process layout.

The formation of a particular type of production system is carried out by an analysis of the component data, production flow data and production past data. In this thesis the basis of family and cell formation is that of production flow analysis (P.F.A.) as this technique can be used to show the advantages of the philosophy put forward. The usual recommended cell size in practice is 5-12 machines, although, occasionally cells have been developed with up to 50 or 60 machines which is exceptional. There seems to be no doubt that the well established group size cell will be the most favourable to take advantage of the benefit of group working such as man management, job satisfaction. It is therefore very important to consider a number of solutions for cell formation and choose the most efficient one. The criterion from which an efficient solution is chosen can vary considerably because of the large number of factors which have to be considered to justify the choice.

A system of generating a number of different solutions, with the aid of computors, based on production flow analysis has been put forward and hence, using a general form of establishing the unit costs, a procedure to choose the most efficient cell formation from an economic view point is proposed.

This procedure only indicates the general guide lines of approach, and individual users can and must determine the way in which the procedure could be most beneficial to meet their own particular requirements.

To illustrate the proposed procedure, a manufacturing company was approached and agreed to supply the necessary data. With the aid of this established data a practical example is explained in detail to show how the proposed procedure can be applied.

CHAPTER 2

PRINCIPLES OF GROUP TECHNOLOGY.

2.0. Principles Of Group Technology.

2.1. General Principles And Implementation Of Group Technology (GT).

2.1.1. Definition Of GT.

Group technology has been defined by many authors for different purposes (2,3,4,5,6,7,8) but in general GT can be described as a complete manufacturing system where similar components are formed into families and are produced on groups of machines (groups of machines being one machine upwards) and involves the transformation of the batch production industries to achieve the similar technical and economical benefits of mass flow.

2.1.2. Historical Aspects Of Group Technology.

After the second world war, the concept of Group Technology (GT) was applied firstly in the U.S.S.R. and then all through east and west Europe including U.K. The early work by Mitrofanov (9) was adopted in Russian and applied to some of its manufacturing industries. He originally suggested the complex or composite component and group tooling in the first major publication on GT titled "Scientific principle of group technology" published in 1955. The idea is to tool-up machines with the help of carefully designed jigs and fixtures, to manufacture a family of components with the least possible set-up time and almost eliminate any resetting.

Coding and classification has figured very prominently in the introduction of family formation as a basis of introducing GT in the rest of Europe, including the eastern countries. The influence of the pioneers of group technology was apparent to start with, from the amount of research translated by writers outside Russia. (9,10,11). Coding and classification ideas and systems flourished and none so famous than the Opitz system (12). More research was concentrated on producing sophisticated coding and classification and component statistical systems. The use of the already tabulated data such as operation sequences, loadings, component quantities machine utilizations was highlighted by Burbidge. He devoted a lot of his researching time to promote the idea of introducing cellular manufacture by the Production Flow Analysis (PFA) system.

Great Britain can be distinguished as being a major contributor to the advancement of group technology. British scientific and industrial institutions may not claim to have led the world in introducing GT internationally, but higher claim can be staked in the pioneering of the advancement of group technology from an aid to existing industrial manufacturing systems to a complete manufacturing and management system in its own right.(13,14).

2.1.3. Coding And Classification Systems:-

Classification can be defined as either the division of lists of items into classes according to their differences, or as the combining of individual items into classes according to their similarities. The first definition takes an analytical view of the problem and the second a synthetic, Burbidge (8).

Classification of components requires:-

a) Geometric definition of external and internal shape.

b) Information on secondary features, e.g. holes, slots..etc.

c) Material type and initial form e.g. bar, forging, casting..etc.

d) Major dimensions, e.g. overall length, diameter..etc.

MacConnell (15) specifies that the system should be easy to learn and follow. It should be easy to handle by sorting component features and can be manipulated by mechanical and electronic data processing machines.

Coding can be defined as the assigning of symbols to classes, in such a way that the symbols convey information about the nature of the classes. The most common types of code, according to the digit used are:-

a) Numerical codes consisting solely of a number.

b) Alphabetic codes consisting of letters were each digit can have 26 characters, recognized symbols can be used e.g. S for steel ..etc.

c) Alphanumeric codes consists of a mixed letter and number digits. This kind is not recommended, because they fall down where there are classes of items starting with the same initial letters. Although this system is suitable for computer data processing, it is complex and costly.

Middle, Thornley & Connolly (16) have reviewed code designs and commented that:-

a) Independent digital significance is recommended for components with like attributes. This makes it possible to recognize common component features by simple code comparison. It also improves familiarizations and makes data processing simpler.

b) A constant number of digits is recommended to reduce errors and ease data processing. A brief notation should be used to make it easier to memorize the code and reduce unnecessary paper work. The code definition should be mutually exclusive i.e. each part must only have one possible code.

Gombinski (17) states that classification is best symbolized by codes that are,

a) Purely numerical.

b) Of uniform length.

c) Made up of surname and christian name e.g. (1234-567) or of surname, middle name; and christian name e.g. (1234-5-678).

Classification and coding systems have to provide a quick and efficient description of an article for decision making. It can be divided under three main catagories:

I) General purpose systems freely available at low cost (e.g. Opitz fig (1), VUOSO fig (2).

Opitz code developed by Professor Opitz in the early 60[s]. It was first used for the establishment of workpiece statistics for the development of new machine tools. It was based on the idea of establishing a universal coding system via geometric and a general purpose coding system. This system consists of a five digit primary code and a four digit supplementary code. Each digit

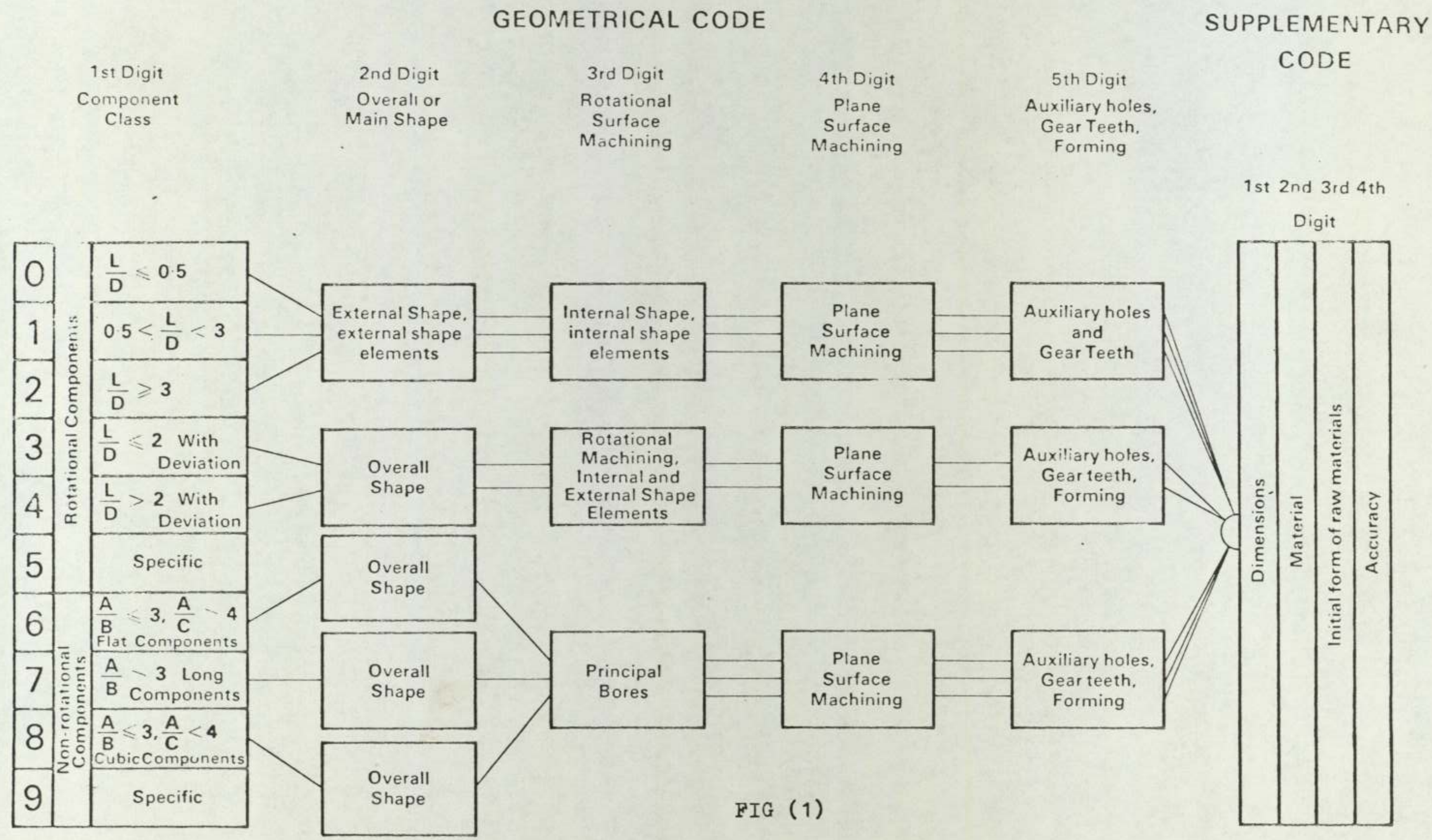

GEOMETRICAL CODE
SUPPLEMENTARY CODE
1st Digit Component Class
2nd Digit Overall or Main Shape
3rd Digit Rotational Surface Machining
4th Digit Plane Surface Machining
5th Digit Auxiliary holes, Gear Teeth, Forming
1st 2nd 3rd 4th Digit
0
1
2
3
4
5
6
7
8
9
Rotational Components
Non-rotational Components
L/D ≤ 0·5
0·5 < L/D < 3
L/D ≥ 3
L/D ≤ 2 With Deviation
L/D > 2 With Deviation
Specific
A/B ≤ 3, A/C ~ 4 Flat Components
A/B ~ 3 Long Components
A/B ≤ 3, A/C < 4 Cubic Components
Specific
External Shape, external shape elements
Overall Shape
Overall Shape
Overall Shape
Overall Shape
Internal Shape, internal shape elements
Rotational Machining, Internal and External Shape Elements
Principal Bores
Plane Surface Machining
Plane Surface Machining
Plane Surface Machining
Auxiliary holes and Gear Teeth
Auxiliary holes, Gear teeth, Forming
Auxiliary holes, Gear teeth, Forming
Dimensions
Material
Initial form of raw materials
Accuracy

FIG (1)

KIND OF WORKPIECE	ROTATIONAL COMPONENTS					FLAT AND IRREGULAR		BOX-LIKE	OTHER, MAINLY NON MACHINED
				GEARED & SPLINED					
	HOLES IN AXIS								
	NONE	BLIND	THROUGH	NONE	THROUGH				
	1	2	3	4	5	6		7	8
CLASS OF WORKPIECE	Dp	L/D	ROUGH FORM			ROUGH FORM	L MAX	ROUGH WEIGHT	MADE OF
0		<1				GIB LIKE L/B 5	0-200	0-30	EXTRUDED FORM
1	0-04	1-6					200-	30-200	BARS
2		>6				PLATFORM L/B 5	0-200	200-500	TUBES
3		<1					200-	500-1000	SHEET
4	40-80	1-4				LEVER-LIKE	0-200	1000-	WIRE
5	80-200	>4					200-		
6	80-200	<3				IRREGULAR	0-200		
7	80-	<3					200-		
8	200-	<3				PRISM LIKE	0-200		
9	VARIOUS	>30					200-		

GROUP OF WORKPIECE	1-3		4-5			6: MAIN MACHINED SURFACES AND THEIR MUTUAL POSITION		7	8		
0	SMOOTH		SPUR GEAR	SPLINED		FLAT, PARALLEL		BOXES, FRAMES, HEADSTOCKS	FLAT	NON MACH.	
1	THREAD IN AXIS		SPUR GEAR	OTHER		FLAT, OTHER		COLUMNS	FLAT	PART MACH.	
2	HOLES NOT IN AXIS		TAPER GEAR	SPLINED		ROTAL, PARALLEL		BEDS, BRIDGES	BENT	NON MACH.	
3	SPLINES OR GROOVES		TAPER GEAR	OTHER		ROTAL, OTHER		OUTRIGGERS, KNEES	BENT	PART MACH.	
4	COMB 1 + 2		WORM GEAR	SPLINED		FLAT AND ROTAL PARALLEL		TABLES, SLIDES	FORMED	NON MACH.	
5	COMB 1 + 3		WORM GEAR	OTHER		FLAT PARALLEL ROTAL OTHER		LIDS	FORMED	PART MACH.	
6	COMB 2 + 3		MULTIPLE GEAR	SPLINED		FLAT OTHER ROTAL PARALLEL		BASINS, CONTAINERS	WELDED	NON MACH.	
7	COMB 1 + 2 + 3		MULTIPLE GEAR	OTHER		FLAT & ROTAL OTHER			WELDED	PART MACH.	
8	TAPER		OTHER	SPLINED		GEARED					
9	UNROUND		OTHER	OTHER				COUNTER WEIGHTS			

The Vuoso System

FIG (2)

(AFTER MACCONNELL)

in the primary code has one broad area of description which is essentially a geometric code. It groups components by a logical arrangement of shape charactaristic and significant features. The supplementary code provides descriptions of dimension, material and initial form. The code layout can be summerized as follows.

Primary code (geometric):

First digit - Component class (rotational or non rotational components) with different diameters to length ratios.
Second digit - Overall shape.
Third digit - Rotational surface machining.
Fourth digit - Plane surface machining.
Fifth digit - Auxiliary holes, gear teeth, forming.

Supplementary:

First digit - Dimension (Diameter of longest edge).
Second digit - Material description.
Third digit - Initial form of raw material (bar, sheet, casting ..etc).
Fourth digit - Accuracy.

The system is suitable for most general applications since it is not based on any one company. Two positions are left open to allow for the classification of two classes of component specific to an individual company. These can be classified either by shape or function or both. Fixed digital significance exists in certain areas with individual digits describing the same features for all classes of components. fig (1).

II) Systems based on general principles but designed to suit certain specific purposes (e.g. Brisch 3 fig (3)).

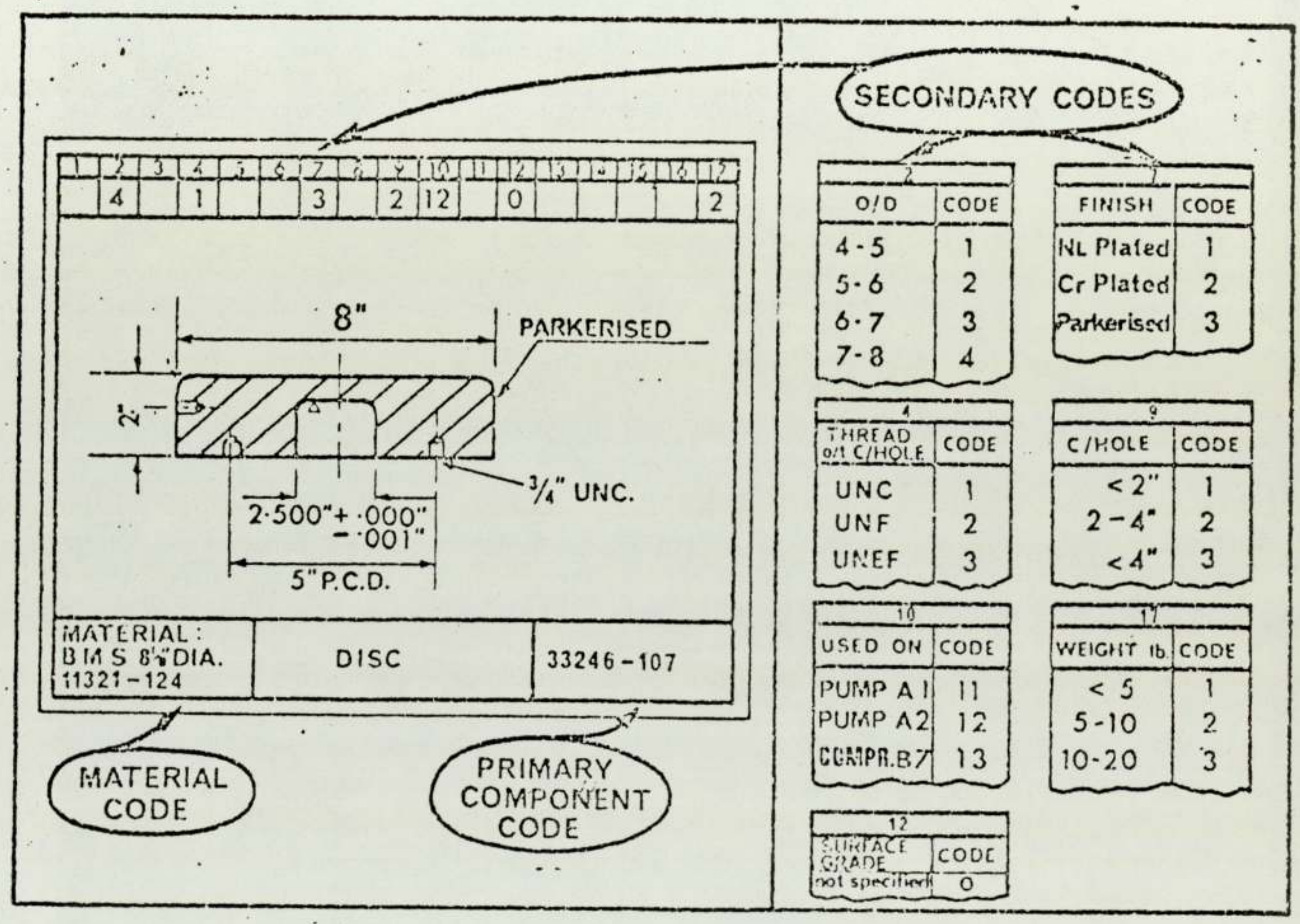
This system was developed by E.G. Brisch andParteners Ltd and can be adopted to suit the requirements of a particular plant. It consists of two main parts, the primary code where each digit amplifies the information given in the previous digit, and the secondary code where each digit is independent of all the other digits. The primary code was designed to describe the geometry and material on a broader basis.

III) Special purpose systems designed for specific applications e.g. Ferodo developed at U.M.I.S.T. fig (4).

This is a specific system made for a specific company because of the peculiarities of the product range. The system was suggested and designed because of the failure of the general purpose coding and classification systems to accommodate the peculiar nature of the product range. Ferodo make friction materials and in particular brake lining (16).

IV) Other Systems:-

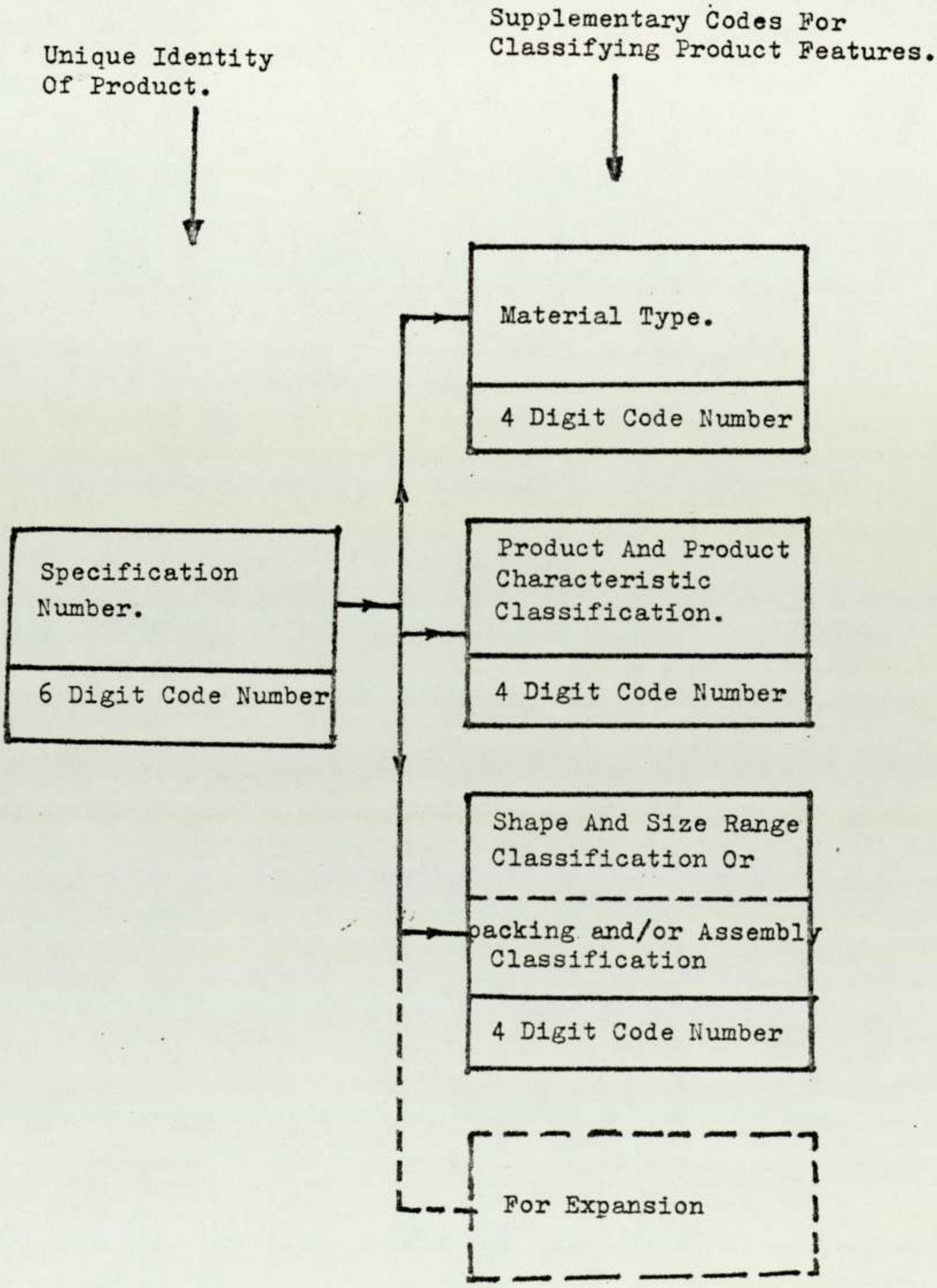
There are other systems which are being used at various industrial quarters such as P.E.R.A. (21) fig (5), D.D.R. standard (18); Zafo system (18). Institute for machine tools and tooling at Belgrade (18), P.G.M. system (18), Williamson system (18), Stuttgart system (18), and many others.



(left). Drawing with component identified by its primary code
(right). Specific features are given secondary codes from the code manual

FIG (3)

(AFTER MACCONNELL)



General Form Of Classification Scheme.

(After Middle, Connolly And Thornley)

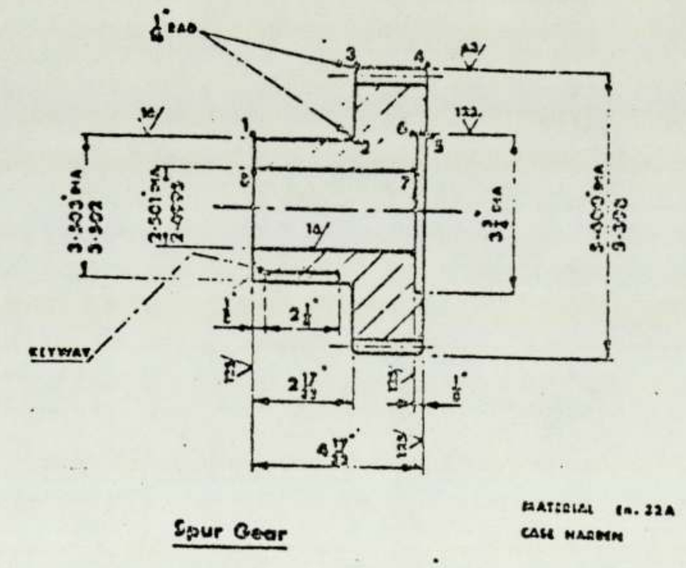
FIG.4.

General Statement.

Company Ref. No.	Serial No.	Total Change Points	Change Point for Maximum Diameter	Change Point for Maximum Length	Workpiece Type	Material	Initial Form	Quantity
6 0	3 0	0 8	0 3	0 4	1	0	0	0 0 0 2

Detailed Statement.

Change Points	x Co-ordinates	y Co-ordinates	Corner Condition	Form	Accuracy	Surface Finish	State of Hardness	Function	Additional Machining Facilities
0 1	0 0 0 0 0	0 0 1 7 5	1	0	3	3	2	6	7
0 2	0 0 2 5 3	0 0 1 7 5	3	0	9	7	2	1	1
0 3	0 0 2 5 3	0 0 2 7 0	3	0	3	6	2	1	6
0 4	0 0 4 5 3	0 0 2 7 0	3	0	9	8	2	1	1
0 5	0 0 4 5 3	0 0 1 8 8	1	0	7	8	2	1	1
0 6	0 0 4 4 0	0 0 1 8 8	1	0	9	8	2	2	1
0 7	0 0 4 4 0	0 0 1 2 5	1	0	3	3	2	6	1
0 8	0 0 0 0 0	0 0 1 2 5	1	0	9	8	2	2	1



The PERA System

FIG (5)

(AFTER MACCONNELL)

2.1.4. Component And Machine Group Formation:-

It has been clearly advocated by many authors (18) and GT supporters that, the most difficult task in group technology is to find the best way to form families of components and groups of machines or cells. By definition the basic aim of GT system is to identify families of similar parts and form production units to produce these families.

There are four main methods which can be used for component and machine group formation.

1 - The "Peropatetic" or "Ocular" visual method.

This method divides components and machines into groups by visual observation using skills and vast expertise of the production engineers. The selection is normally done by eye, from drawings using the simple rule of similar components requiring similar processing are grouped together. Appropriate machines are organized into cells to produce component families. Using this approach English Electric, Bradford, claims that the machine output has been increased by 70% and setting time reduced by 66% (22). The advantages of cost involved when this system is used outweighed by the many disadvantages such as, the requirement of skilled labour and engineers; the difficulty of data manipulation, the size of the project intended to be studied.

2 - Classification Of Design Features:-

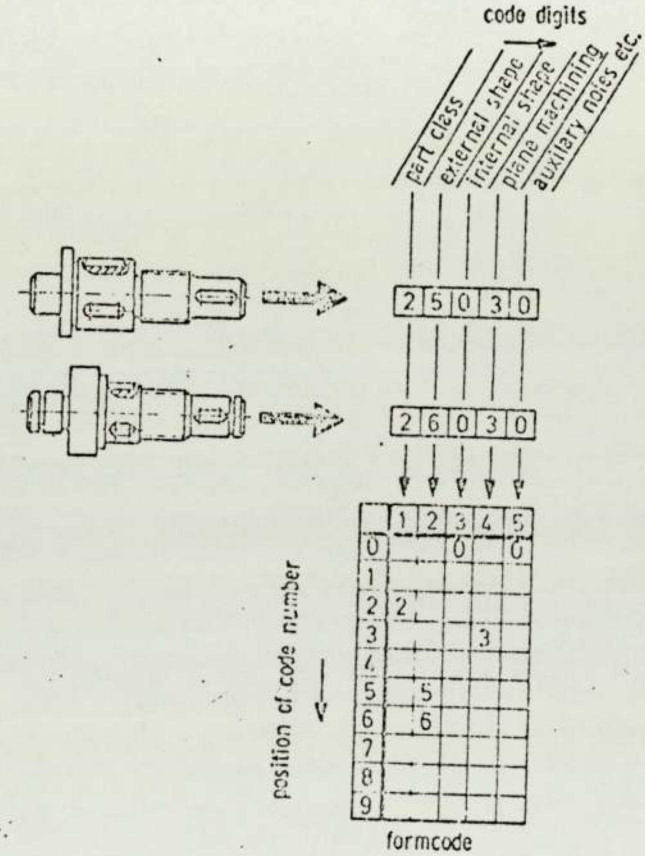
Selection by design features is another system which is used, quite frequently. It is ideal for variety reduction, part retrieval and the reduction of new design costs. This system groups the components which are similar in overall shape, size and possible material. The establishment of groups can be based on certain features such as, basic overall shape, size, material and raw material shape. The first two features can define the type of machine used in production i.e. Turning for rotational parts and milling generally for non rotational components. Brankamp (23) suggests that approach of selecting machine tools to match the existing component range as the requirement for cell formation. The Opitz code comprises most of the items required for family and cells formation based on design features. One of the main criticisms against this system is that not all selected parts in one design family can be manufactured on the same group of machines, fig $(6)_{a,b}$.

3 - Classification Of Production Features:-

Families grouped by their production features can all be manufactured by the same group of machines although they have no apparent design feature similarities. The main characteristic attributable to the component under consideration should include, material, major dimensions, special features, machines used, machining time and quantities to be classified into families by production features.

4 - Production Flow Analysis:-

Production flow analysis have been defined previously in chapter (1). It aims from the beginning to find a total division of all parts and machines in a factory into families and groups. This method ignores component design features and concentrates on



Generation of a code number field.

FIG $(6)_a$

(AFTER BRANKAMP)

	CODE DIGITS									DIGIT NO.	DESCRIPTION
	1	2	3	4	5	1	2	3	4		
1ST SELECTION	0	0	0	0	0	0	0	0	0	1	PART CLASS-ROTATIONAL
	1	1	1	1	1	1	1	1	1	2	EXTERNAL SHAPE-SEVERAL SIDES INCREASING
	2	2	2	2	2	2	2	2	2	3	INTERNAL SHAPE-SEVERAL SIDES INCREASING
	3	3	3	3	3	3	3	3	3		EXCLUDING CONES & OPERATING THREAD
	4	4	4	4	4	4	4	4	4	4	SURFACE MACHINING-OPEN
	5	5	5	5	5	5	5	5	5	5	HOLES & TEETH-HOLES ONLY, NO GEARS
	6	6	6	6	6	6	6	6	6	1	LENGTH - 4" 8"
	7	7	7	7	7	7	7	7	7	2	DIAMETER 1" 2"
	8	8	8	8	8	8	8	8	8	3	MATERIAL-ALL STEELS
	9	9	9	9	9	9	9	9	9	4	RAW MATERIAL FORM-BAR
1ST EXTENSION	0	0	0	0	0	0	0	0	0		
	1	1	1	1	1	1	1	1	1		AS ABOVE BUT DIGIT NO.5 EXTENDED TO
	2	2	2	2	2	2	2	2	2		INCLUDE GEAR TEETH, SERRATIONS ANDSPROCKETS
	3	3	3	3	3	3	3	3	3		
	4	4	4	4	4	4	4	4	4		
	5	5	5	5	5	5	5	5	5		SUBSEQUENTLY WITHDRAWN
	6	6	6	6	6	6	6	6	6		
	7	7	7	7	7	7	7	7	7		
	8	8	8	8	8	8	8	8	8		
	9	9	9	9	9	9	9	9	9		
2ND EXTENSION	0	0	0	0	0	0	0	0	0		
	1	1	1	1	1	1	1	1	1		AS ABOVE BUT COMPONENT LENGTH PARAMETER
	2	2	2	2	2	2	2	2	2		INCREASED
	3	3	3	3	3	3	3	3	3		
	4	4	4	4	4	4	4	4	4	1	LENGTH 1" 4"
	5	5	5	5	5	5	5	5	5		
	6	6	6	6	6	6	6	6	6		
	7	7	7	7	7	7	7	7	7		
	8	8	8	8	8	8	8	8	8		
	9	9	9	9	9	9	9	9	9		
3RD EXTENSION	0	0	0	0	0	0	0	0	0		
	1	1	1	1	1	1	1	1	1		AS ABOVE BUT DIGIT NO. 2EXTENDED TO INCLUDE
	2	2	2	2	2	2	2	2	2		COMPONENTS WITH ONE SIDE INCREASING
	3	3	3	3	3	3	3	3	3		
	4	4	4	4	4	4	4	4	4		
	5	5	5	5	5	5	5	5	5		
	6	6	6	6	6	6	6	6	6		EMPHASIS ON DIGITS 4 & 5 ABOVE 0 TO PROVIDE
	7	7	7	7	7	7	7	7	7		MORE MILLING AND DRILLING
	8	8	8	8	8	8	8	8	8		
	9	9	9	9	9	9	9	9	9		

FIG (6)b COMPONENT DIGIT SELECTION MATRICES

(AFTER PERRINS)

the production method. Besides coding and classification it is the only method which so far can successfully be put as an alternative. Estimated cost of implementation by either method can be used if both systems can be practically applied.

2.1.5. Implementation Of Group Technology:-

The definition of GT has taken a very wide view of the original intentions ranging from GT as a tool, to management, to man power utilization, to job satisfaction, to human aspects, to economic aspects, and application includes industries such as metal cutting (the most widely researched area),,and the metal forming industry e.g. Pressing, Foundry..etc. The decision to implement group technology to any company is that much easier now, because of the amount of research which has taken place with emphasis on practical solutions in industrial environments.

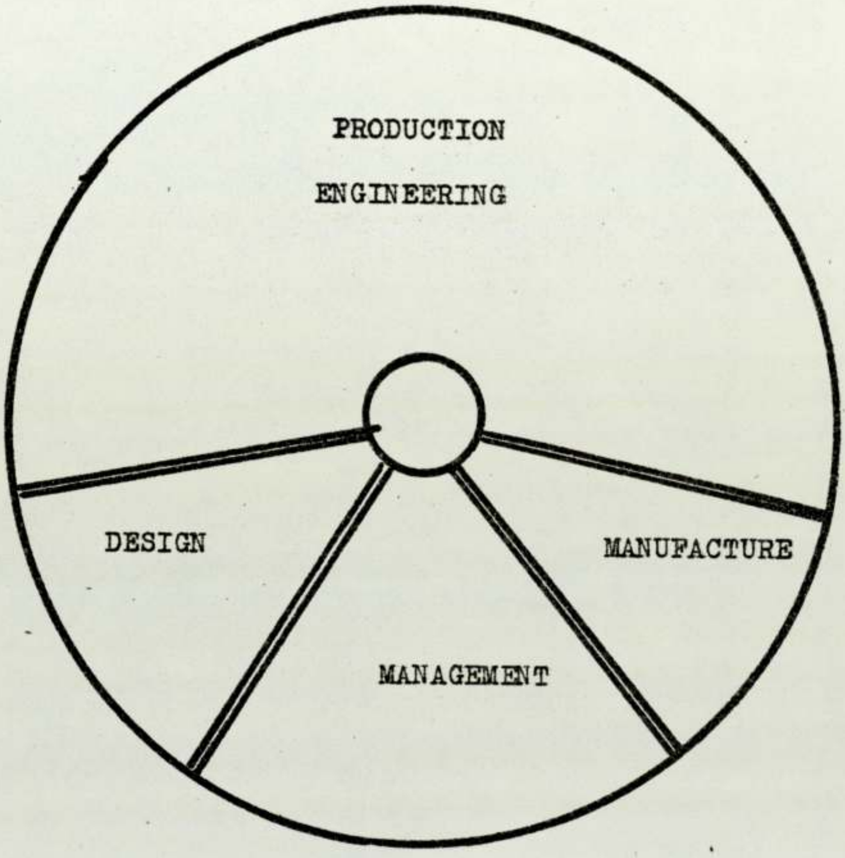
GT has to be considered as a total approach and its introduction can effect the operation and organization of any section of the company under survey. Bennett (24) divides the introduction of GT to any company to three phases. Firstly preliminary survey of potential, the aim being to determine the need for and the scope of GT within the company. Secondly; establishment of pilot machine group, the aim being to establish an effective model on which total implementation will be based by producing and analysing data on which the initial pilot machine group will be formed. Thirdly; Full introduction. While phase one and two will have to be decided at top level, the third phase will involve every-body in the company. The aim is to integrate the total company with GT thinking and commitment and will include not only changes in plant layout, but all subsequent changes such as costing production control, administration..etc.(25).

Total involvement requires the commitment of all parties in the company. There will be very little success in implementing GT without the enthusiasm and total involvement of the management. The main savings can only be achieved if the whole management. philosphy allows changes to take total advantage of the apparent opportunities.

MacConnell (26) presented an analysis of the reasons for 150 companies considering implementing GT. It should be noted that approximately 90 of 150 companies have been committed to implementing GT. The reasons for implementing GT in industry varies considerably according to MacConnell (26) and the analysis and reasons for interest in GT. was carried in two parts;

Part One:-

Definition of the main areas into production engineering design, management and manufacture. Production engineering represents the major part of interest in implementing GT with management as the next important section fig (7), gives a full representation of the areas of interest. Implementation of GT as a total approach was not apparent, in practice at a step, and because of this, it is important that the solution of the initial company study of a problem was carried out in a manner that would not restrict the development of GT as a total approach.



FIG(7) Analysis Of The Main Areas Where Solutions To Problems Are Sought.

(AFTER W.R.MacCONNELL)

Part Two:-

This part deals with the division of areas into specific fields related to the companies reason for implementing GT. A sample of the analysis is shown in figs (8,9,10).

2.2. Cell Formation:-

A cell consists of a machine or number of machines, some of which can be identical, needed to complete the production of the component allocated to the cell. In certain cases exceptions to the rule may be expected, such as heat treatment, which so far have mainly been left outside the cell, otherwise a cell should be a self contained production unit. The two main methods of cell formation are to be considered here.

2.2.1. Cell Formation By Coding And Classification And Production Data Analysis.

The establishment of production cells after component classification and coding is divided into three parts.

a) First Part: Capacity Calculation For Each Family:-

This part contains the simple arithmetic of each operation which includes, set-up time, machining time description and yearly component demand. Calculation of operation time per year per machine type is therefore possible for all different machine used for each family. Williamson (27) indicated that to form a reasonable cell an indication of its size must be set, he claims 6 to 10 operators

Area	Sub-area	Company No.	37	36	35	34	33	32	31	30	29	28	27	26	25	24
DESIGN		RETRIEVAL					(✓)	(✓)					✓			
DESIGN		STANDARDIZATION				(✓)		✓				✓	✓			
DESIGN		VALUE ANALYSIS					(✓)	✓				✓				
DESIGN																
PRODUCTION	PLANNING	ESTIMATING AND COSTING				(✓)	(✓)	✓	✓			(✓)	✓	✓		✓
PRODUCTION	PLANNING	OPERATION SCHEDULE						✓				✓		✓		✓
PRODUCTION	PLANNING	REDUCED TOOLING										(✓)				
PRODUCTION	PLANNING	RETRIEVAL OF PROD. DATA			✓	✓		(✓)	✓	(✓)	✓	✓	✓	✓		✓
PRODUCTION	CONTROL	RE-APPRAISAL OF SUB-CONTRACT WORK							(✓)	(✓)			(✓)			
PRODUCTION	CONTROL	IMPROVED THROU-PUT	(✓)		(✓)			✓	(✓)	✓	✓	(✓)	✓	(✓)	(✓)	(✓)
PRODUCTION	CONTROL	IMPROVED DELIVERY DATES	✓		(✓)			✓	✓	✓	✓	(✓)	✓	✓	(✓)	(✓)
PRODUCTION	CONTROL	WORK SCHEDULING	✓							✓	✓	✓		✓	✓	(✓)
PRODUCTION	CONTROL	REDUCE W.I.P.					✓	✓	✓	✓		(✓)		(✓)	✓	✓
PRODUCTION	CONTROL	MATERIAL UTILIZATION										✓			✓	
MANUFACTURE		PURCHASE OF NEW M/C TOOLS														
MANUFACTURE		DEVELOP NEW MACHINE TOOLS			✓											
MANUFACTURE		MORE EFFICIENT USE OF M/C TOOLS			(✓)						✓			✓		
MANUFACTURE		FACTORY LAYOUT														
MANAGEMENT		REDUCE STOCK		✓				✓	(✓)	✓		(✓)		✓	(✓)	✓
MANAGEMENT		INTRODUCE STOCK CONTROL		(✓)				✓		✓		✓			✓	✓
MANAGEMENT		MANAGEMENT SYSTEMS	(✓)					✓								
MANAGEMENT		CLASSIFICATION AND CODING		(✓)				(✓)		(✓)						

(✓) Prime Interest   ✓ Secondary Interest   (Developed After Implementation Or Discussion)

FIG (8) Example Of Analysis Sheet

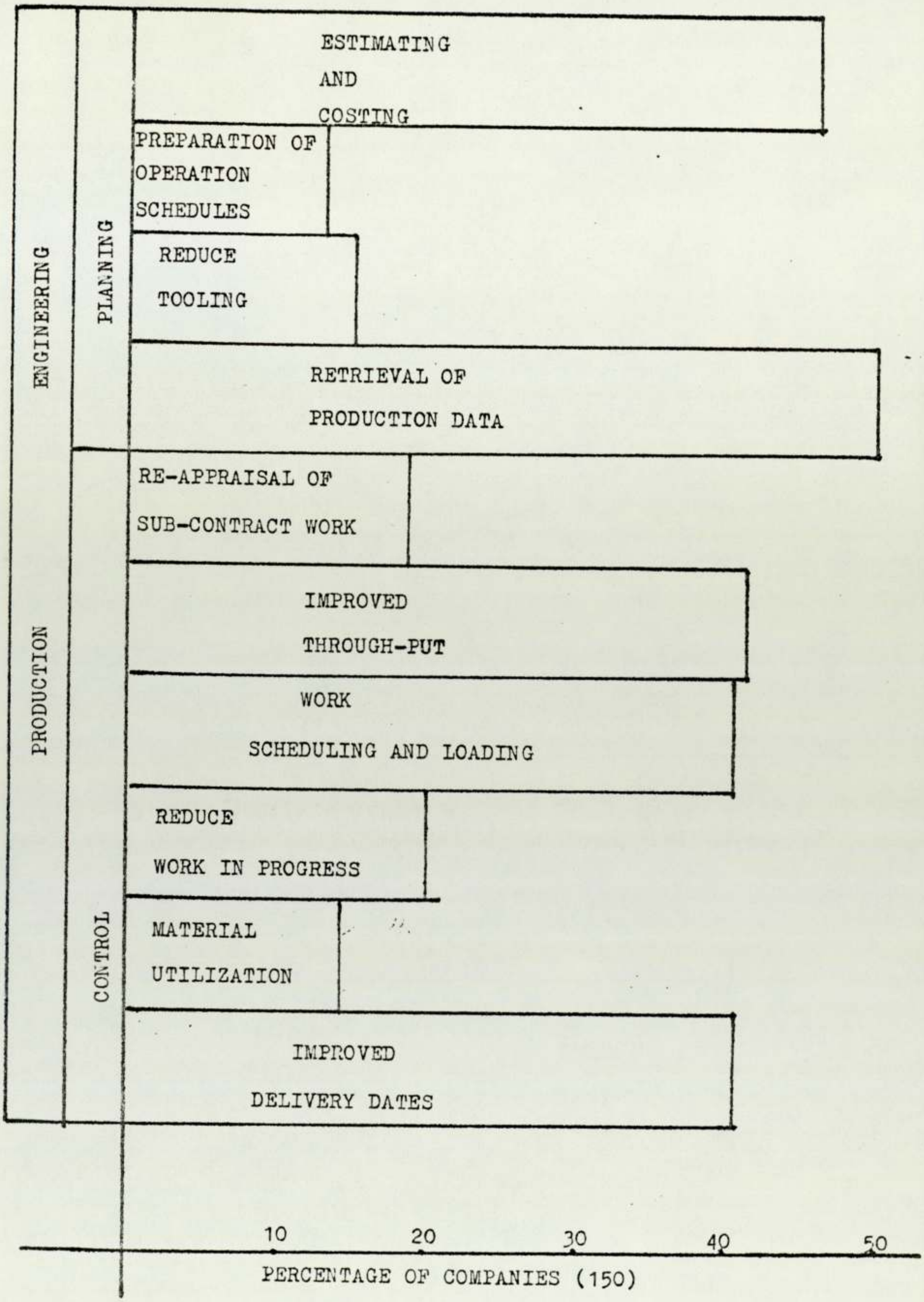


FIGURE 9: REASON FOR IMPLEMENTING GT.

(AFTER W.R.MacCONNELL)

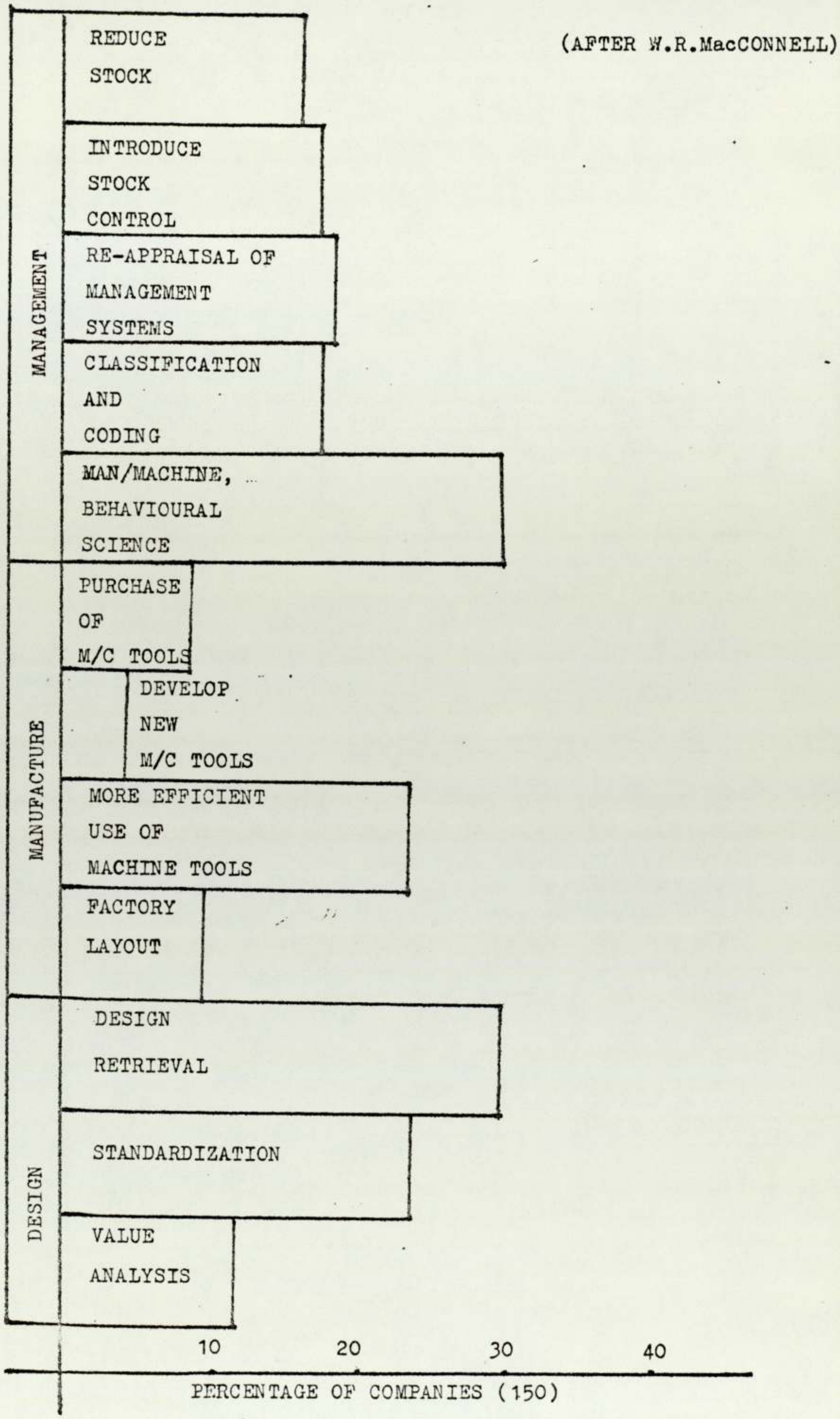


FIGURE 10: REASON FOR IMPLEMENTING GT.

per cell makes a good cell.

b) Second Part: Capacity Balancing By Combining Families:-

The combination of families using similar machines and the addition of their total yearly machining hours can be carried out until an indication of full utilization of 6 - 10 operators is established. It is advisable to aim at the higher figure of 10 to improve the utilization of secondary machine tools. The method should not take place in isolation of each cell and the grouping of families must be balanced. When a family has more total time per year than can be handled by the cell (over utilization), then, in that case the choice is either to break up the family or to form sub groups of machines within the cell.

c) Third Part: The Integration Or Elimination Of Minority Group And Machine Loads:-

Up to this part the tendency to look at individual machine utilization can not be recommended, but the fact that some support (secondary) machines can be left under utilized should not be discarded. The under utilization of secondary machine tools can be dealt with in many ways such as replanning of the work on different machines, reduction of operation and set up times by introducing group tooling, the use of special attachments or unit heads for a limited amount of special work on a certain component in the group, the use of low capital cost machine tools, outside the cell machine which can be shared by other cells, and sharing the work done on a component (some finished products) by different cells..etc.

The analysis of production data is most effective if it is considered in three separate but linked phases namely production flow, production demand, and production technology. The sources of this data are normally planning sheets, route cards, and cost records.

2.2.2. Cell Formation By Production Flow Analysis (P.F.A.)

P.F.A. was developed by Burbidge (9) in the early 60s as an alternative to classification and coding for cell formation. It is a technique used to simplify the material flow system and to find families and groups for group layout.

The component route card is the back bone of P.F.A. system and it should be complete and accurate. To check the accuracy of route cards there should be a separate route card for each item with its comprehensive list of, operations, machine type, methods of production, and operating times. The existance of a considerable amount of data in the form of planning sheets, route cards..etc, reflecting the production flow requirements of the components, made this system of cell formation an attractive and serious alternative competiter to that of coding and classification based systems.

Production Flow Analysis Follows Three Phases.

Phase One: Factory Flow Analysis:-

The basic aim of this phase is to study the establishment of the simplest material flow routes by determination and allocation of components and machines to different departments. The flow routes begin from material supplies through to finished product, figs (11,12,13).

Phase Two: Group Analysis:- (G.A)

This is the phase where families and groups of GT cells are formed. The aim of group analysis is to find the best division of all components into recognized families and the departments into manufacturing GT cells to produce the families. From the route card data the following procedure takes place.

1) A component/machine matrix is drawn to provide the basis to ascertain families and groups, and therefore rough machine loadings required for the cell.

11) Data is manipulated in the matrix to establish families and groups. The logical arrangement is shown in fig (14). As shown a different split in component and machines give a definite cell to produce a family.

111) The machine load profiles and allocation should now be determined for each GT group using machine annual hours.

1V) Exceptional operations should be investigated and eliminated.

V) Specify families and groups, (lists of machine in each group and components in families), and draw final flow system network.

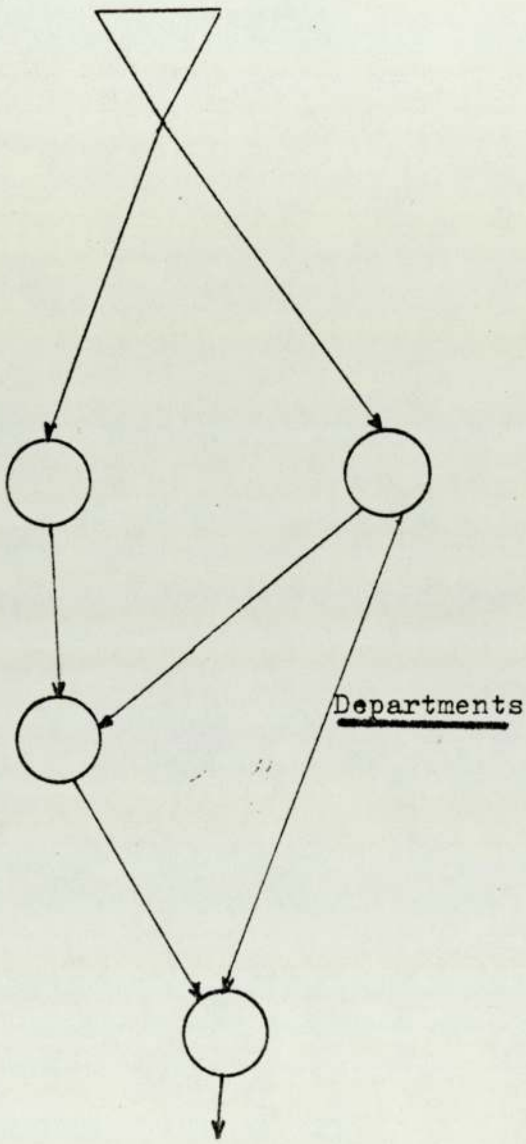
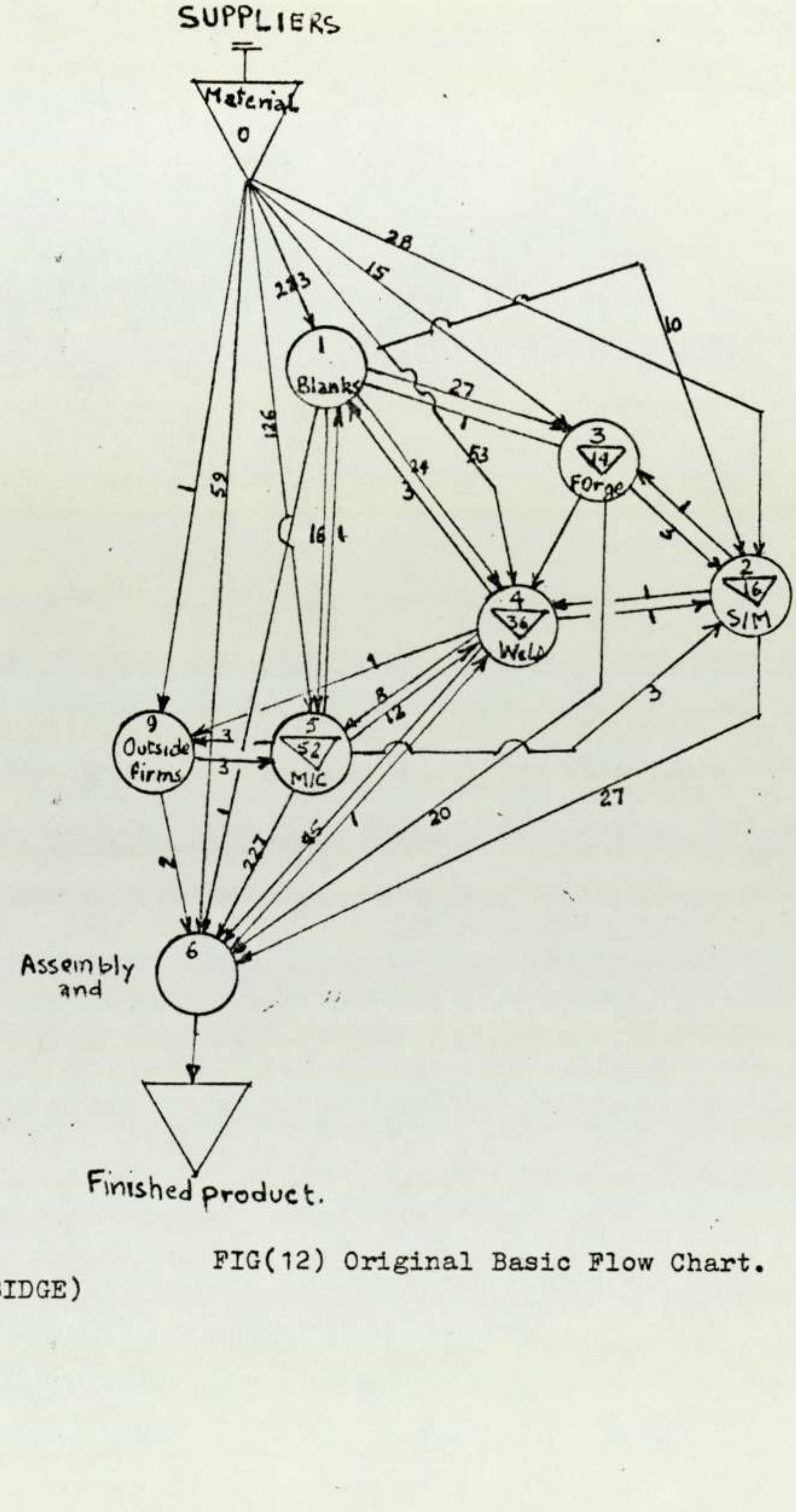


FIG (11) Factory Flow Analysis (FFA)

(AFTER BURBIDGE)



FIG(12) Original Basic Flow Chart.

(AFTER BURBIDGE)

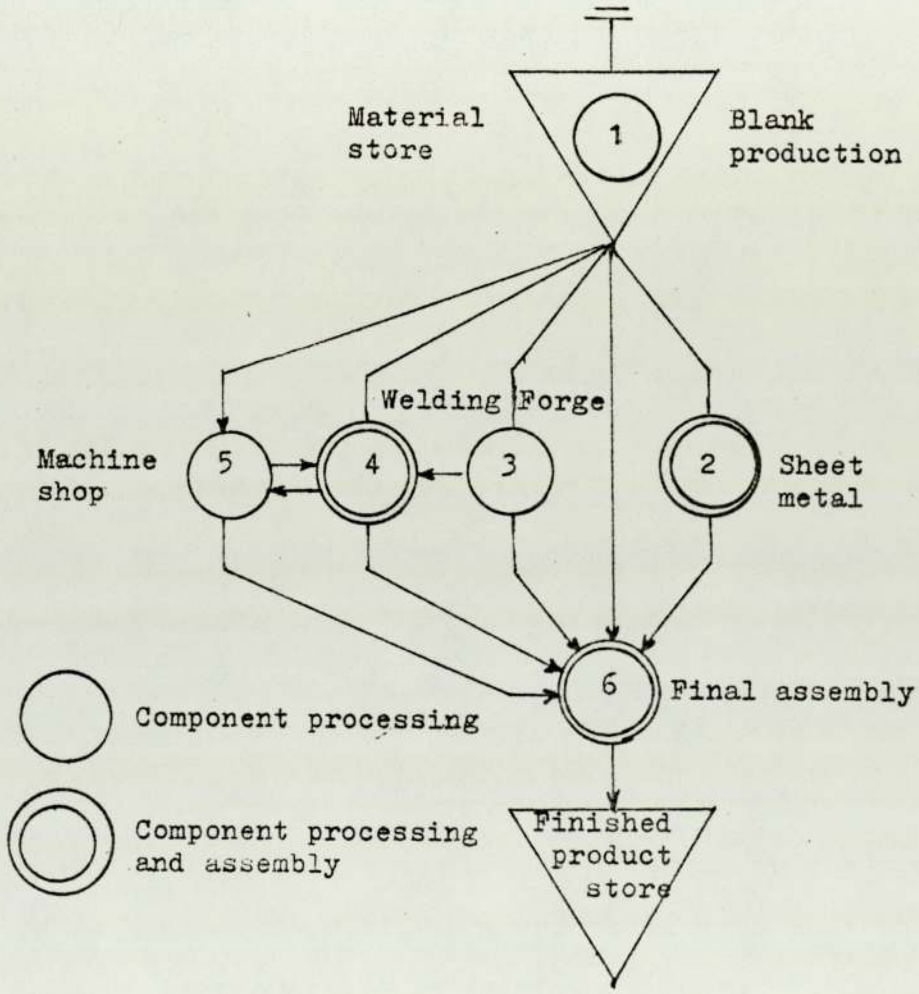
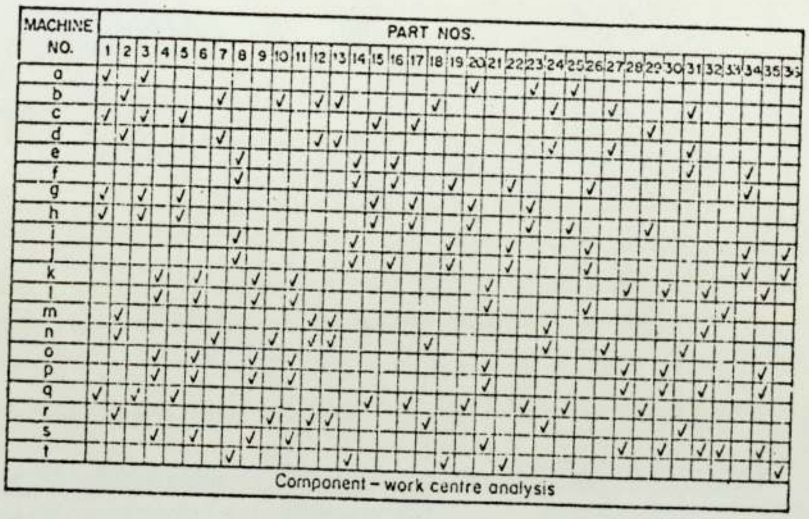
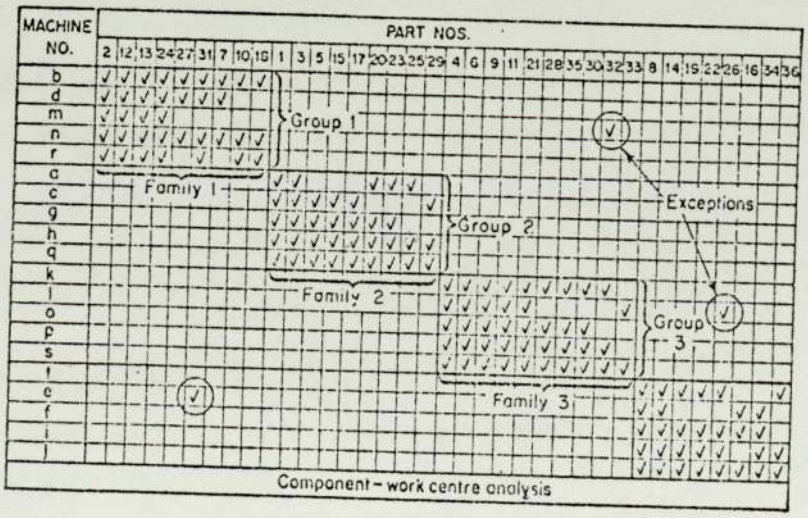


FIG (13) Simplified Basic Flow Chart.

(AFTER BURBIDGE)



(a). Original record



(b) After sorting into 'families' and 'groups'

Note. The two charts are identical except for the sequence in which parts and machines are listed. In practice some machine types will generally be needed in more than one group.

Component—machine analysis chart

FIG (14)

(AFTER BURBIDGE)

For more clarification of the use of machine to component matrix see chapter (4,7).

Phase Three: Line Analysis:-

This final phase concentrates on plant organization within GT's manufacturing cell. It analysis each cell individually.to determine a rational flow line and obtain the best machine grouping. fig (15).

Computer techniques can be used to simplify many areas of calculation and chart drawings of the P.F.A. procedure. One of the techniques based on P.F.A. is component flow analysis EL-ESSAWY. (28). (C.F.A.). The basic approach of C.F.A. can be described as a refinement of P.F.A. techniques, as it takes into consideration some of the aspects of production or manufacture which are neglected by the P.F.A. approach.

2.3. Inter-Cell Flow Analysis:- (18, 53).

Once a cell has been formed it is very important to determine the correct layout of machines within the cell especially those cells containing a large number of machines, where the problem is more complex. It is also necessary to develop the best layout patterns. Analysis of flow patterns will define the unit as a flow line or cell layout.

Where as line layout arranges the plant according to the fixed sequence component flow pattern, cell layout arranges the plant into sections in U Type, circular, square or rectangular

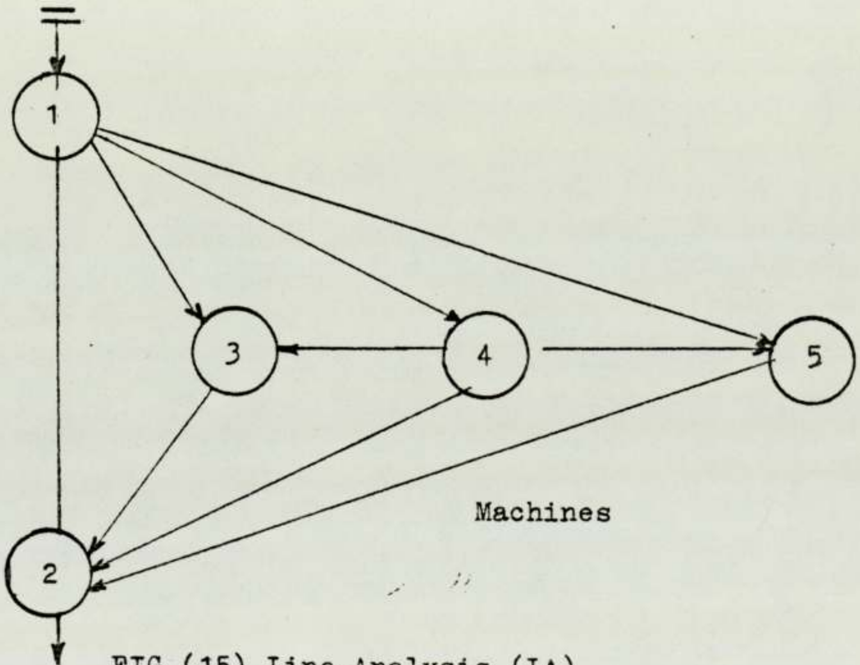


FIG (15) Line Analysis (LA)

(AFTER BURBIDGE)

form to cater for the variable sequence flow pattern and to minimise handling.

2.4. Costing

The problem of establishing a criteria by which to find the best solution ascertained in section 5.1.1. and 5.1.2. from any set of data for any problem is quite difficult. McAuley (40) has stated that for any solution it can happen that a part may have to visit more than one group of machines before it is completed. Intuitively then, it may be thought that the best solution is that which minimizes the number of group journeys. This suggestion seems to favour the solution in which all machines are in one group. A suggestion of improving inter-group journeys was to duplicate machines in various groups thus eliminating some or all inter-group journeys. Another criteria suggested is to maximise "overall machine occupancy". This solution will give each machine as one group.

As seen from those attempts (even though cost has been used to illustrate some points) establishing a criteria of choosing the best solution is essential. Cost as a common factor which summarizes all or most of the advantages of cellular manufacture should be considered. Therefore some method of cost comparison as the main criteria would seem appropriate.

2.4.1. Definition Of Terms: Ref: (46,47,48,49).

1. Cost is the amount of expenditure incurred on, or attributable to a given article.

2. Cost accountancy is the application of costing and cost accounting principles, methods and techniques to the science, art and practice of cost control and the ascertainment of profitability. It includes the presentation of information derived there from for the purpose of managerial decision making.
3. Costing is the classifying and appropriate allocation of expenditure for the determination of the cost of products or service. In other words, costing is the technique and process of ascertaining cost.

2.4.2. Types Of Costing:- ref: (48,49).

a) Historical costing is the ascertainment of costs after they have been incurred and for this reason is also referred to as actual costing.

b) Standard costing is the preparation and use of standard costs, their comparison with actual costs and the analysis of variances noting their causes and points of incidence. Standard cost is a pre-determined cost, it is based on the principle that the cost charged to individual products is the cost that should have been incurred on those products, rather than the cost which was actually incurred.

c) Marginal cost is the amount, at any given volume of output, by which aggregate costs changed if the volume of output is increased or decreased by one unit and of the effect on profit of charges in volume or type of output by differentiating between fixed and variable costs.

2.4.3. Elements Of Cost:- Ref: (47,48,49)

Cost elements comprise the total expenditure identifiable to production, administration, selling and distribution. Expenditure is divided in many ways fig (21).

1. Direct Cost:

a) Direct material is the cost of material which can be measured and directly charged to the cost of the product.

b) Direct labour is the cost of labour used in altering the construction, composition, conformation or conditions of the product.

c) Direct expenses are all direct costs other than direct material and labour.

2. Indirect Costs (Production Overheads).

a) Indirect material are all material costs which can-not be traced as part of the product; e.g. grease, oils, cleaning rags..etc.

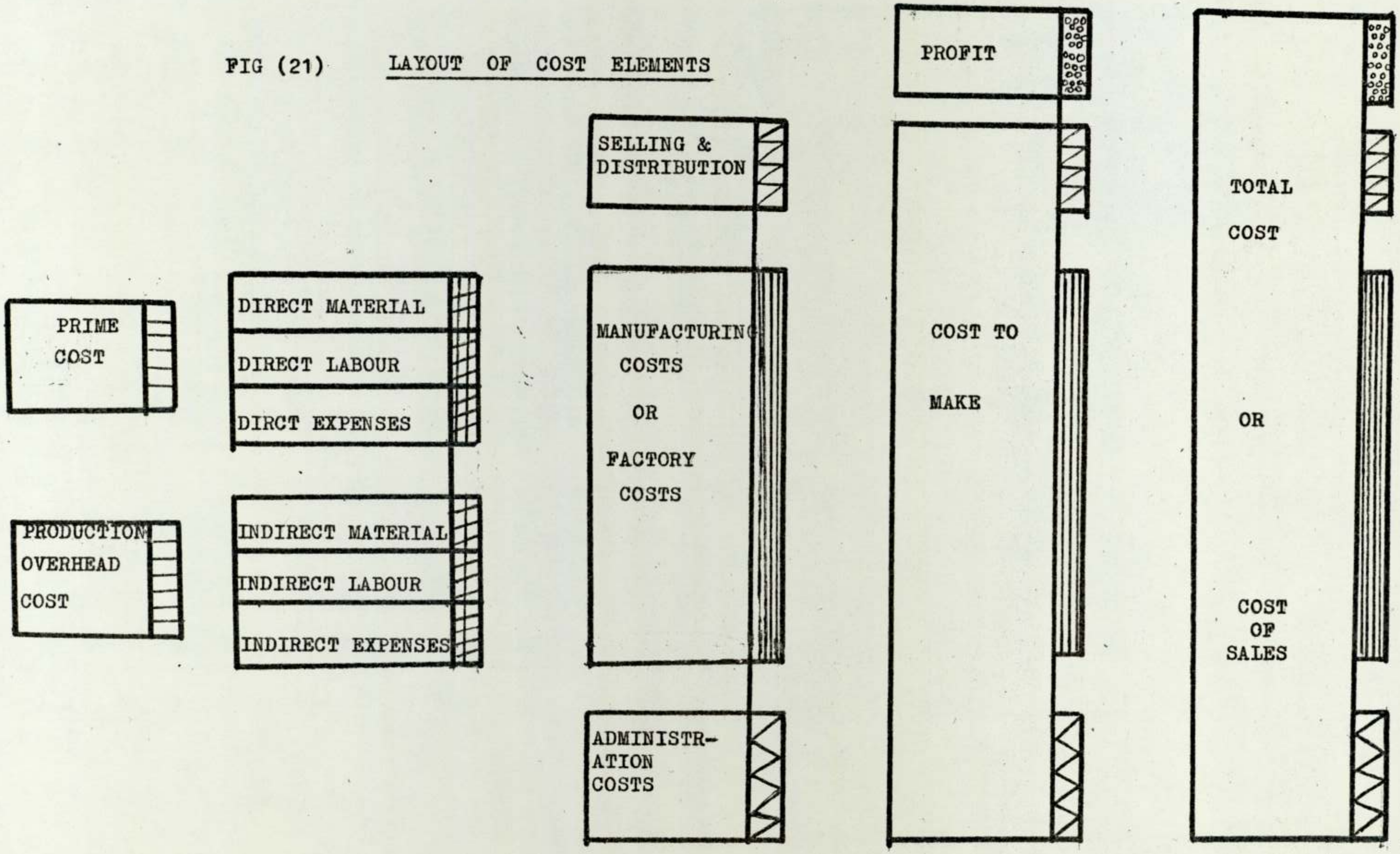
b) Indirect labour are all labour costs which cannot be related to direct labour cost; e.g. supervisors, storekeepers..etc.

3. Administration Cost:-

Is the expense incurred in the direction, control and administration including secreterial, accounting and financial control..etc.

4. Selling And Distribution:-

FIG (21) LAYOUT OF COST ELEMENTS



This is the cost to producers or distributors of promoting sales and securing orders, and of efforts to find and retain customers. Distribution cost includes the expenditure incurred from the time the product is completed, until it reaches its destination.

2.4.4. Methods Of Cost Accounting:- Ref: (48,49)

The fundamental principles of cost ascertainments are the same in every system of cost accounting, but the way of collecting and presenting the costs vary with the type of production to be costed. There are two major groupings of cost establishment:-

a) Job costing.

b) Unit costing or process costing;

from these two groupings seven different types can be developed besides standard or pre-determined costing and marginal costing.

1) Unit costing or output costing.

11) Operating costing, Unit costing as applied to service.

111) Job costing or terminal costing; it includes contract costing.

1V) Batch costing; Form of job costing; The batch cost is there used to determine unit cost of the article produced.

v1) Operating costing, a method of unit costing by operations connected with mass production.

V11) Multiple costing or composite costing.

CHAPTER 3

CRITICAL APPRECIATION OF SOME OF THE BENEFITS OF GROUP TECHNOLOGY.

3.0. Critical Appreciation Of Some Of The Benefits Of Group Technology.

3.1. Some Advantages Gained When Introducing Classification

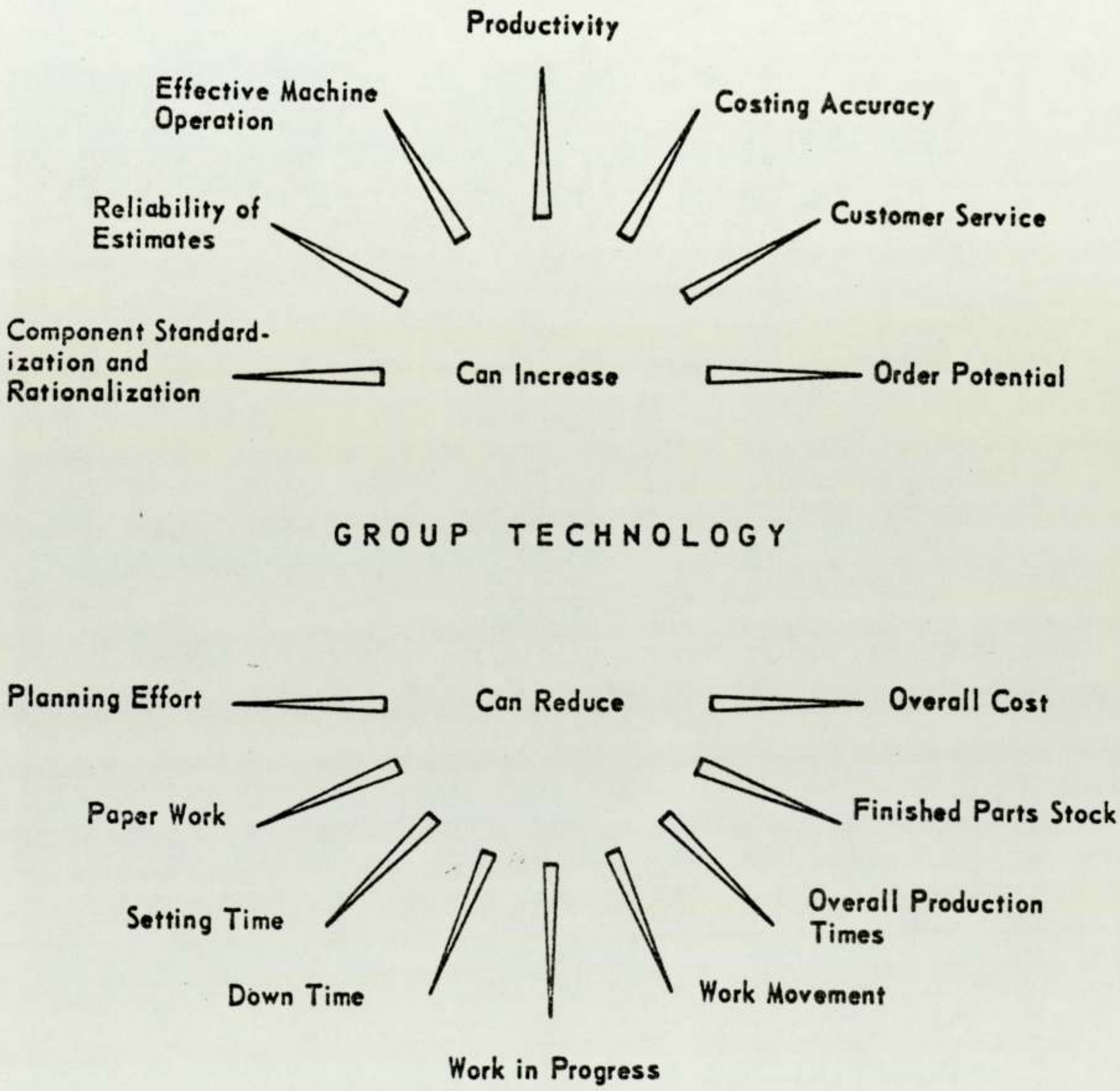
J. Gombinski (3) in a paper about classification and coding, has shown some of the practical applications and uses of the system and states that it is no longer necessary to rely on memory when design features and drawings have been coded and classified. The main advantage here is that component repetition can almost be eliminated and identical problems can be rationalized through the use of superior records and recording a retrieval methods.

3.2. Establishing The Benefits Leading To Cost Reductions:-

Thornley (29) has summarized the general achievements of GT. fig (16). On a number of these items will directly affect manufacturing.

3.2.1. Savings And Reductions In Setting-Up Time:-

Reduction of setting up time has always been a very popular reason for the implementation of group technology. The method of trying to reduce set-up time and eventually to reduce cost varies from one study to another, and depends on the importance of points raised by different researchers when introducing or discussing GT and cellular manufacture as a total production system. Many people have claimed lower, in some cases drastic, reductions of set-up times when introducing GT through such things



General Achievements of Group Technology

FIG. 16

as batch sizes,product geometry and size..etc. But in some cases, the grouping of families in itself will not reduce the overall setting time but may increase it as outlined by Craven (30). Unless the features and dimensions of sequential components are identical and not just approximately similar, many alterations in tooling or shop setting have to take place. There is a fundamental difference between turning operations, milling operations and drilling operations, for example, principally because of the effect of the three elements of set-up namely :-

i) Holding the workpiece.

ii) Tool location/size/capability.

iii) Relative movements in several planes of the workpiece per tool.

This leads to the conclusion that set-ups can be more simply standarized with greater flexibility of application on milling and drilling operation rather than on turning with conventional lathes.

Since Mitrofanov (9) many authors have concentrated on exploring the possibilities of set-up time reductions by devising group fixtures instead of special individual fixtures. This has led to new designs and modification of tools and attachments. Mitrofanov (9) introduced group fixtures with interchangeable adaptors which led to the reduction in set-up time of about 80% and also led to modernization and specialization of equipment.

In practical terms and apart from the claims of 80% setting up time reduction by Mitrofanov (9) in 1958 and the 66% reduction claimed by Knight (31) 1972 - 1974; Durie (32) 1970, has found out that a reduction of 66% in setting-up time can be achieved when a first run was made on a family of components after detailed analysis on 55 of the jobs picked at random. He also claimed, in a conferance in Turin (32), in 1969 that setting -up time for small turned components can be slashed by about 95%. In 1967 a company (37) adopted family grouping techniques to drastically reduce machine set-up time by 50% and overcome a severe shortage of skilled setters. As a part of Ferranti's work, small turret lathes are employed extensively in the production of turned parts; although those machines have long been proved effective for the type of work that is undertaken, the frequent but necessary changes in set-ups has been a matter of serious concern, on average the changes accounted for 40% of the setters operations time. Tool pre-setting is examined as an answer to the problem, with the object of being able to reduce to a minimum the non-productive times for the machines during set-up changes. The operators now spent only 5% of their time on changes of set-ups. The reduction in set-up time amounted to about 88% and the overall operation time to about 40%. Output was increased by 75%, since the operators are completely familiar with the tooling set-up, which does not change from job to job, Down time between jobs has been reduced to a maximum of 15 minutes, which is the time required to study the part drawing and the machining procedure. Due to increased outputs, lathes were not fully utilized in some cases.

These are some of the claims of cost reductions which resulted from reducing set-up times when introducing GT. However, criticism must be levelled at those responsible, for not (in most claims) showing reductions of set-up times in terms of actual manufacturing cost value instead of assuming they can be transferred directly from time to cost values. Set-up time reductions have been achieved through being directly the cause of concern (e.g. Ferranti); or as a result of family grouping (e.g. Mitrofanov); or as a result of introducing or modifying the manufacturing system (e.g. group technology cell system). Whatever the cause of changes in set-up, a general effect through the system, which includes this change, must be used, rather than claims of individual isolated items. For example in many cases as was said before, when designing cells, utilization of some machines can be quite low, while reduction in items such as set-up times could be achieved. The question therefore must be; Is it justifiable to accept lower utilization and a reduced set-up time, and the answer should be included in a procedure where all claims would be justified. Cost, and in particular unit cost, should be the common denominator, in the procedure; where all increases and decreases can be appropriately transformed into an understandable yard stick.

3.2.2. Through-Put Or/And Lead Time:-

Through-put time is the time required for a specified item or items to pass through a specified segment of a material flow system. Throughput time reduction is of a great importance in handling urgent work, spares orders and in restoring omissions. It is claimed (34) that families created through production flow analysis tend to give maximum savings in through-put time, while families created by shape and geometric characteristic tend to give high savings of set-up time.

The introduction of GT cellular manufacture has made reductions in through-put time possible. In terms of cost savings and shorter deliveries reductions in through-put time, may mean a larger share in the market, The inability to provide a reliable delivery performance is a direct reflection on the inadequecies of the traditional approach to batch production which uses the functional layout of plant as a basis for its manufacturing system. It is here that one sees the greatest benefit occuring to the majority of industry from introducing GT. The nearer the through-put time approaches zero the easier it is to ensure that items are available at the right time.

Looking at the present application of GT in Great Britain gives a guide to possible savings of through-put times of an average of about 80% see table (1). As an example of what has been achieved in one company, where the organization has been re-modelled to GT, in terms of production through-put time it was found that by rationalizing casting operations, it was feasible to cut through-put time from 40 to 11 weeks or by 72.5%. (34). In a case study where the introduction of GT cellular manufacture of precision measuring equipment resulted in a 54% to 84% (35) reduction in through-put time or typical deliveries have been reduced from six to two weeks. Serck Audco Ltd. published its achievements and reported a reduction of through-put times by about 66% (24), another companys account of through-put time reduction is that, in the cells which are producing turret slides, through-put time was reduced from thirty six weeks to three or about 92% reduction (36). In the year cell through-put time was down from eighteen weeks to three weeks or 84% reduction (36).

As in the set-up time reductions, emphasis have only been to the comparison between the long and inadequate through-put time using the conventional manufacturing systems, to those reductions in times which accompanied the change to GT cellular manufacturing system. Careful consideration should also be given to the side effects occuring with the change to or improvement of GT manufacturing system, such as reduced labour or plant, redesigned quantities and product mix..etc. As has been suggested before, all these percentages can be deceiving and managements might show some sense of reservation to accept the recommendations but, if those percentages and the side effect were all translated into a cost factor (in particular unit cost factor) then managements may be persuaded to accept some or all changes.

3.2.3. Work In Progress:-

The correct application of GT procedures should generate substantial reductions in work in progress, which is the main reason for most companies activity in this field. The opportunities of reducing work in progress are several:-

i) Reduction stems from quicker through-put time.

ii) Cellular manufacture; Particularly in complex businesses with a wide product range, if the whole of the machine shop is of a cellular nature, there can be a far closer response of the production programme to the constantly changing order input. The controls stemming from this facility enable changes in overall levels of business to react much more quickly and of even greater importance, random changes in demand for particular products can be recognized and dealt with more speedly.

iii) Lower stock holding in finished product stores and the manufacture of smaller batches. The quicker through-put time enables changing market needs, errors, random demands..etc, to be quickly dealt with and for stock-outs to be corrected more speedly. With regard to reductions in batch size, it is most important that proper judgments are made on the savings to be obtained from stock holding compared with the increase in cost associated with smaller batches and more frequent set-ups. This point endorses the need to develop lower cost set-ups, together with the facility for sequential scheduling, to obtain minimum set-ups.

In practical terms work in progress can be reduced considerably by the introduction of GT cellular manufacture. The arrangement of pre-planned work load with trained operators on turret lathes equippedwith turret plates, the work in progress have been cut from twenty six and half days to three days (37).

The experience and results in the cells that have been operating for some months fulfill the expectations of the planners. For example in a cell producing turret slides, work in progress was reduced by 92%, and in the gear cell work in progress was down by about 72% (35). A spot check, taken at Wickman Scrivener (38) after the group layout system had been operating for some months, showed that there were 548 jobs within the system compared with 726 immediately before group layout was introduced. Assuming that each job averages the same work content, this would seem to indicate that a reduction of work in progress of around 25%. However the number of operators at the time of the check was increased from 30 to 36 machinists (17% increase), which meant a drop of the queue of work per machinist, which in turn reduces work in progress up to 38%. This measure could be misleading as an overall measure of advantages, because the increase in labour may result in an increase or drop of other items and hence may give a different economic situation. The application of GT in Great Britian has resulted in a cut in work in progress of about 60% table (1).

3.2.4. Increased Machining Capacity:-

Generally, this item is not an automatic benefit and in some cases the implementation of GT may lead to an overall reduction in effective machining capacity (36). It is generally accepted that certain machines will be under-utilized, and a prime factor in the construction of cells is the necessity of ensuring that higher capital cost machines are fully utilized.

This could prove very difficult under some of the existing circumstance of introducing GT to solve some problems in the short term an ignoring the side effect which can develop in the long run.

The internal balance of machine loading is some what dependant on the scale of the family range and variation of batch size. Designing cells with a well balanced work load, and smaller cells based on narrower families can lead to gross under utilization particularly on second and subsequent operation machines. It is often unfortunate that, when the question of under utilization is discussed, the cell proposals are based on a comprehensive analysis using data which has been calculated with some accuracy. and compared with what may be a false assumptions of previous individual machine loading. Where a section is already seriously production limited, particular care needs to be paid to the validity of the decision for changing to GT. Steps can be taken to couteract specific reductions in capacity but such problems need to be recognized and solutions determined at an early stage.

3.2.5. Other Benefits:-

There are many claims made ofadvantages other than those which have been mentioned during the discussions in the previous sections, for example labour, where often the number and some skills required of workers will be expected to change due to the all characteristics and the management policy on redundancy At Mercer factories (34) GT working was claimed to have considerably improved manpower utilization in the plant over a period of time. In support of this claim the organization quotes a decrease in labour force of 20% to a total of about 400 with no drop in output. On the otherhand, at Wickman's (38) as a result of introducing group working the number of operators was increased from 30 to 36 as a result of increasing demand, this in turn caused the working queues per machinist to be reduced by about 40% and the saving in W.I.P. was about 38%.

Stock holding is another factor which can be useful in the comparisons of GT benefits. The levels of improvement differs from company to company, due to the emphasis given to this important item. The level of stock at Serck Audco (25) for example was reduced by 40%. Standardization and quick change over machines make it possible to produce smaller batches of parts a considerable number of times a year compared to the small number of times with large batches, which in turn reduces stocks.

The idea of introducing GT prompted some people to suggest group working. The use of group working is widely advocated as a solution to some of the behavioural problems of flow line work, such as absenteesm and job satisfaction (39), other advantages and benefits are shown in table (1).

The main criticism of the claims made by different organizations and individuals, can be directed to the inconsistency of the findings, and that is so because every individual case has itself been linked to improving certain isolated problems. Also missing is the lack of emphasis on side effects, that is, when a problem in one section of the factory is tackled by introducing GT the result will most likely be improvement or disappearance of this problem, but, what would be the side effect on other sections of the factory. The only way to avoid this kind of shortsighted conclusion is to consider GT manufacture as a total solution and all aspects of the factory considered.

3.3. Cost Benefit:-

The lack of evidence of actual direct cost reductions when claims of implementing GT are made is evident. Many authors and researchers have claimed that a reduction in time will lead to reductions in cost. This claim should be very carefully considered because it could be misleading when studying similar problems.

It is only after a comprehensive study of GT that one can appreciate how difficult it is to calculate costs and savings. Companies have used group technology because of the belief that it is an obvious improvement. From the cost information available to them they also know that in a lot of cases the costs are neither accurate nor appropriate for the changing circumstances of GT cellular manufacture.

3.3.1. Total Cost Comparison:-

Dr. Knight (31) has been one of the very few people who has used cost for comparison purpose. He has compared between a conventional method and GT system using cost comparison and areas of savings. table (2). The main areas of cost reductions in this case were in capital investment, annual running cost and material cost. The author has concluded that his simplified cost comparison has provided an indication of cost comparison when introducing GT, and he anticipates that the saving in set-up and through put times are typical of those that have been achieved by other companies which have used GT. The author also claims that similar savings and others can be expected to be gained when GT is introduced in the manufacturing industries. These could be misleading conclusions because every company and organization has its own peculiarities. To make such claims on those bases can be dangerous where certain companies may have the belief that if they apply GT all their problems will be solved on top of the expected cost savings.

3.3.2. Unit Cost Comparisons:-

Articles and literature on the proper use of cost formula designed to show the variation of unit cost with differing types of manufacture appears to be negligible or non existant as far as it can be ascertained. The importance of introducing unit cost as a basis for comparison when considering the introduction of GT manufacture as a complete and total production system, would seem to be a natural conclusion.

CHAPTER 4

BASIS OF THE PROBLEM TO BE STUDIED IN THIS PROJECT.

4.0. Basis Of The Problem To Be Studied In This Project:-

Cost is the goal to which managements are aiming to control to their advantage. It is the most important factor to summarize any achievement which can be obtained in the manufacturing industries. Many authors have claimed different types of saving at different levels of introducing GT (31,32) as a total manufacturing system as discussed in chapter 3 but certain items have been ignored and taken for granted, such as what is the acceptable level of utilization of the so called minor machine tool (e.g. secondary operation machine tools).

Whether the plant is a functional layout system, single machine system, cell layout system or group flow system, the emphasis on carefully utilizing the main machines and, perhaps, ignoring the low utilization of the so called minor machine tools is apparent. In most cases the plant is divided into a main primary machine where most of the work is done and minor machines where finishing operations are perfomed.

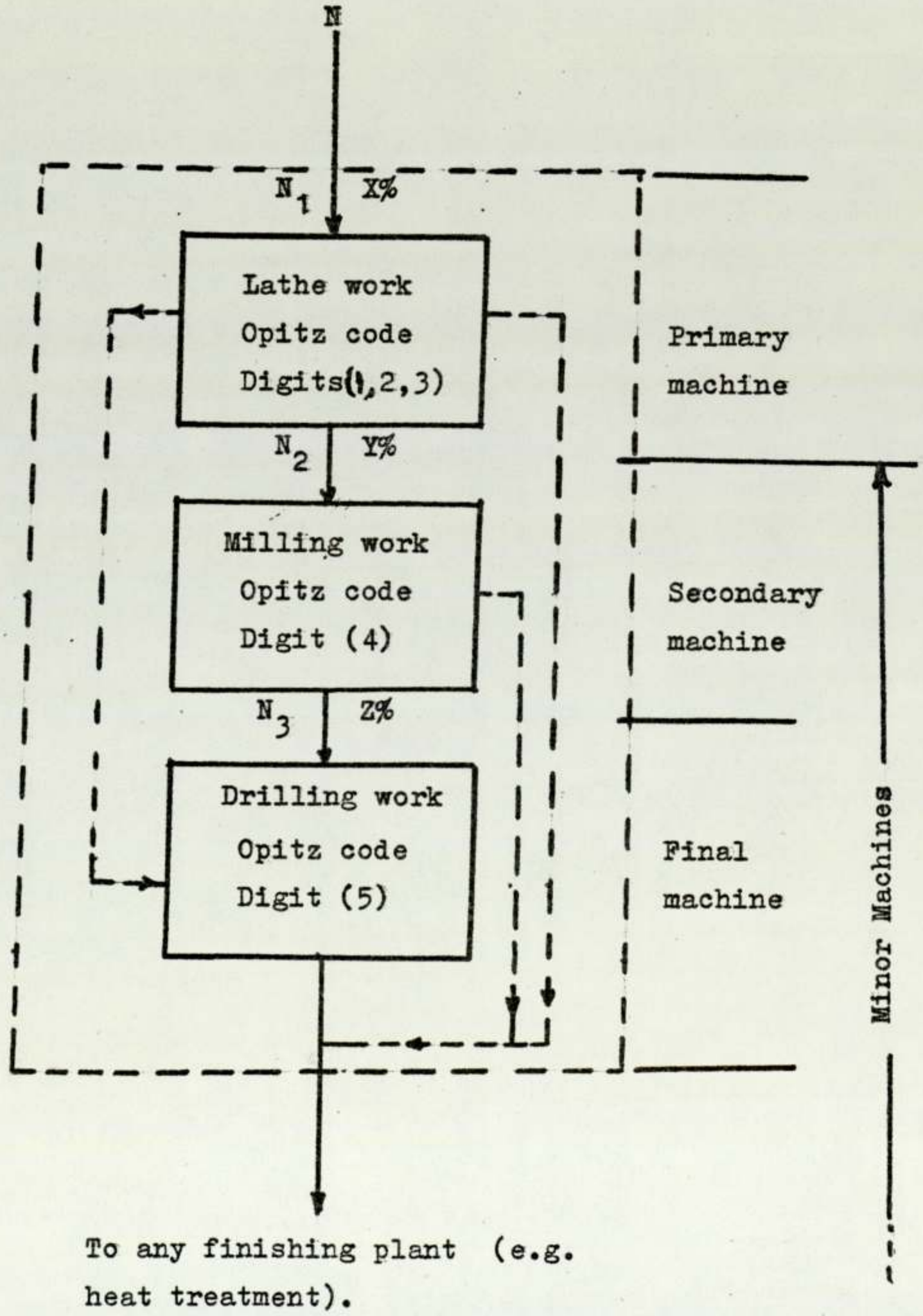
All methods of grouping machines to create cells, in the metal cutting industries, tend to classify the plant in general form of main machine, secondary, and final machines. Using the Opitz code as an over simplified illustration, the second and third digit operations are performed on primary machines, the fourth digit and fifth digit on the minor machines.

Under utilization of secondary plant or equipment is regarded as built-in excess for flexibility in the plant to achieve a good balance for production control. It is assumed in many cases that because of the usually low capital cost of secondary machine tools the latter assumption can be justified. The possibility of exploring the improved use of the so called secondary and finishing machine tools is usually ignored.

The philosophy put forward in this thesis is to create a situation whereby to design a cell, many solutions should be established where solutions can range from individual units to all machines in one cell. The relationship between total quantity to be manufactured in the cell and the quantity of each component is quite important to the calculations to increase or decrease individual machine utilization, with the minimum of calculation repetition. Unit cost representation against the utilization of machine or plant for different solutions is the common denominator which is used to establish a meaningful comparison.

The most important aspect of applying cellular manufacture is that of as many operations as possible being completed within the cell without the work having to leave it, and to try to achieve a flow of component work in one direction only or design of definite flow line of components to go through the same machine sequence. In the metal cutting industry for example the conventional build up of machine groups will follow the machining processes of the vast majority of components. In most cases such a build up will include turning operations, machining of plane surfaces, milling, drilling, gear cutting, grinding, heat treatment..etc.

An over simplified devision of machines in relation to the Opitz code can be suggested to illustrate and clarify the above ideas. Supposing that a plant is divided into three main machine tools, primary machine tool, secondary machine tool and final machine tool. The ideas can be further clarified with the aid of the flexible Opitz coding and classification system as follows:-



4.1. Primary (First) Operation Machine Tool:-

(i.e. Rotational work); represented by the first second and third digits of Opitz code. This is an over simplification of the definition of late work in terms of the Opitz code since digits two and three can differ considerably in the latter part of the code.

Supposing that X% of the parts manufactured in the system (e.g. cell) will go through this machine tool where $X \leq 100\%$. The part , can be individual, or part of a family or part of a number of families. As the operation represented by the second and third digits of Opitz system are the most common operations performed in the metal cutting industries, this machine tool can be regarded as very highly utilized, hence because the primary (main) machine that every body is concerned with.

The relationship between machine utilization (η) and quantity (N) is linear, therefore (X) is directly related to (η) it can be classified as follows:- Assuming a production period

If $X_{11} = \frac{N_{11}}{N}$ ..... 1 For each part (quantity ratio).

And $N_{11} \times t_{p_{11}} = N \times X_{11} \times t_{p_{11}}$ For one part.

Or $N_{11} t_{p_{11}} + N_{12} t_{p_{12}} + N_{13} t_{p_{13}} + \ldots + N_{1i} t_{p_{1i}}$

$$= N(X_{11} t_{p_{11}} + X_{12} t_{p_{12}} + X_{13} t_{p_{13}} + \ldots + X_{1i} t_{p_{1i}})$$

$\sum_{1}^{i} N_{1i} t_{p_{1i}} = N \times \sum_{1}^{i} X_{1i} t_{p_{1i}}$ For more than one part.

Also if $$\eta_1 = \frac{N_{11} t_{p_{11}}}{R}$$ For one part.

or $$\eta_1 = \frac{\sum_{1}^{i} N_{1i} t_{p_{1i}}}{R}$$ For more than one part.

Therefore in general $$\eta_1 = \frac{N \sum_{1}^{i} X_{1i} t_{p_{1i}}}{R} \quad \ldots\ldots 1$$

Where

N is the number of parts (units) going through a system annually

X_{11} primary or first machine share of (N) or quantity ratio.

R is the annual actual labour time available to employ the plant.

η_1 is primary machine utilization (in terms of cutting time) (set-up time)

N_{11}, N_{12}.... are the usage quantity/annum of parts 1 and 2...respectively

$t_{p_{1i}}$ is production time (No of set-ups x set-up time + machining time) in relation to the first machine.

4.2. Secondary (Second) Operation Machine Tool:-

(e.g. Milling work), represented in the Opitz system by the fourth digit. This part of the over simplified representation of the Opitz code is not exclusive to mill work only.

Assume that (Y%) of the total of parts (N) going through the system will need second operation, which means employing this machine. Many of the research institutes and industries involved in group technology and cellular manufacture, have accepted the under utilization of secondary operation machines as economically in-significant due to the expected gains made by high labour utilization and the use of low capital cost machine tools in certain cases. This acceptance of the under utilization, for the above mentioned reasons, has resulted in ignoring the possibilities of the advantages which may be gained by investigating the extent of improving the machines utilization. The question which is asked by many people connected with GT is to what extent secondary operation machine tool under utilization should be accepted. The economic significance of employing the machine individually or as part of a cell should be the most important factor. The effect of unit cost to the utilization of each machine individually or as part of a cell could be the key to show this significance. The increase in total quantity is one known way of improving the utilization, this method should be considered as long as W.I.P. is not increased to such an extent as to undermine the intended improvements. This can be done by a balanced load and good scheduling system, the effect on labour utilization can be beneficial. The increase in W.I.P. will result in long delays and has undesirable delivery time.

The bad effect on labour of other processes can be limited or eliminated if the whole company has been taken into consideration and GT has been introduced as a total system. In fact it can be expected that if introduced properly GT should improve labour utilization.

The relationship between machine utilization (η) and quantity (N) for the secondary operation machine tool can be defined by the following formulations:-

General form: $\eta_2 = \frac{N\sum_1^i Y_{2i} t_{p_{2i}}}{R}$

Where η_2 is secondary machine utilization (in terms of cutting time + set-up time).

Y_{2i} is secondary machine share of N (quantity ratio)

$t_{p_{2i}}$ is production time of secondary machine.

Other items are the same as in 4.1.

Assume one family one part therefore $N = N_1$ Total quantity of family one

From the general form :

$$\eta_2 = \frac{N}{R}\sum_1^i Y_{2i} t_{p_{2i}} \quad \text{.......(3)}$$

$$N = N_1 = N_{21} + N_{22} + N_{23} + \text{.......} + N_{2i}$$

$$= N_{21} + \sum_1^i N_{2(i+1)} \quad \text{..............(4)}$$

Where $N = N_1$ is total quantity of family one.

N_{21} is quantity of part one of family one.

$(N_1 - N_{21}) = \sum_1^i N_{2(i+1)}$ is the quantity of the rest of parts.

Therefore $$\eta_2 = \frac{N_{21}}{R} \cdot Y_{21} \cdot t_{p_{21}} + \sum_1^i \frac{N_{2(i+1)}}{R} \times \sum_1^i Y_{2(i+1)} \times t_{p_{2(i+1)}} \quad \text{..5}$$

From. (4) Assume That:

$$N_{2(i+1)} = 0$$

$$\eta_2 = \frac{N_{21}}{R} \cdot Y_{21} \cdot t_{p21}\text{;} \quad \text{Supposing } \frac{t_{p21}}{R} = k \text{ (constant).}$$

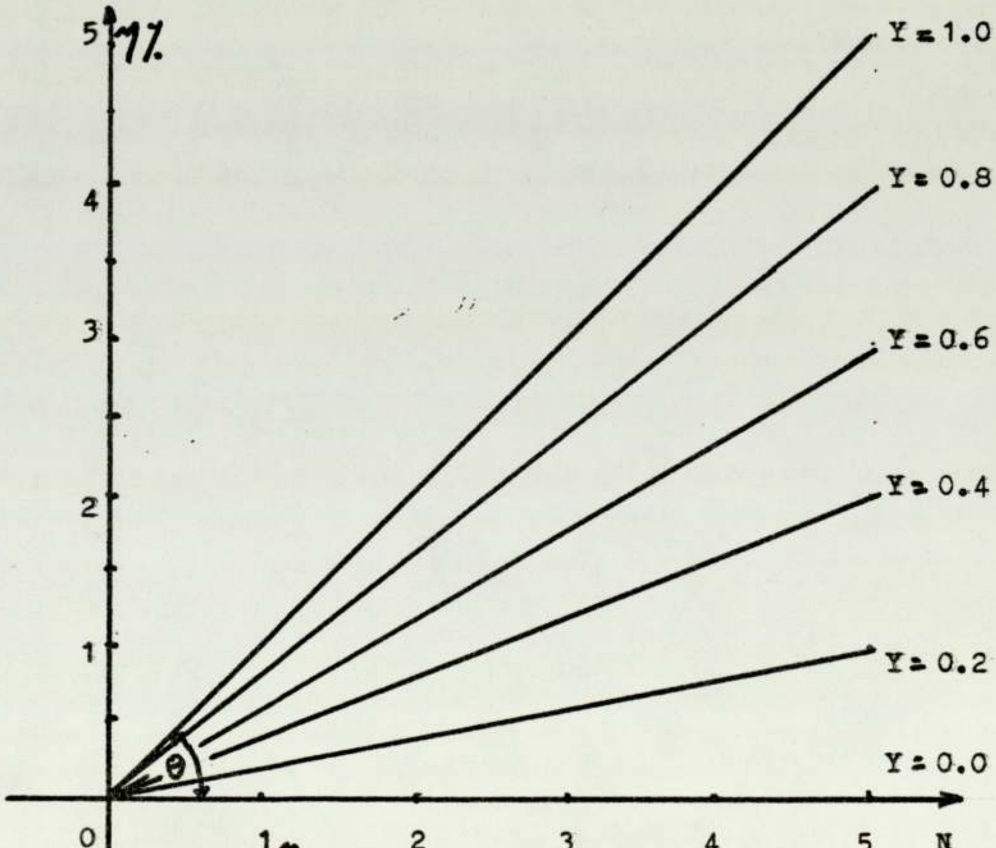
Then $$\eta_2 = N_{21} \cdot Y_{21} \cdot k .$$

At N_{21}/Y_{21}	0	0.2	0.4	0.6	0.8	1.0
quantity.						
1	0	0.2k	0.4k	0.6k	0.8k	1k
2	0	0.4k	0.8k	1.2k	1.6k	2k
3	0	0.6k	1.2k	1.8k	2.4k	3k
4	0	0.8k	1.6k	2.4k	3.2k	4k
5	0	1k	2k	3k	4k	5k
⋮	⋮	⋮	⋮	⋮	⋮	⋮
N_{21}	0	$0.2N_{21}k$	$0.4N_{21}k$	$0.6N_{21}k$	$0.8N_{21}k$	$1N_{21}k$

Where (N_{21} is 1,2,3,4.......)

N_{21} is number of units of the part.

From the above data the following representation can be plotted:



$\tan\theta = \frac{\eta}{N} = \frac{X}{N}$ (k Y_{21})

$\tan\theta - \max = k$ Where $k = \frac{t_{p_{21}}}{R}$

$\tan\theta - \min = 0$

As can be seen (Y) is designed to be a decisive factor in the utilization of the machine tool as it is a function of the quantity. The higher the value of (Y) the higher the utilization of the machine tool. $\tan\theta = k \cdot Y$ (k constant) for the same or increased outputs.

4.3. Final (Third) Operation Machine Tool:-

(e.g. Drilling work) represented by Opitz system fifth digit, (and not exclusive to drilling work). On the same lines described at 4.1. and 4.2, it is safe to assume that a Z% of the components required their final (third) operation on this machine. This machine may be found to be more under utilized even than that of the second operation machine tools.

The same procedure and formulas devised to test the improvement of the secondary operation machine utilization can be applied to this machine replacing Y% by Z%.

It is important to reach a level, in the case of cell design containing primary, secondary and other machines (which represents the majority of industrial cases), where the utilization of the so called minor machines can be a decisive factor in the choice of cellular manufacture both technically and economically. Once an acceptable level of machine utilization has been established all machine tools below that level should be considered to be investigated for improvements on the existing level.

The increase or decrease in the value of machine utilization does not necessarly follow a direct increase or decrease in quantity only as traditionally thought, but equally important are components to machine distribution (loading), machine to cell arrangements (plant layout), product mix, machine or cell reshuffle, design alterations..etc.

Many criteria have to be considered to determine the most economical cell and the best way to start is by determining a number of cell solutions for the same machine tools using the same GT method or different methods, so that a unit cost comparison can be carried out to choose the best solution.

The results which can be obtained from these projected comparisons can provide engineers and managements with a comprehensive and convincing conclusion. The accuracy of those conclusions will depend entirely on the methods chosen to calculate and illustrate all the necessary data leading to the choice of the most feasible cell. The inclusion of machine utilization factors, product mix and quantity ratios, machine reshuffle and quantity manipulations is highly recommended as shown through-out this chapter and can give help to establishing well controlled data to provide the basis to determine the most feasible cell.

4.4. Summary:

Cell formation can be summarized as follows:

By operation (process)	1st Operation	2nd Operation	3rd Operation
Classification (e.g.PFA)	machine	machine	machine
By Coding & Classification	1st,2nd & 3rd	4th	5th
(e.g. Opitz Code)	digits	digit	digit
By Machine Tool			
Classification	Lathe work	Mill work	Drill work

This is an over simplification of cell formation as a manufacturing method and the method is not exclusive to drilling or milling but any other production machines will fit the procedure.

The main two known methods of establishing cells are P.F.A., and the coding and classification with production data analysis. Both methods claim their advantages and each others disadvantages.

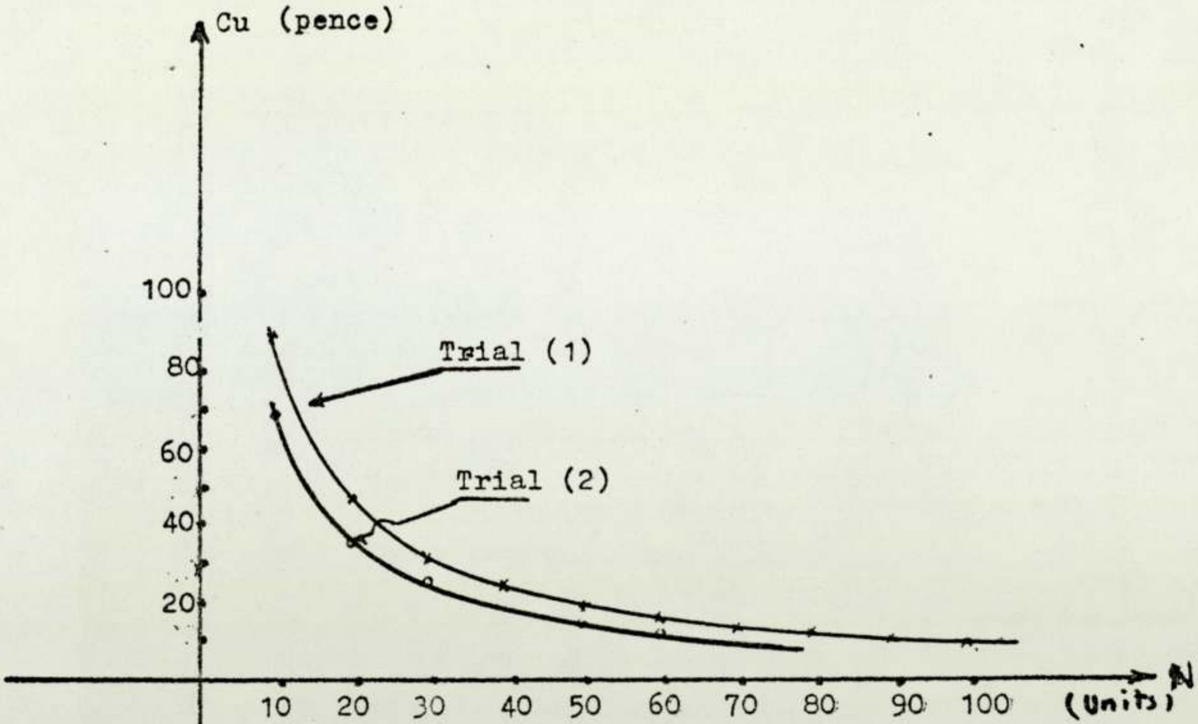
4.5. Illustrations Of The Basic Points Raised Through This Chapter:-

To illustrate the procedure proposed in this chapter a small example was taken from G. Kruse's (18) feasibility study for the implementation of GT system in a multi-product company. The report presented by G. Kruse covers the following stages of fundamental GT analysis:

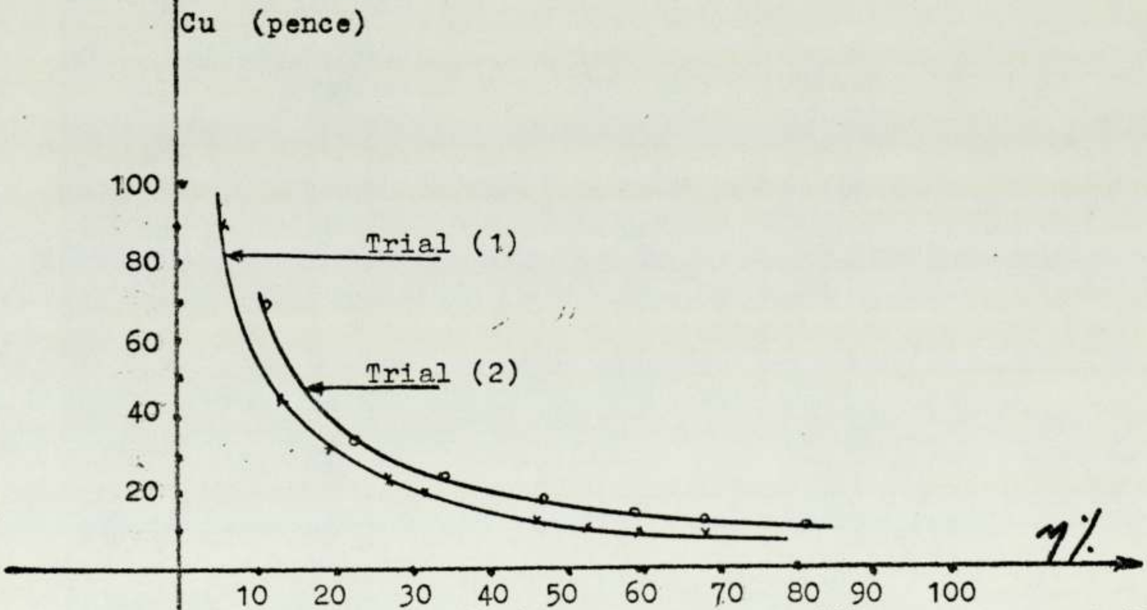
i) review of the plant and its problems to test its GT suitability.
ii) assessment of objectives and predictions of financial benefits .
iii) the analysis of the total component spectrum
    a) to design the overall cell layout of the plant.
    b) to design a prototype cell.

The case study reached a conclusion to its objective that of establishing a number of cells to manufacture certain ranges of company's components. Two trials of family formation of the sample under consideration (T_1) trial one (T_2) trial two - was under taken; Total quantities of components produced are 73606 units and 65280 units respectively. During the first trial the cell manufactures families one and eight, ($F_{1,8}$) when the family formation was reshuffled the second trial included new families of one, eight and twenty ($F_{1,8,20}$). The quantity ratio was developed for every component related to the total imput of units for both trials. To establish a quick form of unit cost comparisons, a general form of, unit cost=(variable cost + fixed cost per quantity); ($C_u = V + F/_N$) was selected and quantity was expressed in terms of quantity ratio and machine utilization as shown previously in this chapter (section 4.1. and 4.2.).

To determine the choice of the best trial G. Kruse (18) has not attempted to compare unit cost between trials, but has reshuffled the quantities as a method of reaching a better product distribution per cell. The author of this thesis has take the advantages of the existence of the data and has concluded from fig $(17)_a$, (unit cost to quantity relationship) that the second trial is more economical; however from fig $(17)_b$, (unit cost to utilization) the first trial gives a more economical range of machine utilization, from fig (18) (for each individual machine) that has been classified at the beginning of this chapter, sections (1,2,3) and for the same utilizations, the results are as follows:-



a) Unit Cost (Cu) To Quantity (N)



b) Unit Cost (Cu) To Utilization (η) Average Per. Cell.

FIG.(17) Unit Cost Comparison Between Trials 1 & 2.

For all machines in the cell. (table (16).)

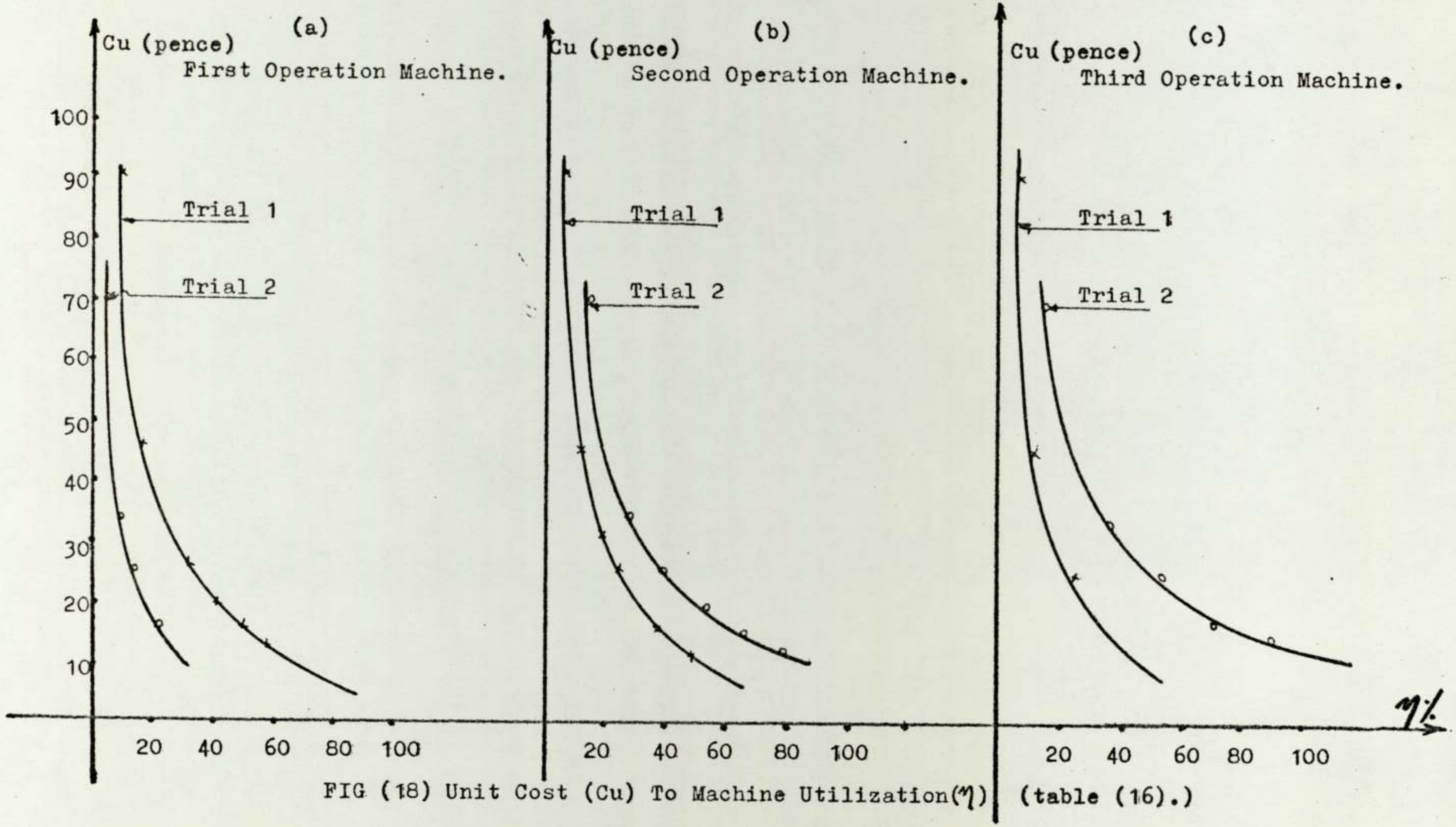


FIG (18) Unit Cost (Cu) To Machine Utilization(η) (table (16).)

a) First operation machine 1st trial is more economical.

b) 2nd operation machine 2nd trial is more economical.

c) 3rd operation machine 2nd trial is more economical.

The improvement of the second and third operation machines is apparent from the graphs after component reshuffle, table (3) (T_2). The improvement in those machines was counter balanced by the rise in unit cost of the first operation machine fig (18). On the average cell utilization trial one (T_1) gives a better unit cost for the same utilization. table (16).

The results above can be summarized as follows:-
For the same quantities and utilization:

	Trial one (T_1)		Trial two (T_2)
Unit cost to quantity	Cu_1	higher than	Cu_2
Unit cost to utilization	Cu_1	higher than	Cu_2
Utilization to quantity	θ_1	higher than	θ_2

The results are illustrated by three dimensional figures fig (19) and fig (20). These results are exclusive to this particular exercise, but the same procedure could be used for different cases and of course may produce different results.

In general terms the results can be clarified by stating that for the same unit cost, (T_1) has a higher quantity input and lower machine utilization compared to (T_2), in other words (T_2) which has a slightly lower quantity input has an improved machine utilization range. If quantities are the main

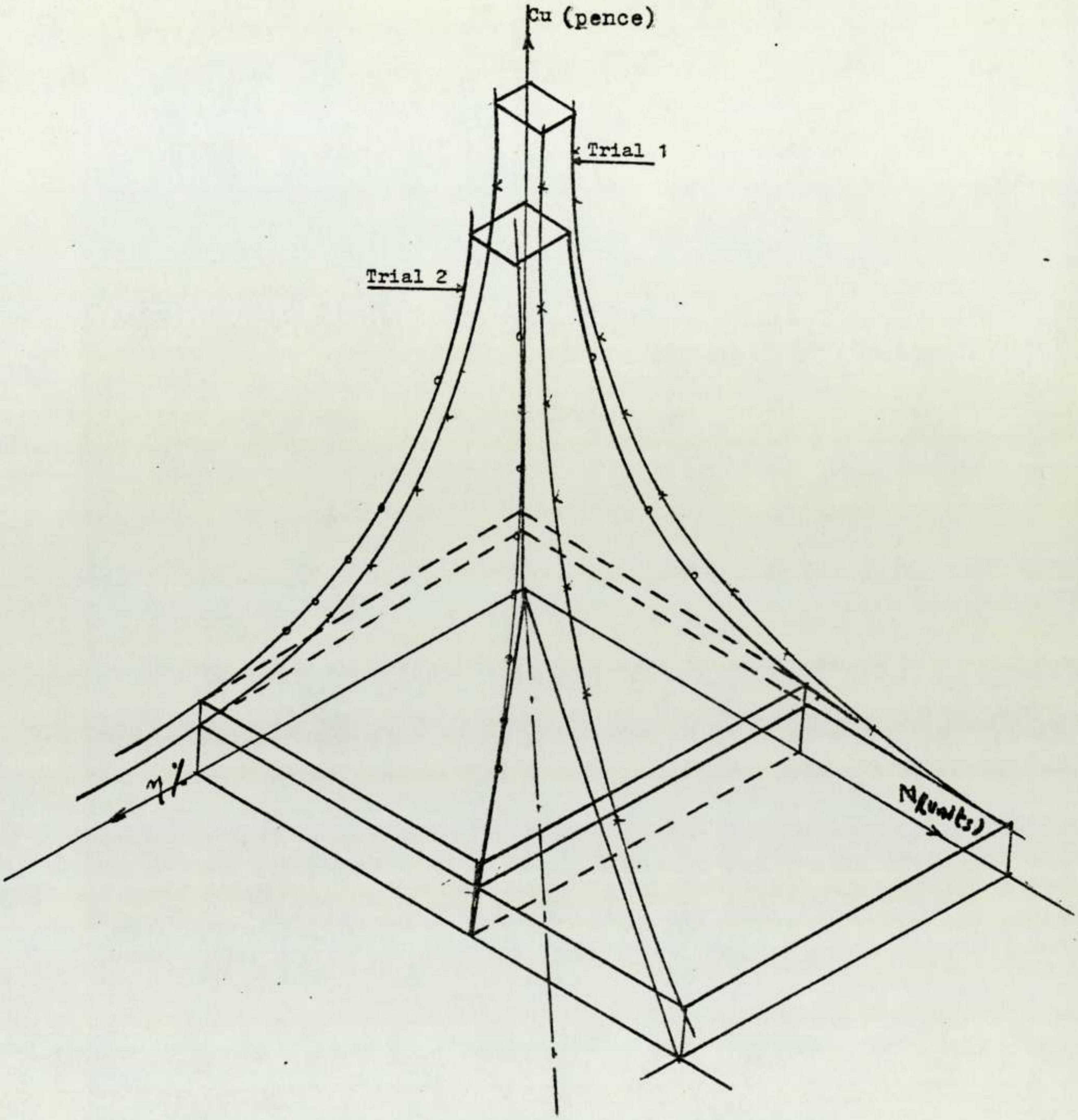


FIG (19) Unit Cost (Cu) To Utilization (η) To Quantity (N) Of Trials 1 & 2 For The Cell.

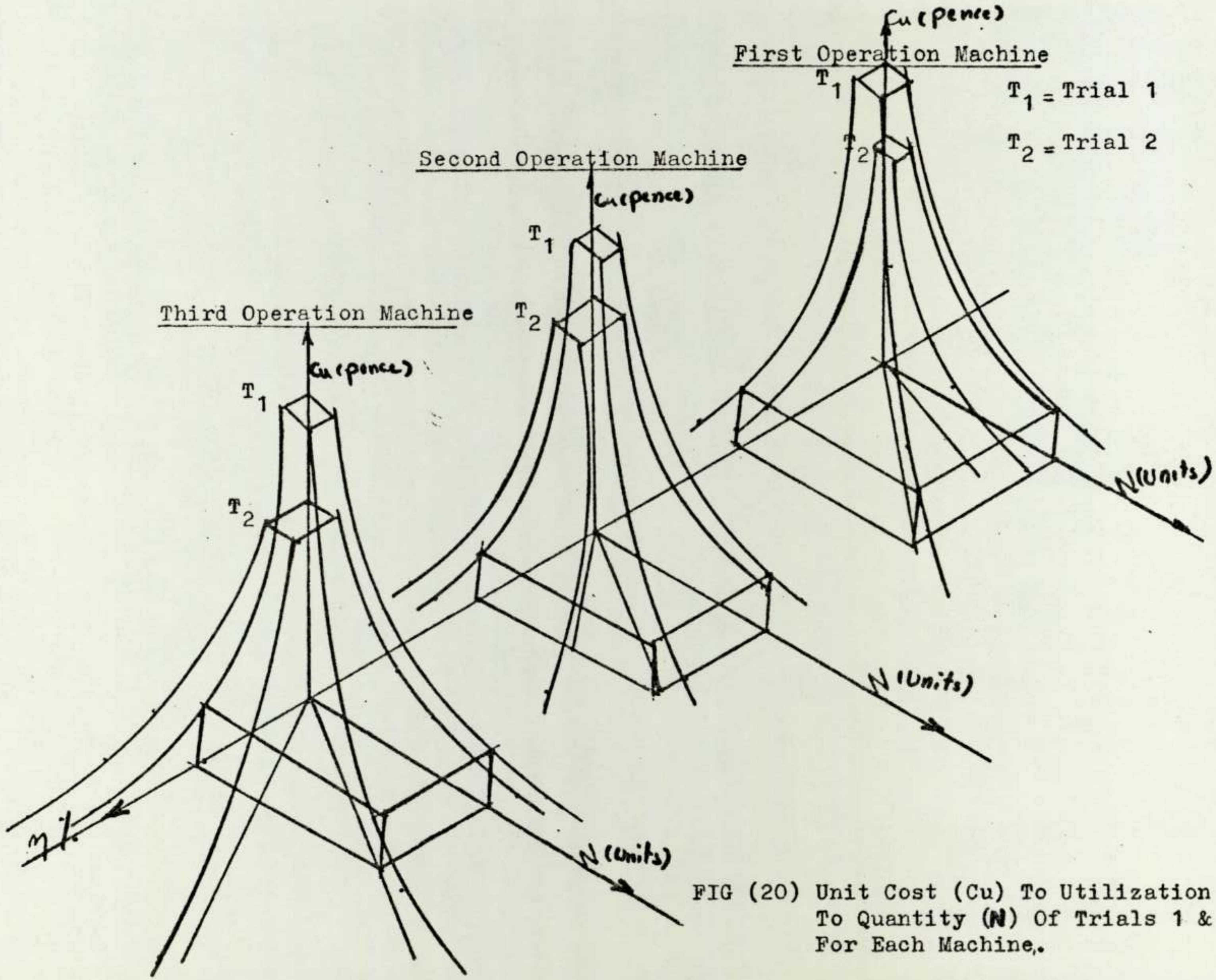


FIG (20) Unit Cost (Cu) To Utilization (η) To Quantity (N) Of Trials 1 & 2 For Each Machine.

factor then (T_1) should be chosen; The choice of (T_2) gives the emphasis to utilization with a good product mix. fig $(18)_a$, $(18)_b$ and $(18)_c$. To illustrate the variation in the utilization of primary, secondary and final machine tools in the cell, figs (18) and (20) shows that while imput quantities were reduced, second and final machine utilizations have been improved with an improvement in unit cost. The primary machine tool had suffered reduction in utilization but the overall utilization of the cell and the unit cost of components produced have been improved fig (19).

CHAPTER 5

PROPOSED METHOD OF FAMILY AND CELL FORMATION.

5.0. Proposed Method Of Family And Cell Formation.

The existance of the part to machine matrix, which can be created in most group technology investigations, prompted the idea of a better way of establishing machine and family groupings on the same basis of production flow analysis described by "Burbidge":

He stated that production flow analysis (P.F.A.) was "concerned solely with methods of manufacture". It does not consider the design features or shape of components. This method is concerned with the change to group technology by first changing to group layout with the existing methods and with the least possible investment in new plant. While the component classification method finds families and then creates cells to manufacture them, P.F.A. defines both the families and cells at the same time.

Different methods of finding groups of machines and components have been devised and computers have been introduced to speed up the solution.

In this thesis the use of Clusters is proposed which will result in establishing a number of solutions where families and cells are defined. The problem is to find a way by which the best solution is chosen. From the existing technical information such as operation sequence, balancing, transportation and plant layout, a fair criterion can be devised to choose the best solution.

The problem of establishing a criteria by which to find the best solution from a given set for any and every problem of this type proved a difficult task since each application is likely to have its own peculiarities. The thinking was devoted therefore to finding a criteria which would be a common denominator to most manufacturing industries i.e. unit cost. The first step though, is to define the solutions of group of components and machines from the given data.

5.1. Back Ground To The Use Of Cluster Analysis To Form Cells:-

Taxonomy is defined by Sneath (41) as "the theoretical study of classification, including its basic principles, procedures and rules". Taxonomy, like classification has been used to distinguish the end products of the Taxonomic process. Where classification is defined as "the ordering of objects into groups (or sets) on the basis of their relationships, that is of their associations by contiguity, similarity, or both" (41). To make the definition general the term objects have been chosen deliberatly as this method is widely used in many fields such as biological science, ecology, physiology. For the purpose of this research objects will be defined as machines and/or (parts) since this study is involved in the classification of machine and/or (parts) into useful groups.

Numerical taxonomy can therefore be defined as the "numerical evaluation of the affinity or similarity between taxonomic units and the ordering of these units into taxa on the basis of their affinities". The outstanding aims of numerical taxonomy are repeatability and objectivity. It is hoped that by the use of numerical methods to approach the goal two researchers, working independently will obtain accurate and identical estimates of the resemblance between two forms of objectives, given the characters on which to base their judgement.

The estimation of resemblance is the most important and fundamental step in numerical taxonomy. It starts with the gathering of information about characters in the taxonomic group to be studied. The required information may exist and merely need extraction from records or it may have to be defined from new, or, as in most instances both cases will need to be applied, for to obtain reliable results many characters are needed. Care should be taken into examining the facts of the choice of characters and guard against the characters which are not an accurate expression of the properties of the objects. A taxonomic character can be defined as "any attribute of an object or of a group of objects by which it differs from an object belonging to a different taxonomic catagory or resembles an object belonging to the same catagory". (41).

The actual computation of a measure of affinity can be done in a variety of ways. Most methods result in coefficients of similarity section (5.2.) ranging from unit (100%) for total similarity to zero for none at all. Except in small cases calculations are long and tedious and the use of computers will be needed.

Classification in numerical taxonomy is based on a matrix of resemblance, and it consists of various techniques designed to disclose and summarize the structure of the matrix. A rough, graphical representation of the structure can be obtained by differential shading of the elements of the matrix. In this manner the structure of the assembly of taxonomic entities becomes immediately apparent if they have previously been roughly grouped so that supposedly similar forms are near each other. Computational methods of clustering can also be used to process the data equally efficiently whether they are ordered or not, which should be preferable, section (5.2.).

The most convenient way of representing the results of numerical taxonomy is by graphical representation in the form of a dendrogram section (5.2.). The abscissa of such a graphical shape has no special meaning only to separate the objects names. while the ordinate is in some similarity coefficient scale ranging from zero to one (e.g. fig (22) .

From the dendrogram groups of objects can be extracted at different levels of similarity coefficients and information about the objects should be recorded in relation to those results. From this, specimens can be identified to their group quite easly.

The main charactaristic of adopting numerical taxonomy principles for this particular case in hand centres on the P.F.A. system and the use of part to machine matrix from job cards and company records. The already existing information about the functional properties of parts and the machines used to manufacture them is the most encouraging factor into integrating numerical taxonomy ideas to be used for family and machine grouping. Once a part to machine matrix have been set, all the information needed to create machine groups and part families from a P.F.A. stand point are there. The calculation of similarity coefficients for every pair of machines has been based on the criteria of the visits of parts to machines or machines visited by parts. see chapter 7 section(7.3.1) for definition. Once the similarity coefficients are derived the grouping can start by the use of a clustering method. The major difficulty which has been encountered during the research is that, while in most cases of biological and ecological studies the attributes are of fixed and equal magnitude, they vary considerably in the cases of machine and part grouping i.e. when comparing between two machines at one extreme a machine can be visited by one part, while the second machine to be paired with might have 300 parts visiting it. Careful consideration should therefore be given to the method of computer read and write formats which may have to be modified for different test cases to overcome the difficulty of using existing computerized numerical methods for pairing machines.

The cluster computer programme which has been used by McAuley (40) was to stablish inter group journeys and plant lay-out and this programme has been further used and developed in this project fo cell formation.

The existing clustan programme available to this method has a restriction of attributes which can be processed and, as most of industrial cases by far exceed the number of attributes allowed (250 attributes max), the programme has to be modified and the core enlarged to accept larger samples.

Other programmes apart from the one used are in existance in different forms e.g. algorithms but while one clustan processes the whole problem from establishing similarity coefficients (from part to machine matrixis) to producing dendrograms, the others process each part of the procedure independently and hence in comparison can be quite expensive to use.

There are many different types of coefficients in use to compare two objects, apart from similarity coefficients, such as distance coefficient and they are determined for use according to the need of every case. In this particular case the emphasis is in how similar machines or parts can be to each other. In other cases the grouping might require how apart two machines can be put. Also there are different types of clustering of objects into groups according to their similarities e.g. single linkage, group linkage..etc. Single linkage cluster analysis has been used for this particular case purely because of its simplicity of application. section (5.2.1).

Adopting this method required redefinition and identification of objects from those related to biological science to those related to manufacturing systems and in particular cellular manufacture. The method of calculation and definition of establishing groups of machines and families of components will be fully explored and explained throughout this chapter and is summarized as follows:-

1. Choice of area of research
   (machine and parts)
   (e.g. All factory or a section)

2. Establishment of criteria e.g.
   P.F.A. or Geometrical coding.

3. Setting-up of machine to part
   matrix data.

4. Calculation of similarities
   between machines/parts.

5. Clustering of machines/parts
   into a dendrogram.

6. Identification of distinct groups/
   families from (5).

7. Recording of appropriate machines
   /parts into appropriate groups/
   families.

5.2. Establishment Of Multi Solutions For A Manufacturing System Using Cluster Analysis.

5.2.1. Theoretical Background Of The Numerical Method To Be Employed:

(i) Similarity Coefficients;

The approach adopted, is to calculate for each pair of machines a similarity coefficient which attemps to describe the likeness between the two machines in terms of the number of parts which visit both machines and the number of parts which visit each machine. The same method could be used in arranging families of parts.

The basic arrangement of data for the establishment of the similarity coefficient is two x two matrix as shown below.

Machine or/part j

Machine or/part k	+	−	
+	N_{JK}	N_{jK}	N_K
−	N_{Jk}	N_{jk}	N_k
	N_J	N_j	

The data consists of N characters scored for two machines labelled j and k, and can be aquired from the machine part matrix. In theory (J.K.), capital letter subscript will indicate positive (shown by X as the matrix) when both machines are visited by the same part. The lower case letter subscripts (j.k.), will indicate negative (empty box), when both machines are not visited by any part. N_{JK} therefore is the number of parts which visit both machines, N_{jk} is the number of parts which visit neither machine. N_{Jk} and N_{jK} are the number of parts which visit one machine and not the other respectively. Let the number of characters in matched section $m = N_{JK} + N_{jk}$, and the number of characters in the unmatched section $u = N_{Jk} + N_{jK}$. Then the total number of characters

$$n = m + u = N_{JK} + N_{jk} + N_{Jk} + N_{jK}$$

$$= N_J + N_j = N_K + N_k.$$

The fundamental formula consists of the number of matches divided by a term implying the possible number of comparisons but varying in its detailed composition. In this project the coefficient of Jaccard (Sneath) (41) will be used. The formation is $S_{jk} = N_{JK} / (N_{JK} + u)$. It is clear that $S_{jk} \rightarrow 0$ as $N_{JK}/u \rightarrow 0$ and $S_{jk} \rightarrow 1$ as $u/N_{JK} \rightarrow 0$. This similarity coefficient, S_{jk}, as shown above omits those parts which do not visit either machine. It is the simplest of the coefficients in its class. The number of positive matches i.e. parts which visit a particular machine (as seen from any machine/part matrix) is small compared to the total number of components. Also the number of rematches i.e. components visiting neither machines, is large compared to those visiting both machines. If the large number of those parts visiting neither machine (compared to the small number of the parts visiting both machines) are incorporated in the similarity coefficient it would give an artificially inflated factor. A comparison between all possible coefficients are possible as shown by Sneath.

A measure of similarity is very important in establishing groups of machines and parts by clustering. A number of different solutions at different levels of similarities is expected.

ii) Definition Of Cluster Analysis:

This general term means a large class of numerical techniques for defining groups of related machines (parts) based on high similarity coefficient.

There are different types of cluster analysis some of which are:-

a) Elementary cluster analysis: This is the simplest form of clustering. It consists of arbitrarily selecting a level on the scale of similarity coefficients. All coefficients above this level are written down and the relationship expressed by the coefficients are indicated by lines or links connecting the machines (parts), which are represented as points because of the possibility of overlapping clusters, this kind is generally an unsatisfactory procedure.

b) Single linkage cluster analysis: This method clusters together those machines (parts) which are mutually related with the highest possible similarity coefficient, then it successively lowers the level of admission by steps of equal magnitude. The admission of a machine (part) or a cluster into another cluster is by the criterion of single linkage. If a similarity level of y% would admit a machine (part) into cluster, a single linkage at that level with any member of that cluster would suffice to warrent admission.

c) Complete linkage cluster analysis: This method is similar to the previous one, except that admission of a machine (part) is by the criterion of complete linkage. A given machine (part) joining a cluster at a certain similarity coefficient must have relations at that level or above with every member of the cluster.

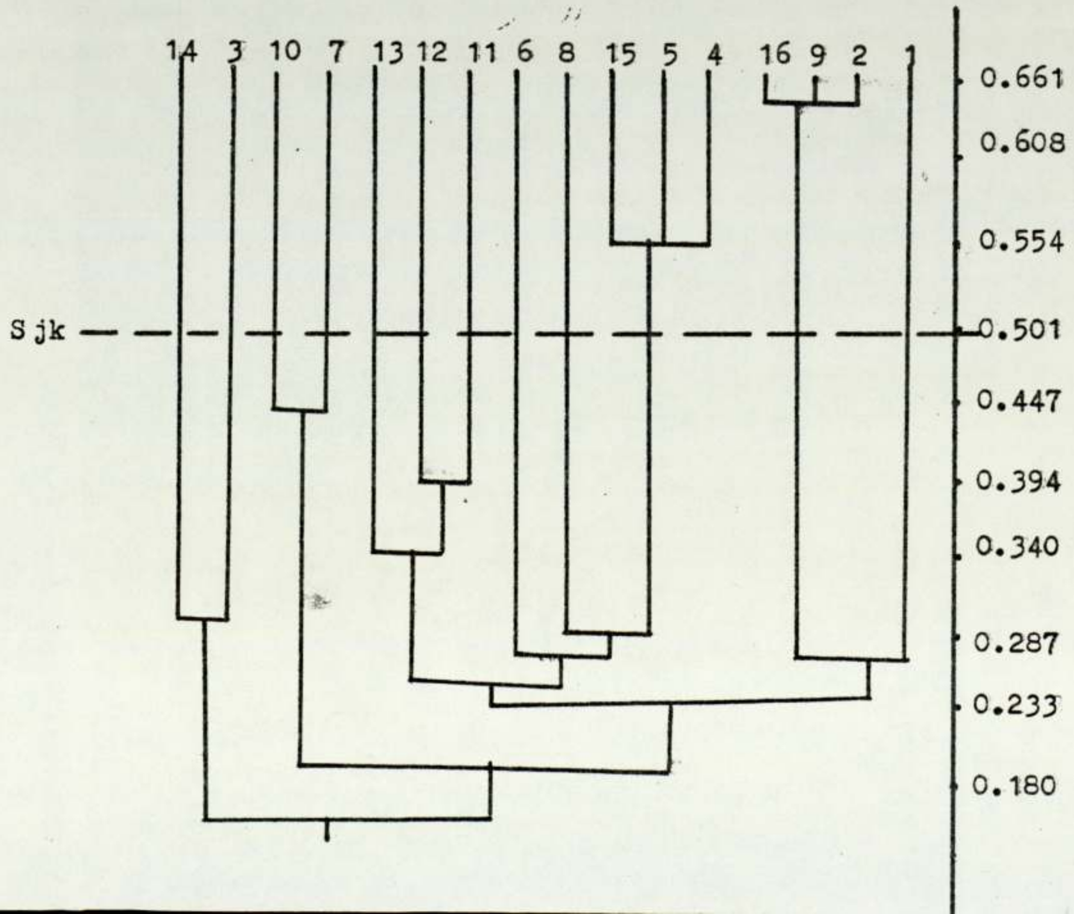
d) Average linkage cluster analysis: This method can be applied to all types of similarity coefficient matrices. Admission of any individual into a cluster is based on the average of the similarities of that individual with individuals already in the cluster. The method permits only one machine to join a cluster (or two clusters to come together), during any one computational cycle. This method will occupy a lot of time due to the recalculation of the similarity matrix at the end of each computation cycle.

From previous studies and suggestions, also due the lack of time to test all methods, the single linkage clustering analysis method with the coefficient of Jaccard (Sneath) has been adopted for this study.

A method of comparison and evaluation of clustering techniques is possible and could be a useful exercise.

iii) Representation And Summation Of Results:

The most convenient and common representation of results is on a dendrogram. The absicca has no special significance, only to separate and identify the machines, while the ordinate is in some similarity coefficient scale (usually 0 : 1.000) as shown below. Points of junction between stems along such a scale mean that the resemblance between the two stems is at a similarity coefficient value shown on the ordinate. If a horizontal line is drawn across the dendrogram at an S_{jk} per cent similarity coefficient then there exists different solutions at that level.



5.2.2. Method Of Computing Groups Of Objects By Hand For Small Cases.

It will be very helpful to devise an illustrative example, to show step by step the method of computing. For small problems a manual method is adequate but for large problems computer programming is advizable.

Supposing this small machine/part matrix has been presented for analysis

Machine \ Part	1	2	3	4	5	6
1		X		X	X	
2	X		X			X
3		X		X	X	
4			X			X

Calculation Of Cell Formation.i.e. Machines.

1. Similarity coefficient using Jaccard (Sneath) method.

$S_{jk} = N_{JK}/(N_{JK}\ u)$

$S_{1,2} = \frac{0}{0+6} = 0$; $S_{1,3} = \frac{3}{3+0} = 1$; $S_{1,4} = \frac{0}{0+5} = 0$;

$S_{2,3} = \frac{0}{0+6} = 0$; $S_{2,4} = \frac{2}{2+1} = 0.667$;

$S_{3,4} = \frac{0}{0+5} = 0$;

	1	2	3	4
1	1	0	1	0
2	0	1	0	0.67
3	1	0	1	0
4	0	0.67	0	1

Because the similarity coefficient matrix will be a mirror image, above and below the diagonal ($S_{jk} = S_{kj}$), only a triangular matrix of the similarities with the leading diagonal value omitted is calculated. If there are N machines (parts) the number of coefficient to be calculated is $\frac{1}{2}N\ (N-1)$.

2. Single Linkage Cluster.

From the above calculated similarity matrix the following fusion point of clusters are established. It starts with R clusters, each containing a single individual, which are numbered according to the input order of indiviuals. In each of (R-1) fusion steps, those two clusters which are most similar are combined and the resulting union cluster is labelled with the lesser of the two codes of its constituent clusters. It has been suggested that the process can be stopped when a significant drop or discontinuity in the fusion coefficient value is observed.

Group 1 fuse points 1 and 3 at similarity coefficient of 1.000 1 2 1 4

Group 2 fuse point 2 and 4 at similarity coefficient of 0.667 1 2 1 2

Group 2 fuse point 1 and 2 at similarity coefficient of 0.000 1 1 1 1

Fusion summary.

1 and 3 at similarity coefficient 1.000

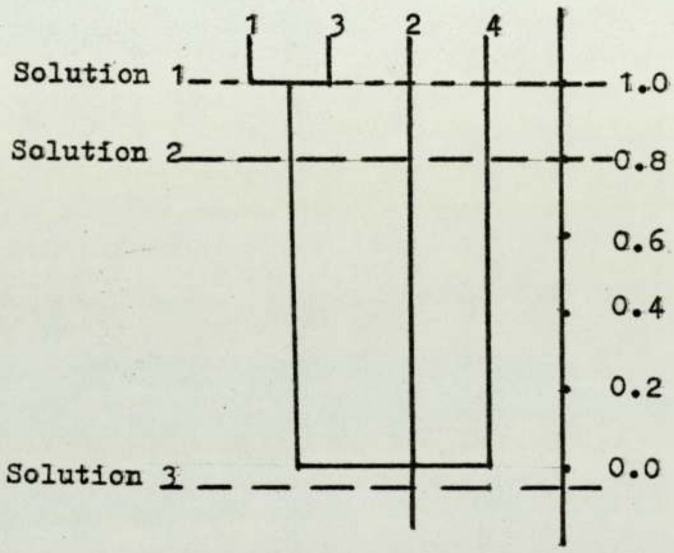
2 and 4 at similarity coefficient 0.667

1 and 2 at similarity coefficient 0.000

From the above results the machine order is 1,3,2, and 4.

3. Dendrogram drawing.

From the information given in 2 a dendrogram of the results can be established. (shown below)



4. Results; By drawing a horizontal line at different levels of coefficient and then gradually lowering it:-

Solution 1. at 100% similarity coefficient there are four cells of machine tools.

C_1, C_2, C_3 & C_4 or each machine represent a cell.

Solution 2. at 80% similarity coefficient there are three cells of machine tools.

(C_1C_3), C_2, C_4. machines 1 & 3 have joined together to form a cell as shown on the dendrogram. Lowering the similarity coefficient value will not group any more machines together for this particular example.

Calculation For Family Formation, i.e. Parts

1. Similarity Coefficient:

$S_{1,2}=\frac{0}{0+3}=0$; $S_{1,3}=\frac{1}{1+1}=0.5$; $S_{1,4}=\frac{0}{0+3}=0$; $S_{1,5}=\frac{0}{0+3}=0$; $S_{1,6}=\frac{1}{1+1}=0.5$;

$S_{2,3}=\frac{0}{0+4}=0$; $S_{2,4}=\frac{2}{2+0}=1$; $S_{2,5}=\frac{2}{2+0}=1$; $S_{2,6}=\frac{0}{0+6}=0$;

$S_{3,4}=\frac{0}{0+4}=0$; $S_{3,5}=\frac{0}{0+4}=0$; $S_{3,6}=\frac{2}{2+0}=1$;

$S_{4,5}=\frac{2}{2+0}=1$; $S_{4,6}=\frac{0}{0+4}=0$;

$S_{5,6}=\frac{0}{0+4}=0$;

1	2	3	4	5	6	
1	0	0.5	0	0	0.5	1
0	1	0	1	1	1	2
0	1	1	0	0	1	3
1	0	0	1	1	0	4
1	1	1	0	1	0	5
0.5	0	0	0.5	0	1	6

2. Single Linkage Cluster Analysis:

Group 1 fuse points 2 and 4 at similarity coefficient. 1.00

1 2 3 2 5 6

Group 2 fuse points 2 and 5 at similarity coefficient 1.00

1 2 3 2 2 6

Group 3 fuse points 3 and 6 at similarity coefficient 1.00

1 2 3 2 2 3

Group 4 fuse points 1 and 3 at similarity coefficient 0.5000

1 2 1 2 5 6

Group 5 fuse points 1 and 6 at similarity coefficient 0.5000

1 2 1 2 5 1

Group 6 fuse points 1 and 2 at similarity coefficient 0.0000

1 1 1 1 5 1

Group 7 fuse points 1 and 5 at similarity coefficient 0.000

1 1 1 1 1 1

Fusion Summary:

2 and 4 at similarity coefficient=1.000

2 and 5 at similarity coefficient=1.000

3 and 6 at similarity coefficient=1.000

1 and 3 at similarity coefficient=0.500

1 and 6 at similarity coefficient=0.500

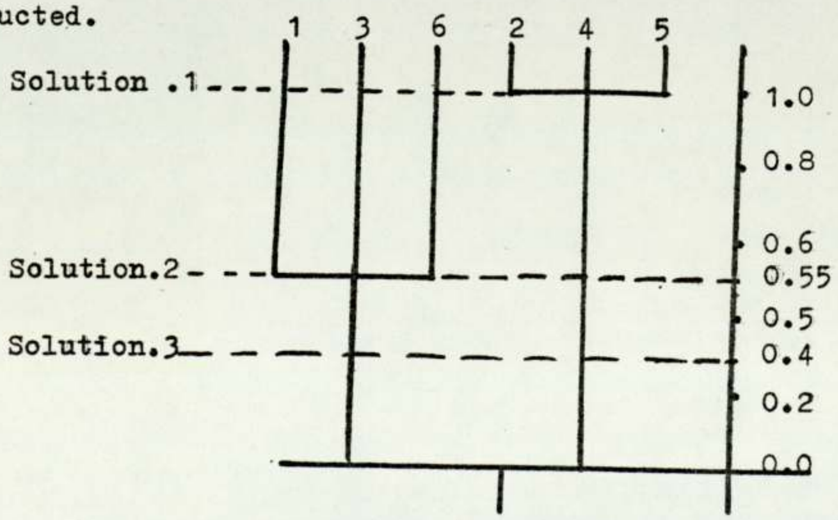
1 and 2 at similarity coefficient=0.000

1 and 5 at similarity coefficient=0.000

From above the sequence of parts is 1,3,6,2,4, and 5

3. Dendrogram Drawing:

From the information given in 2 the following dendrogram can be constructed.



4. Results:

Solution 1. at 100% similarity coefficient, each component represents a family. There are 6 families.

F_1, F_2, F_3, F_4, F_5 and F_6.

Solution 2. at 55% similarity coefficient there are 4 families.

F_1, F_3, F_6 and $F_{(2,4,5)}$.

Solution 3. at 40% similarity coefficient there are 2 families.

$F_{(1,3,6)}$ and $F_{(2,4,5)}$.

Summary Of Results:

Combining the results of cell formation and family formation a new reshuffled parts to machine matrix can be constructed.

	1	3	6	2	4	5	
1				X	X	X	Group 1
3				X	X	X	
2	X	X	X				Group 2
4		X	X				

Family 1 Family 2

Conclusion:

As can be seen from the summarized machine part matrix two cells are formed (machines 1,3) and (machines 2,4), the first cell is assigned to manufacture family one (parts 1,3,6), and the other cell will manufacture family two (parts 2,4,5). The grouping of machine 2,4 occurs at similarity coefficient of zero.

5.2.3. Method Of Computing Groups Of Objects With The Aid Of Computers (For Large Cases)

Although in general many programmes have been devised to group machines and components in this project the interest is concentrated on "Clustan". Programmes that are written-up for cluster analysis should contain.

1. Description of the general idea of the programmes capability.
2. Descriptions of the maximum capacity of the programmes i.e. number of machines and components.
3. Description of the mathematics of the model to be used.
4. Descriptions of details refering to operating instructions for the particular component.
5. Description of output format of the data.
6. Description of output format of the results.

Illustrative examples for execution, input and output are added for new readers.

The programme used in this project is UACLUSTANC, and (42) basically uses the idea described in section 5.1.1. It is described as a suite of fortran programmes designed for the collective study of several methods of cluster analysis. UNCLUSTANC will allow several programmes to be run within one job.

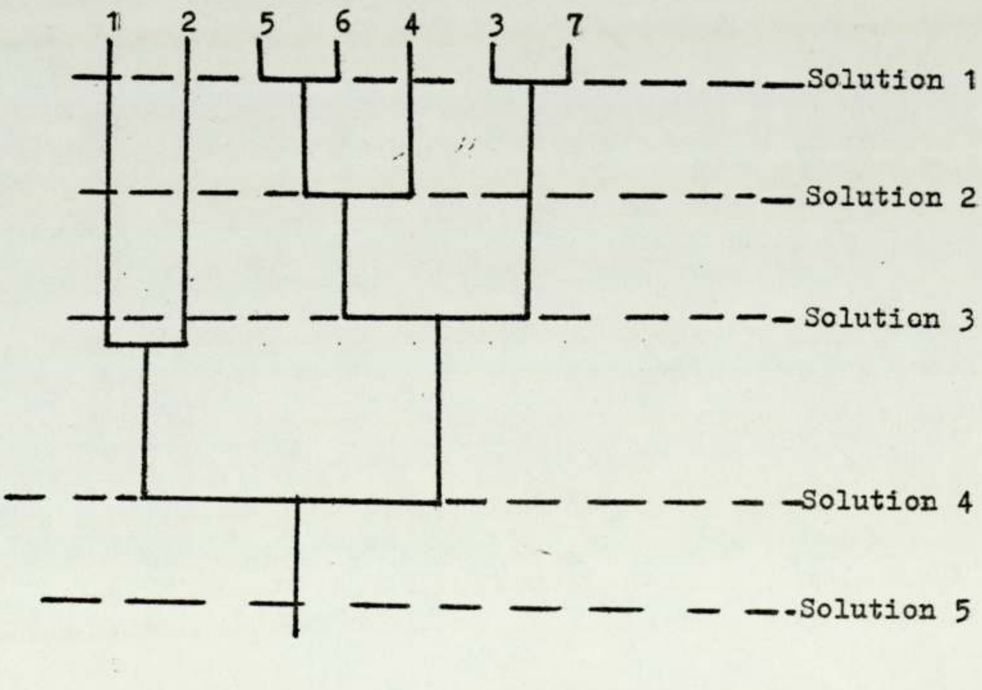
The first programme of this package is A.T.F.I, which reads row observation data and stores it on the common disc-file. It also computes the principal component analysis and other basic statistics. All the input and computed results are stored on the disc file. The row data is listed, read in and may be used for checking purposes. Both continuous and binary data is accepted separately or mixed.

The second programme is A.T.C.O, which computes the similarity matrix and clustan linkage lists from all or part of the data from the data file created by A.T.F.I.

Programme A.T.R.I. is the third programme and is specifically designed to output part of the data, such as, computed statistics, coefficient matrix..etc.

The last programme is called A.T.H.A, which consists of two main parts. Firstly the programme starts with N clusters, each containing a single individual, which are numbered according to the input order of the individuals. In each of (N-1) fusion steps, those two clusters which are most "similar" are combined and the resulting union cluster is labelled with the lesser of the two codes of its constituent clusters. Secondly when the programme completes all (N-1) fusions, it summarizes the sequence in a dendrogram graph which is outputed on the graph plotter. The programme works from the similarity matrix data produced by A.T.C.C. For full details see worked example in Appendix (1).

The main results of interest to this project is the sequence or order of the objects according to their similarity. It is very important to point out at this stage that the criteria from which two objects can be declared similar or have similarities should be decided before any data is loaded onto the programmes. A result which can be useful is the percentage occurance for binary variables and the binary variable frequency. From the dendrogram a number of solutions can be obtained by establishing horizontal lines at different levels of similarity coefficient ratios, as shown below and for further illustrations see Appendix (1).



CHAPTER 6

COST ELEMENTS ASSOCIATED WITH GROUP TECHNOLOGY.

6.0. Cost Elements Associated With Group Technology.

6.1. Cost Of Introducing GT.

With all the benefits claimed of GT it is very important to take steps to find whether the system is suited to a particular company seeking production improvement. The cost of introducing GT is a very important factor to consider when a company decides to consider a GT system and although this particular study is only concerned with manufacturing costs it is valuable to bare in mind this cost. Gombinski (3) believes that ignorance of the cost of introducing GT are a major stumbling block. This would, infact, appear to be one main reasons why GT has not been introduced, or has been slow to be accepted. This is not entirely surprising for, as is pointed out by Connolly (45), and Edwards (22) even in the best of circumstances the true cost can be impossible to calculate, either for reasons of the erronous nature of information from costing departments, or because the cost is an obscure one, difficult to quantify, and may be offset by some saving as a direct result. For instance savings in storage space due to lower w.i.p. may be offset by extra plant which has to be purchased, ..etc.

The recommended stages of introducing GT as suggested by the GT centre (24) is as follows:

i) A preliminary survey of potential

ii) Establishment of pilot machine group

iii) Full introduction

The costs includes:

a) Selection of component families and machine groups by classification and coding and production data or production flow analysis.

b) Alterations to the machine shop and the cost of studying the possibility of introducing GT can be quantified to:

$$\left\{\frac{\text{Salary of engineer}}{\text{Days worked/year}}\right\} \text{X (No of team members) X} \left\{\begin{matrix}\text{No of days of} \\ \text{Exercise}\end{matrix}\right\}$$

6.2. Other Costs For Comparisons (Storage And E.G. Manufacturing Costs)

The aim is to formulate to minimise the unit cost produced under GT systems in comparison to that produced through conventional or other methods.

The total cost of manufacturing a component (unit) can generally be formulated to equal fixed cost of ordering a quantity into production plus variable costs which include items such as material, labour, storage, set-up, wip, capital cost tied up..etc.

Therefore costs associated with storage and manufacture can be formulated as follows:-

(Cu) total unit cost = storage + progressing + production

$$= (K_r x Q) + (K_f x Q) + (F/_Q x V)$$

where K_r Fixed cost rate related to finished product storage.

K_f Fixed cost rate related to raw material storage.

F Total fixed cost related to the rest of the plant.

V Avarage variable cost per component (unit).

$$Cu = (K_r + K_f)Q + F/_Q + V$$

$$\frac{\partial Cu}{\partial Q} = K_r + K_f - F/_{Q^2} = 0 \text{ (to minimize)}$$

$$K_r + K_f = F/_{Q^2}$$

$$Q = \sqrt{\frac{F}{K_r + K_f}}$$

Where (Q) can be termed as the economic (batch) quantity for this particular study consideration will only be given to the part of the cost where the general formulation of unit cost = (Fixed cost/quantity + variable cost). The formula and the make up of its terms will be discussed indetail in chapter (6).

6.3. Unit Cost As A Method For Comparison:- Ref (50).

Part of the principle of group technology as a complete manufacturing system involves the devision of the shop floor and its manufacturing activities into a number of cells or groups of machines. Each is engaged in a network of processing and manufacturing operations producing many units of different types of components which are assembled into catagories of marketable products to the inevitable variations in production rates on each job and the relative similarity of dimensions, size, functional properties etc..of each component families may be formed. Through the establishment of permissible zones of variability which are designed to ensure the effective integration of all activities and components conforming to these boundaries. This approach involves a fundamental shift from direct concern with each unit of each resource used directly in making each component of each family to direct concern with the average amount of each resource used directly in making the average component of each family. Under such conditions there is a shift from the measurement of the actual cost of each component to the average cost of the average component of each family.

Theoretically the average direct unit cost, might be determined by measuring the actual direct costs for every single unit of family produced in a given operation and then averaging these. This is not the procedure in common use, Instead, what is done is to measure the total costs of each direct resources used in a operation during a given period of time and then dividing these totals by the number of units produced during that period, even at the level of single operations, average direct unit cost really represent a relationship between total costs and total output rather than an average of the actual costs of each unit of output.

Two points have to be made here one is that unit costs firstly represent statistical averages rather than determinations of the actual cost of producing each unit of output, and secondly, that unit cost actually represents a relationship between total costs during a given period and the volume of output during that same period.

Unit cost can accuratly be used, when introducing family formation and cellular manufacture, in establishing the zone of variability or ranges of families, which are designed to ensure the effective integrations of all activities and the components conforming to these boundaries (e.g. a cell). The same principle can be applied for those very well defined families of which the measurement of the average cost of each direct input in the average component of each family is required.

Set-up times, batch size, product mix, machine utilization and production volume can be considered the most important items in establishing and manipulating unit cost for comparison.

Unit cost can be divided into:

a) fixed cost which will, in total, remain fixed during changes in production volume and the rate per unit will consequently vary.

b) variable cost which will remain constant per unit of productions but vary in total.

Variable cost carries the big part of unit cost and includes items such as direct labour, direct material and variable overheads. Direct material cost can be determind from raw material cost records and is the easy part of the variable cost. Direct labour and variable overheadson the other hand are quite difficult to ascertain and careful consideration should be given to the method of establishing these costs.

Even though the variable part of the unit cost does not vary with changes in volume (quantity), it is very important to ascertain these costs accurately to obtain a good data to use for unit cost comparison. This part of the unit cost can be ascertained for each component for example, so items such as set-up time, batch quantity, production mix, utilization and/or their variation through different production periods would be taken into account.

To illustrate the effect of overhead costs in a cell situation the following example can be used which takes into consideration set-up time and batch quantity.

$$Cu = \left\{ \Sigma t_c + \frac{\Sigma t_s}{Q} \right\} oh + C_o/_Q \quad (44)$$

is the general unit cost formula.

where C_u Unit cost.

Q Production batch quantity.

t_c Cutting time.

t_s Set-up time.

oh Variable cost rate.

C_o Fixed cost of ordering a batch into production.

If $$C_{u_1} = \left\{ \Sigma t_c + \frac{\Sigma t_{s_1}}{Q_1} \right\} oh_1 + C_o/_{Q_1} .$$

is the unit cost formula for conventional method.

and $$Cu_2 = \left(\frac{\sum t_c + \sum t_{s_2}}{Q_2} \right) oh_2 + C_{o_2/Q_2}$$

is the unit cost formula for cell system.

Cell system is assumed to be an improvement to that of the conventional method.

or $$C_{u_2} < C_{u_1}$$

$$\left(\frac{\sum t_c + \sum t_{s_2}}{Q_2} \right) oh_2 + C_{o/Q_2} < \left(\frac{\sum t_c + \sum t_{s_1}}{Q_1} \right) oh_1 + C_{o/Q_1}$$

for the same batch quantities:

The variable cost for cell system < variable cost for conventional.

Another example of unit cost is:

Unit cost $= M + W + (D_m + M_m + T_o + F_o + P_o + N_p)$ (43)

where
M Material cost per unit.
W Labour cost per unit.
D_m Machine tool depreciation cost/unit.
M_m Machine tool maintenance cost/unit.
P_o Expenditure of power/unit.
F_o Expenditure of jigs and fixture/unit.
T_o Tooling cost/unit.
N_p The rest of overheads.

The aim is that when introducing GT the following condition shall apply - Unit cost of cell system < Unit cost of conventional method

or $$M_2 + W_2 + (D_m + M_m + T_o + F_o + P_o + N_p)_2 < M_1 + W_1 + (D_m + M_m + T_o + F_o + P_o + N_p)_1$$

Many existing methods of calculating variable costs can be adopted to be used in cellular type of manufacture. When considering a cell, comprising a group of machines as a cost centre, it's likeness to a miniature factory makes a meaningful situation for calculating cost centre rates, on the same lines, as in the conventional way, to establish the variable cost. Some of the methods which can be followed are:-

1. Calculation of change over points when for example comparing between two cells capable of producing a product/family (44).

	Production time (min)		Unit cost £/unit					
			labour		variable		material	fixed
	t_c	t_s	L_r	L_u	oh	O_u	M_u	F/Q
Cell† 1.								
Cell† 2.								

Where t_c & t_s Cutting and set-up times respectively.

L_r Labour rate/time unit.

L_u Labour cost/unit.

oh Variable overhead rate/time unit.

O_u Variable overhead cost/unit.

F Fixed cost/Q number of units.

(†) A cell can be one machine upwards.

2. Analysis of variation in product unit cost. (51)

Items of cost classified by factors causing costs to vary.	Range of unit cost for batch[+] size of Q_1 components to Q_n components.								
	Cell[x] 1			Cell[x] 2			Cell[x] 3		
	M/C1	M/C2	M/C3	M/C1	M/C2	M/C3	M/C1	M/C2	M/C3
Items unaffected by volume change; material labour miscellaneous & process									
Items affected by volume change: product tooling									
Items affected by batch size: set-up time/(labour)									
Items affected by machine utilization part & machine charges									

(+) If the costs have been derived for total manufacturing quantities it would be necessary to assume an average batch size for each component so that the number of set-ups, and hence setting labour cost, could be determined for each total manufacturing quantity.

(x) Cell can be one machine upwards.

3. Product cost estimate summary for group technology method of production (52).

Description: type of product QTY:

Family one During period of: e.g. 1st qtr.

Cell or (M/C)	Operation discriptions	Production time		average variable cost £					fixed £ cost
		t_c	t_s	L_r	L_u	oh	O_u	M_u	F
1	Cut off								
2	Upset								
3	Centre								
4	Thread								
.	Drill								
.	Heat treat								
.	Finish								
.	Inspect								
.	.								

Where t_c & t_s Cutting and set-up times respectively.(minutes)

L_r Labour rate/time unit.

L_u Labour cost/unit.

oh Variable overhead rate/time unit.

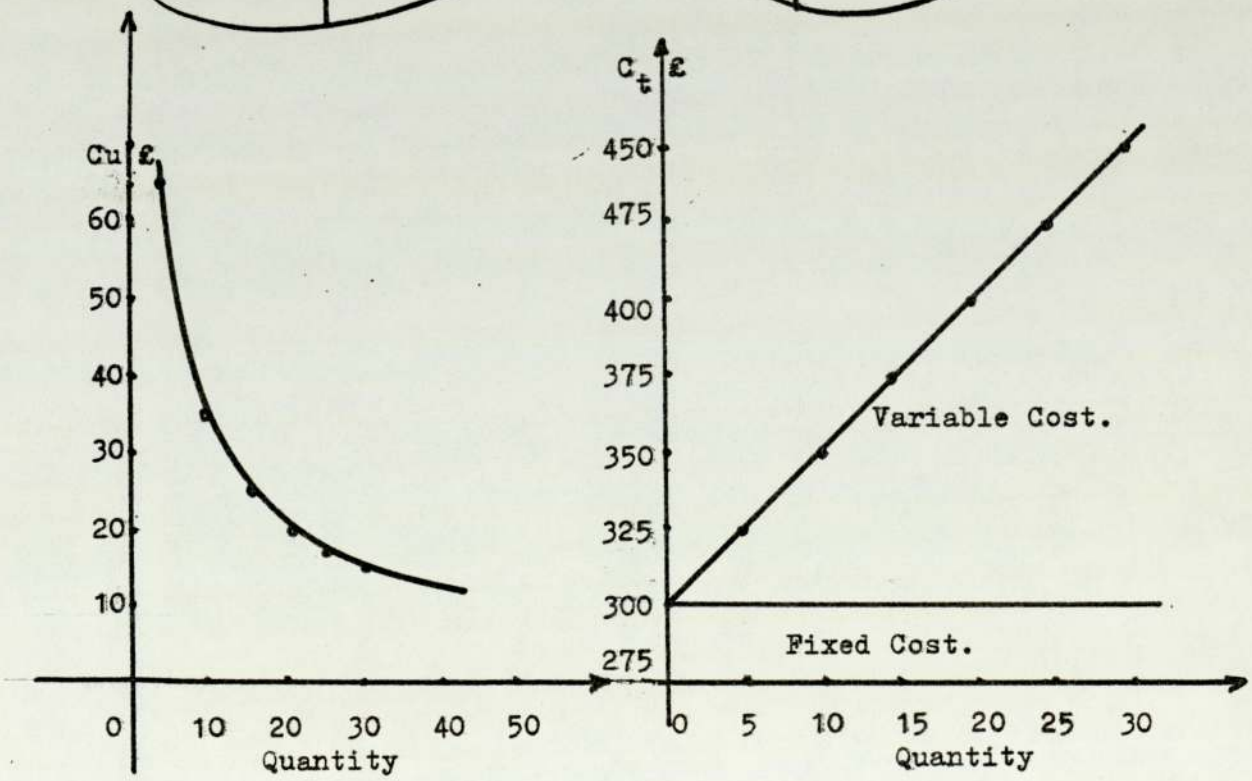
O_u Variable overhead cost/unit.

M_u Material cost/unit.

4. Summary of average unit cost/cell (49).

e.g. Cell 1.

No of units (Q)	Average (V) variable cost/ £	Fixed cost (F) £	Unit cost $(V+F/_{Q})$ £	Total cost $(V.Q+F)$ £
5	5	300	65	325
10	5	300	35	350
15	5	300	25	375
20	5	300	20	400
25	5	300	17	425
30	5	300	15	450



6.4. Unit Cost Method Chosen For This Project:- (46,47,48,49).

For this particular project unit cost will be used as a general form to establish cost comparison between different solutions, different cell formations, family formations and for other purposes.

General Definition Of Variable And Fixed Costs:-

It is often found convenient in accounting, to make a further division of the cost elements defined previously, into variable and fixed catagories. It is acknowledged that different types of cost vary to different degrees as volumes change, and consequently need to be treated in different ways. Variable cost are those costs which tend to vary directly with changes in volume of output, such as direct material, direct labour and overheads; while fixed cost are those costs which tend to be unaffected by changes in output, e.g. selling, distribution and administration. However, normally, most of the fixed costs are found in the indirect or overhead items, and it is therefore good practice to table each item under headings such as fixed or variable costs.

From the fig facing the following can be extracted:-

At zero (q_o) $F = F_o$

$V = 0$

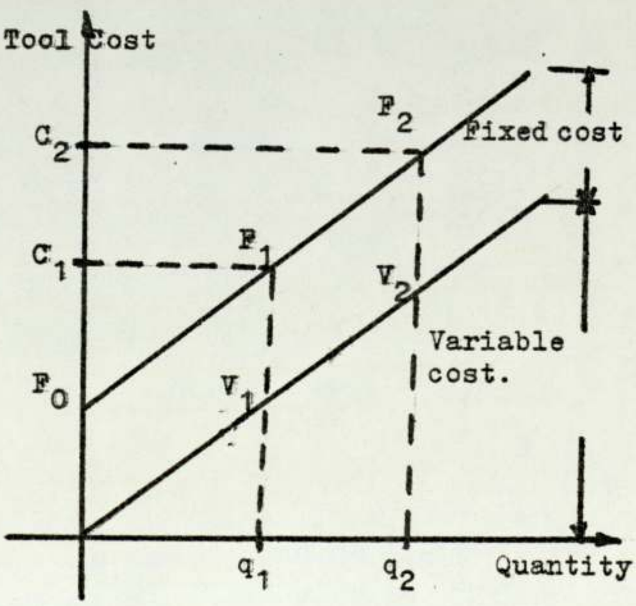
At 1 (q_1) $F = F_1$

$V = V_1 = Vq_1$

If C_1 is total cost at q_1

Therefore $C_1 = F_1 + Vq_1$

The same applies for point 2.



If. C_2 is total cost at q_2

Therefore. $C_2 = F_2 + Vq_1$

and in general $C_i = F_i + Vq_i$

where $F_1 = F_2 = F_i = F$

With significant increases in volume, variable costs per unit of output (V) remains constant, while fixed costs per unit (F/q) are reduced.

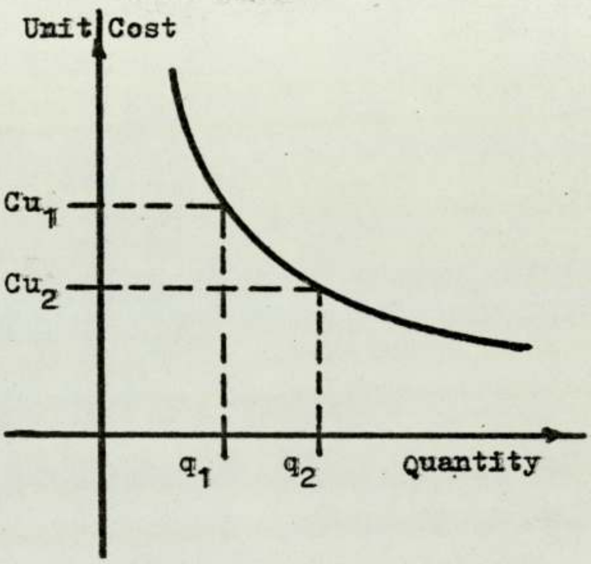
From the Fig the following can be ascertained.

If $C_i = F + Vq_i$

Then $Cu_i = C/q_i = F/q_i + V$

At q_1 $Cu_1 = F/q_1 + V$

At q_2 $Cu_2 = F/q_2 + V$



This is the general form of unit cost which will be used for this project. In the next chapter the model will be investigated with the aid of a case study which will involve family production in cellular manufacture.

The various fixed and variable elements in the cost behaviour have had the effect of bringing into prominence the technique of marginal costing, which mainly depends on the differentation between fixed and variable costs. The recent emphasis on decision making is causing industry to consider the measuring of the variability of cost with the volume of output and other decision variables.

6.5. Summary.

It is important to realize that costing methods and cost information are chiefly designed to provide the answers required by managements for cost control and cost establishment. As technology rapidly advances, economic and cost problems grow more important, therefore, management must be more aware of not only the technological feasibility of a manufacturing systems but also its economic viability .

There are many different cost systems to choose from, and different companies, in fact, use different systems suited to there own environment. For this particular study the general unit cost formula, discussed in section 6 is proposed to be used to establish a form of economic feasibility and cost comparison. The choice of a general unit cost formula was deliberate, in order to allow users the possibility of defining their own cost formula and cost elements to meet their particular need.

It is most important and appropriate that engineers in the manufacturing industries should become cost-conscious and be thoroughly familiar with the way in which costs are built up. The fact is that the design of a product which cannot be manufactured at a cost permitting it to be sold at a profit is just as much a failure as if it did not function correctly.

CHAPTER 7.

CASE STUDY.

7.0. Case Study.

7.1. The Company:-

The company is an engineering one totaly committed to group technology. There exist twenty six cells which have been designed by the company's engineers and it was agreed after consultation that a large cell for rotational parts be used for this case study. The idea is to reconsider numerous cell designs which would be capable of matching the output of the present cell but which would be evaluated on the basis of the unit cost of items produced. No additional machines could be used over and above what exist in the present cell.

7.2. The Product:-

The company divided the range of their rotational parts into three groups. The first group cell A, consists of all parts with diameter 2" - - 4" that do not require, Vertical Milling, Slotting, Broaching, Keysetting, Thread Milling, Cridan, Automill and Hurth. The second group cell B, includes parts with diameter 2" - - 4" and ommitted from the first group (i.e. those requiring the operations described in the first group). Also in the second group are all parts with diameter 4" - - 6" and all parts with diameter above 6" requiring, Threadmilling, Cridan, Automill and Hurth. The third group cell C is all parts with diameter above 6" that do not require, Thread Milling, Cridan, Automill and Hurth.

In this project the first group cell A only will be dealt with in which the total number of parts inputed, to the cell was 639 parts with a total annual usage quantity of 50629 units at an annual cost value of £58744.

7.3. Availability Of Data And Information:-

A lot of data was provided, by the company and consisted of:- the part to machine matrix (provided as a computer output), full details about the parts coding and classification, machining time, an indication of set-up times, machine and labour utilization, and the number of machines and labour requirements. As far as cost data was concerned not much could be obtained. The only available information was a total cost and a percentage of the make up of that cost of material, labour and overheads. The company have now appreciated the need to establish a good costing system which can be used for future studies, and as a result their costing system and data is under going a detailed review for improvement.

7.3.1. Data Provided To Produce Machine Groups. (Using Cluster Analysis):-

Part To Machine Matrix:-

There are nineteen machine tools involved in cell A. The number of parts which are to be tested was 639 consisting of an annual usage of 50629 units. On the machine part matrix the operation sequence was recorded with an X for the operation on a particular machine and empty space when no operation was required table (4).

Following the part to machine matrix a detailed breakdown of every individual family of parts was produced. This includes machining time, part number, number of part/family and the usage of parts (quantity); a sample is shown in table (5). All parts were previously coded and classified by the company using the basic "Opitz Code System"; (a key to the coding was supplied). The regrouping of parts using Production Flow Analysis was established on the basis of the similarity between:-

a) Those parts which go to the same machines;

b) Those parts which require the same operation on the same machines and thendeviate to different machines.

c) Those parts which require different operations on different machines.

This criterion may not be perfect nevertheless, it produced satisfactory results. It was tested on well established examples and it produced similar answers to the results produced by hand or other methods (e.g. Burbidge) see App (1). The criteria used to produce machine groups was to calculate for each pair of machines a similarity coefficient, which attempted to describe how similar they were in terms of the number of parts which visit both machines and the number of parts which visit each machine. Full details of this procedure is described in section 5.2.1. and 5.2.2. chapter (5). The establishment of the machine similarity matrix was tested on the same examples mentioned previously in this section, and very satisfactory results were established, Appendix (1).

Once similarity ratios were calculated and printed on a triangular matrix form, clustering could start from the above mentioned results and using single linkage cluster analysis dendrograms for machine and part groups were drawn. All calculations were carried out on the I.C.L. computer using a suite of a fortran programme designed for the collective study of several methods of cluster analysis (42).

The suite consists of a number of programmes, the following were the most important to this study to establish all the necessary information.

a) The first programme reads raw observation data and stores it. (contains the data required to produce the similarity matrix).
b) The second programme is very important because it computes the similarity matrix. The results will be stored and used as an imput to the other programmes.
c) The third programme prints out the computed statistics, e.g. raw data, similarity coefficient matrix..etc.
d) The final programme, assumes that a similarity matrix has been computed by the second programme, then it starts the process of clustering until it completes it and summarizes the sequence in a "Dendrogram" which is outputed on the graphplotter.

7.3.2. Data Provided To Produce The Rest Of Pre-Cost Calculations:-

Quantity Ratio:-

In order to manipulate quantities and reshuffle families of parts, it was found very helpful to establish a calculation procedure. To maintain the same product mix as it was designed by the company; a quantity ratio was established for different operation machines "see chapter (4)". section (4.1)". Quantity ratio between the total quantity input to the cell, (A cell can be a group of machines or one machine) and individual part quantities. (e.g. X for turning machines; Y for Milling machines; Z for Drilling machines;..etc). This ratio (X) is multiplied by production time (t_p) (including set-up time) to produce ($t_p.X$) (minute) for each part. A total of $\sum_{1}^{i} t_{p_i}.X_i$ is established for a family and also for each machine operation and then for each cell. The main advantage is that once a ratio is established, the repetition of calculation (due to reshuffle of families, machine or total input to the system) using the same individual quantities per machine or cell, can be avoided. A small computer programme was written to calculate and sum up all those ratios, Appendix (2). The results will be used in establishing unit cost for comparison of different solutions. The resultant $\sum_{1}^{i} t_{p_i}.X_i$ is also used to quickly establish machine utilizations. To produce an accurate machine loading ratio to that of the company, firstly effective performance (E.P.) should be added i.e. $\sum_{1}^{i} t_{p_i}.X_i + E.P\%.$). The values of 1920 hours/year as a full 100% load for one machine and 75% effective performance are used by the company. Given the type of the machine tool, then the number and utilization required for cells and/or machines can be established. Multiplying $(\sum_{1}^{i} t_{p_i}.X_i)$ by total quantity to the system (machine or cell), then divided by 1920 x 60 a utilization factor (η) is established. Therefore the general form for utilization will be

$$\eta = \frac{N \times (\sum_{i} t_{p_i} . X_i)}{1920 \cdot 60}.$$

As emphasis has always been given to the use of primary secondary and extra machines in the cell, utilization of machines can play a very important role in establishing the seniority of those machines, or suggesting that all machines are equally senior. For example the position of an assumed secondary machine of high capital cost within a cell can be reviewed by its high or low level of utilization and a reshuffle of the cell formation and/or part rerouteing might prove fruitful.

7.3.3. Data Available To Produce Unit Cost Comparison:-

The use of unit cost for comparison purpose within the company has been neglected to date, mainly due to the lack of adequate cost information. The company at the present time is reviewing its cost system and the elements which make up that system. It was made clear from the beginning that, because of the inadequacy of the system, detailed costs of items would not be easy to ascertain and therefore assumptions had to be made to produce satisfactory results. The existance of a good cost system in the manufacturing industries is vital to show the economic advantages of any major or minor changes. The cost breakdown used by the company is:

a) Material cost

b) Labour cost

c) Production overheads.

d) Fixed overheads.

It was agreed that for this particular project, the most realistic breakdown of the total lump sum of cost given in the company's data was 90% to variable cost and 10% to fixed cost. It must be appreciated that these figures are estimates and may not necessarily represent the correct cost data. These figures may also not be representative of all the companies.

7.4. Establishment Of Unit Cost For Comparison:-

Once different solutions of machines groups have been established, the use of unit cost formula for comparisons to choose the most favourable solution can start. The formation of cells for this particular case study have ranged from each machine tool as a single cell capable of performing the required operations on the part, to all the machine tools grouped as one cell (this is the existing situation in the company) capable of producing the families.

7.4.1. Derivation Of General Formula Used To Establish Unit Cost For Comparison Purposes:-

Supposing that there are three machine tools in the cell, first, second, and third operation machine (see chapter (4). Quantity ratio is X,Y and Z respectively, the relationship of quantity ratio and (η) utilization is linear. If output is increased then:

$$\eta_w = \frac{N}{R}\left[\sum_1^t \frac{P_{1i}\cdot X_{1i}}{W_1} + \sum^t \frac{P_{2i}\cdot Y_{2i}}{W_2} + \sum^t \frac{P_{3i}\cdot Z_{3i}}{W_3}\right].$$

Where N; is number of units going through the system (cell or single machine).

X,Y and Z are quantity ratios.

R is a full 100% load for one machine/year (1920hrs).

W is number of machines involved.

$\eta_{av} = \frac{\eta_1 + \eta_2 + \eta_3}{3}$ is average utilization of the system (cell or single machine). If machine utilization for one family is:

at quantity N_{21} for the family $\eta_1 = \frac{(\sum_1^i t_{p_{1i}} \times X_{1i}) \times N_{1i}}{RW_1}$ ......

generally for first operation machine;

$\eta_2 = (\sum_1^i t_{p_{2i}} \times Y_{2i}) \times N_{2i}$ ...... generally for second operation machine;

$\eta_3 = \frac{(\sum_1^i t_{p_{3i}} \times Z_{3i}) \times N_{3i}}{RW_3}$ ...... generally for third operation machine;

i Number of units in the family.

In this case $N_{1i} = N_{2i} = N_{3i} = N_1$ Quantity of the family (units).

Therefore $$\eta_{av} = \frac{N_1}{R}\left[\frac{\sum t_{p_{1i}} X_{1i}}{W_1} + \frac{\sum t_{p_{2i}} Y_{2i}}{W_2} + \frac{\sum t_{p_{3i}} Z_{3i}}{W_3}\right]_1$$

In general form of unit cost derived in chapter 6 section 6.5. will be used and that is:

$Cu = V + F/N$ · Cu is unit cost £/units.

F is fixed cost £.

Unit cost in terms of output. V is variable cost £/units.

For this case; If $Cu = V + \frac{F}{N_1}$. N is total quantity units.

$$\text{and } N_1 = \eta_{av} \cdot R \Big/ \left[\frac{\sum t_{p_{1i}} X_{1i}}{W_1} + \frac{\sum t_{p_{2i}} Y_{2i}}{W_2} + \frac{\sum t_{p_{3i}} Z_{3i}}{W_3}\right]_1$$

Unit cost in terms of machine utilization.

For Two Families:- at quantities N_1 & N_2 respectivally

$$\eta_{av} = \frac{N_1 + N_2}{R}\left[\frac{\sum t_{p_{1i}} X_{1i}}{W_1} + \frac{\sum t_{p_{2i}} Y_{2i}}{W_2} + \frac{\sum t_{p_{3i}} Z_{3i}}{W_3}\right]_1 + \frac{N_1 + N_2}{R}\left[\frac{\sum t_{p_{1i}} X_{1i}}{W_1} + \frac{\sum t_{p_{2i}} Y_{2i}}{W_2} + \frac{\sum t_{p_{3i}} Z_{3i}}{W_3}\right]_2$$

For j families:-

$$\eta_{av} = \frac{N_1 + N_2 + \cdots + N_j}{R}\left[\left[\frac{\sum t_{p_{1i}} X_{1i}}{W_1} + \frac{\sum t_{p_{2i}} Y_{2i}}{W_2} + \frac{\sum t_{p_{3i}} Z_{3i}}{W_3}\right]_1 + \left[\frac{\sum t_{p_{1i}} X_{1i}}{W_1} + \frac{\sum t_{p_{2i}} Y_{2i}}{W_2} + \frac{\sum t_{p_{3i}} Z_{3i}}{W_3}\right]_2 + \cdots \cdots + \cdots + \left[\frac{\sum t_{p_{1i}} X_{1i}}{W_1} + \frac{\sum t_{p_{2i}} Y_{2i}}{W_2} + \frac{\sum t_{p_{3i}} Z_{3i}}{W}\right]_j\right]$$

The general form of unit cost will be

If $Cu = V + F/(N_1 + N_2 \ldots + N_j) = V + \frac{F}{\sum N_j}$) in terms of quantity.

$$\text{Therefore } Cu = V + \frac{F}{\eta_{av} \cdot R\left[[\ \ ]_1 + [\ \ ]_2 + \cdots + [\ \ ]_j\right]}$$

in terms of utilization.

The same method could be applied for any number of machine tools within the cell.

$$\text{Unit cost of a system} = \text{variable cost} + \frac{\text{fixed cost } \sum(\text{quantity ratio} \times \text{time})}{(\text{System utilization x R x no of machines})}$$

Where a system is an individual machine or group of machines representing a cell.

7.4.2. Assumption Summarized:-

a) To explain the procedure chapter 4 it was assumed that there were three main machine tools, Turning, Drilling and Milling, but for this case study there are Turning, Drilling, Milling and Grinding machines.

b) To simplify quantity, utilization and other calculations a quantity ratio was established.

c) Variable costs were assumed to be 90% from total, and fixed costs were assumed to be 10%.

d) A percentage factor between total quantity input to a system designed by the company, and quantity input to individual machines was developed, App (4), for the purpose of data manipulations.

e) Because of the nature of the data provided for the case study, and in order to show the effect of reduction and increase of quantity inputs to cells as a useful exercise, the following was established.

1) Effect of quantity changes at constant quantity ratio

2) Effect of quantity changes at different quantity ratio by assuming the same utilizations and number of machines.

Therefore if $N_1 = \eta \times R \times \text{number of machines } (\sum t_p \cdot X)_1$

$$N_2 = \eta \times R \times \text{number of machines } (\sum t_p \cdot X)_2$$

Then $$\frac{N_1}{N_2} = (\sum t_p\ X)_2 \text{ or } (\sum t_p \cdot X)_2 = \frac{N_2}{N_1} (\sum t_p \cdot X)_1$$

f - Number of parts were 639, at total cost of £58 774 and kept constant throughout the calculations, and a constant cost per part of £91.9311 was used as basis for unit cost calculations to establish realistic results. see section 7.5.2.

g - Because of the importance attributed to machine utilization in cell formation, unit cost calculations were established for equally divided utilizations from 10% to 100%.

h - To give a practical and realistic illustration most of the existing conditions such as, floor area, number and kind of machines, manpower, tools, material requirements..etc. were assumed to be as the company's records indicated.

7.5. List Of Results:-

7.5.1. Single Linkage Clusters Analysis Results:- (Computer Programme Findings).

i) Machine grouping (cells).

From the machine dendrogram fig (22) and table (6) at different levels of similarity coefficients a number of solutions were established. At a similarity ratio of 50% machine (1) (Turning) joins up with machine (4) Drilling to form the first multiple cell with other machine tools remaining as singular cells. The same pattern is followed by lowering the admission criteria then more machines join in until all existing machines become one cell, which is the existing situation in the company. At the level were all machines are one cell, the criteria chosen for this particular example is very low and is represented by a zero similarity coefficient. table (6).

ii) Part grouping (families).

From the part analysis, the dendrogram fig (23), and table (7) were compiled. Because of the already existing cell manufacturing system in the company the 639 parts were coded and classified and formed into 233 groups using a basic Opitz coding system. To save computer time and expense all identical parts

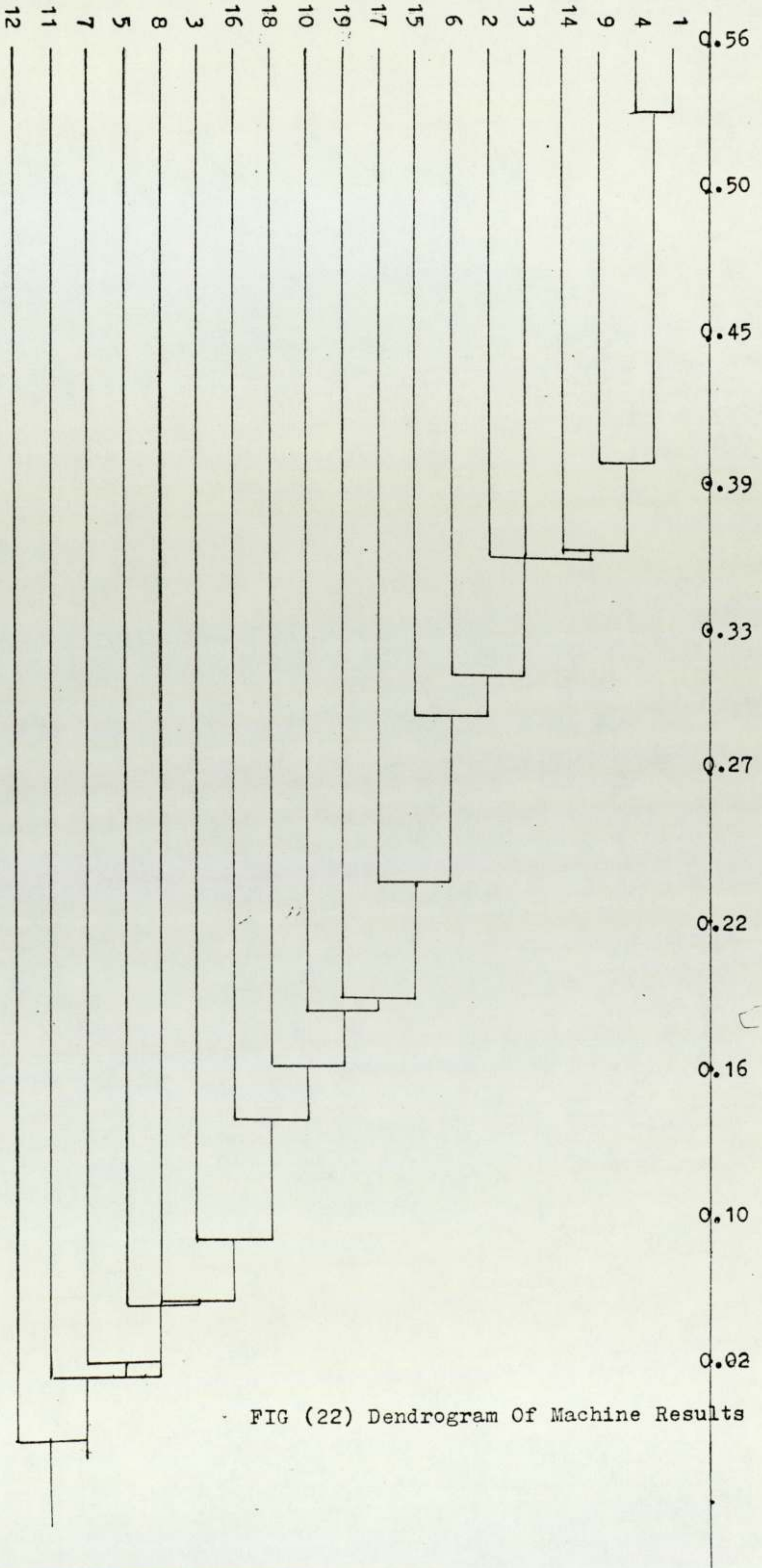


FIG (22) Dendrogram Of Machine Results

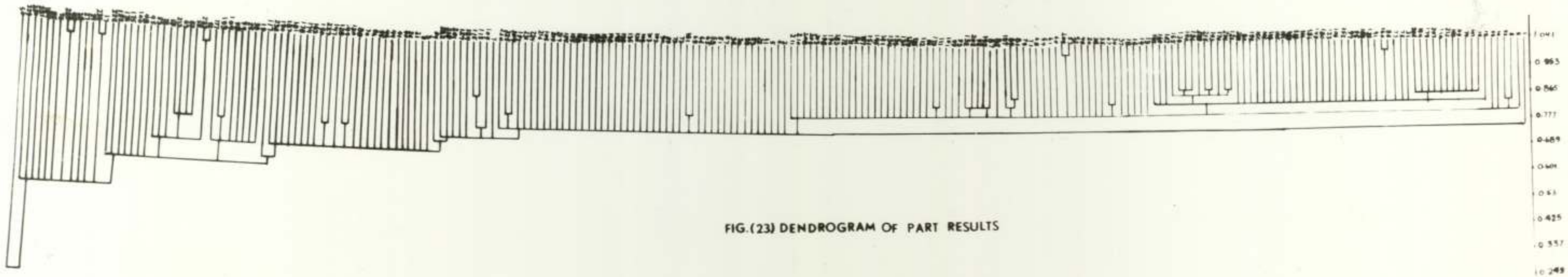


FIG.(23) DENDROGRAM OF PART RESULTS

are grouped together and taken as an individual group, and clustering between the groups was carried out. The results were very satisfactory and at a 95% similarity ratio the first new families were formed to include groups (57 and 209) also groups (42 and 223); groups (17 and 233) and groups (43 and 228) while the rest remained individual families, lowering the criteria of admission into the families, more groups can join in and new families would be formed. At a very low similarity coefficient all parts are grouped into one family. At 100% similarity coefficient every group is separated as an individual family, and that is the existing situation. table (7).

iii) Other useful data

As a bonus the programme yields useful statistical data such as binary variable frequency, or how many times an object occurs or appears in the data sample. It also produces a percentage occurance for the binary variable as shown in App(1). These two items can be used in the studies for developing adequate scheduling systems.

7.5.2. Establishment Of Unit Cost Comparison Between Solutions Using Machine Grouping:-

The first test for the existing data selective solutions based on, all parts as one family were established:-

a) Solution 1.

At similarity coefficient (100%) number of cells 19 each individual machine is considered as a separate cell. Before the actual calculation of the unit cost were made the following items were determined.

i) preparation:-

From the small programme written to calculate the sum of quantity ratios multiplied by machining time, results were obtained for individual machines, (i.e. ($\sum t_p \cdot X$). Quantity input to each machine tool was given by the company, so that utilization of each machine as a cell and the number of machines required is found. Not surprisingly due to the given data it was established that the existing machine numbers and utilizations resembles those calculated by the companies own method. Those machines which do not exist in the companies plant were assumed, see table (8).

A flow of units into individual cells was outlined to be used for comparison with other solutions and to clarify the movements of parts see fig (24).

Unit cost ascertainment and manipulation is based on data obtained from company records. Total cost to produce 639 parts was £58744 per annume at a cost of $\frac{58744}{639}$ £91.9311 per part (C_p). Each cell will be capable of producing (P) number of parts of quantity (N) units, therefore the total cost for the particular cell is £(P x C_p), and the unit cost is $\frac{P \times C_p}{N}$. If variable costs were v percent, then $V = \frac{P \times C_p}{N} \times v\%$; £/unit; and fixed cost

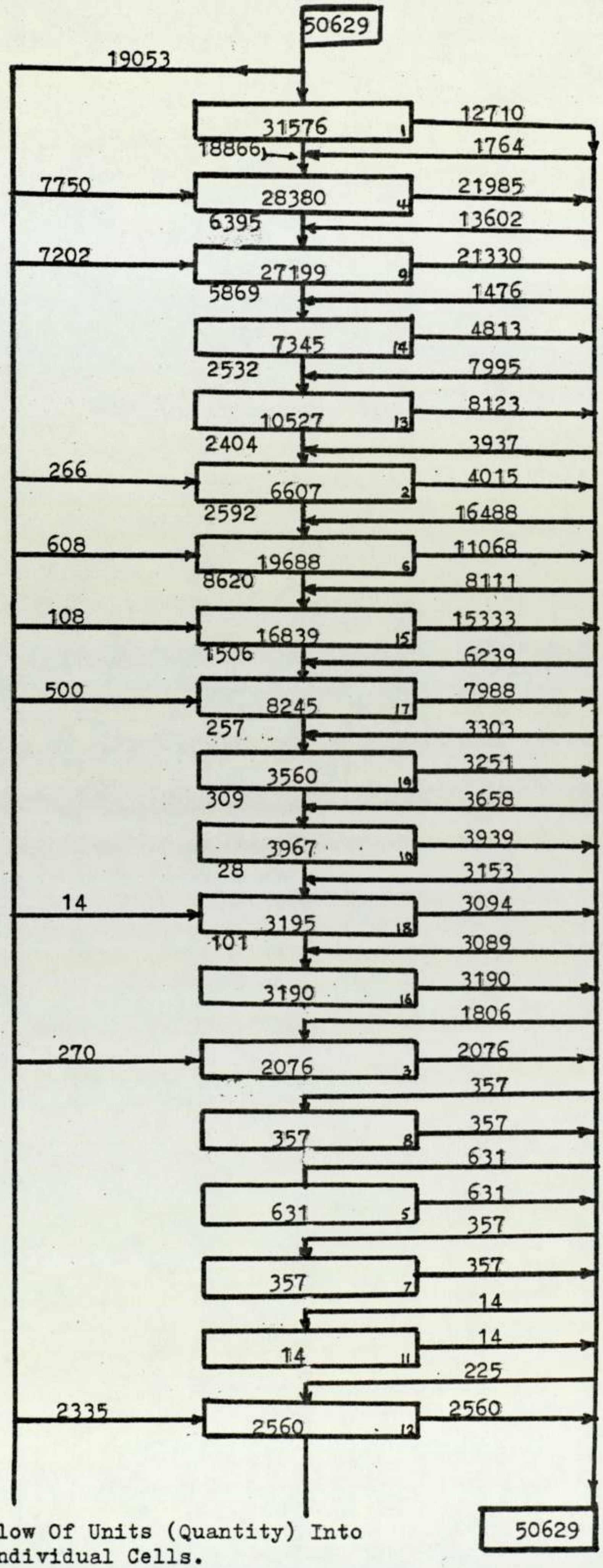


FIG (24) Flow Of Units (Quantity) Into Individual Cells.

is f% x $(P \times C_p)$. The same calculation is repeated for each cell. see Appendix (3).

ii) Calculation:-

The unit cost is calculated for 10 equally divided machine utilization factors from 10 to 100%. At each utilization the unit cost (Cu) is ascertained,

$$Cu = \text{Variable cost} + \frac{\text{Fixed cost} \times \sum t_p \, . \, X}{\eta \times R \times \text{number of machines } (W)}$$

Also calculated is the quantity (N) at η_1.

$$\frac{\eta_1 \times R \times \text{number of machines } (W).}{\sum t_p . X}$$

Sample of the detailed calculation is given in Appendix (2). The reverse of the calculations is true, that is, at certain quantities a unit cost and utilization could be established. All the results of Cu, and N are summarized in fig (25) to show graphically unit cost line significance of each cell.

b) Solution 2.

At a similarity coefficient of 50%; number of cells 18; machines (1) (Turning) and machine (4) (Turning) were joined together to form the first multiple cell. The rest of the machines remain as individual cells. The same procedure of preparation and calculation explained above was followed. see results summary in Appendix (3). Variable cost is £1.10142 per unit. The fixed cost is £5029. Unit cost at the given quantity of 41090 units and utilization of about 90%, is £1.2238 per

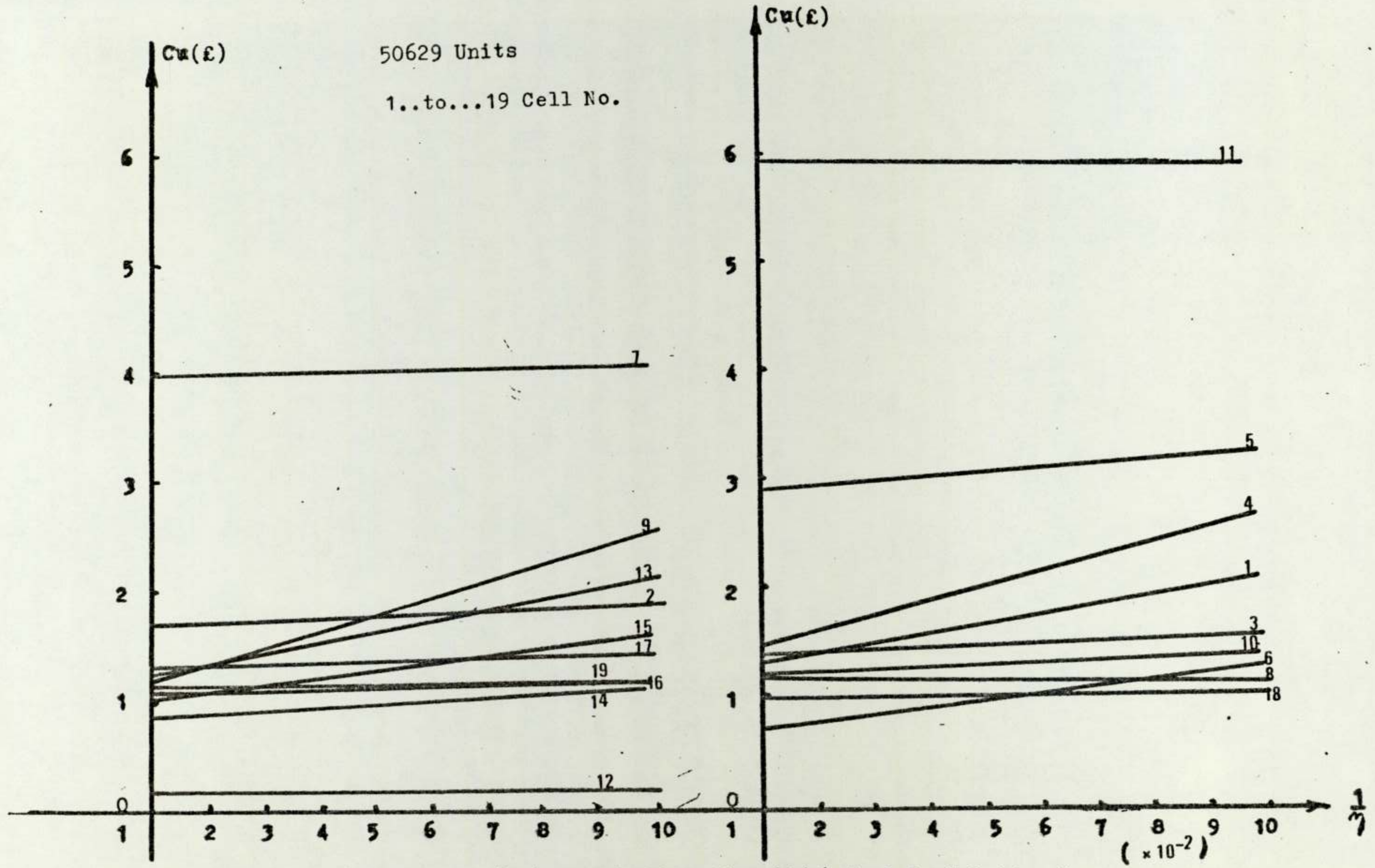


FIG (25) Unit Cost (Cu) To 1/Utilization (1/η) Test 1, Solution 1.

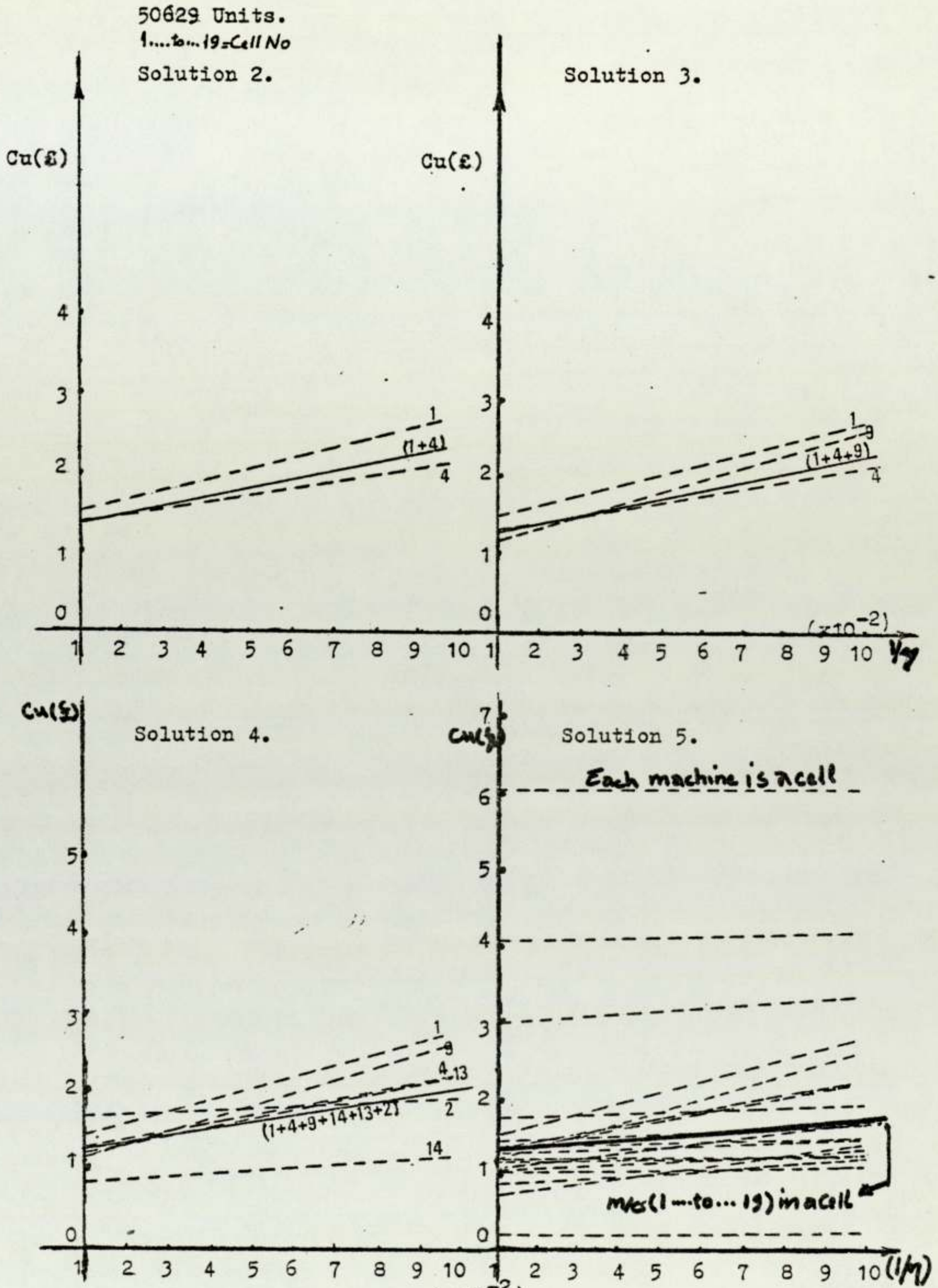
unit, and representations of the relevant results are shown in fig (26). There is an improvement in unit cost value of machine (4) as part of the new cell, while machine (1) shows a slight improvement at a very high utilization from the single machine cell solution;

c) Solution 3.

At a similarity coefficient of 38%, number of cells are 17; machine (1) (Turning), (4) (Turning), and (9) (Drilling) were joined together as a cell. This combined cell produces 598 parts containing 48322 units. The rest of the machine tools are individual cells. The calculation of unit cost will be for the newly constructed cell, the rest already having been calculated, see results summary in Appendix (3). The same procedure of unit cost calculation is followed; variable cost is £1.0239 per unit and fixed cost is £5497, unit cost at the given quantity of 48460 units and utilization of about 99% is £1.13767. Representation of the important results are shown in fig (26). There is an improvement in unit cost value of machine 4 and 9 as part of the new cell, while machine (1) shows a slight improvement only at a very high utilization from the single machine cell solution.

d) Solution 4.

At a similarity coefficient of (27%), number of cells 14, machines (1,2,4) Turning, (9) Drilling, (13) Milling and (14) Grinding represented by individual machines.



(x10^{-2})

FIG (26) Unit Cost (Cu) To (1/Utilization) (1/η) Test 1.

(e.g. 1/η = 1x10^{-2}; and η = 100%)

Total units are 48460 from 602 parts which visit the new cell variable cost is £1.02782 per unit, and fixed cost is £5534; unit cost at the given quantity of 48460 unit and utilization of 80% is £1.14202.

All calculations are summarized in Appendix (3), and the relevant results are shown in fig (26). This is an improvement in unit cost value of machines (1,4,9,13) & 2 as part of the new cell, while machine (14) has shown no improvement on the single machine cell solution.

e) Solution 5.

At a similarity coefficient of zero the number of cells is one. All machines are combined in one cell. This is the same situation that exists in the company at the moment. The variable cost is £1.04425 per unit. The fixed cost is £5874; unit cost at a given quantity of 50629 units and utilization of 45% is £1.16 per unit.

Summary of all the calculations are tabulated in Appendix (3), and representation of the relevant results were shown in fig (26). There are definite improvements in unit cost of machine tools especially those with high unit cost when machines began to join together to form cells solutions 1 to 5

2. For the proposed new data.

Based on machine grouping and all parts as one family, because of the already existing group technology system in the company, it was found very difficult to show the affect of reshuffling the parts into different families with each solution of machine grouping. The reshuffling of parts into different families from scratch would have given different outputs to each machine grouping solution at different family solution, hence the results would have been shown to be more effective. To combat these existing difficulties and to show the effect of reshuffled unit cost was calculated for these proposed quantities at constant quantity ratios and at a changeable quantity ratios (product mix).

i) Constant Quantity Ratio:-

At 30000 Units:-

From the assumption list a new quantity for each machine was established, related to the same ratios designed by the company. The same procedure of calculation in section 7.5.2; was followed, to establish new machine utilization, new variable and fixed cost for each machine, and new unit cost at this new proposed quantity. All data and results are summarized in Appendix (4) and table (10). and the relevant results were shown in fig (27).

At 40000 Units:-

The same procedure and assumptions described above were used. All data and results are summarized in Appendix (4) table (11) and the relevant results were outlined in fig (28).

At 60000 Units:-

The same procedure and assumptions described above were used. All data and results are summarized in appendix (4) table

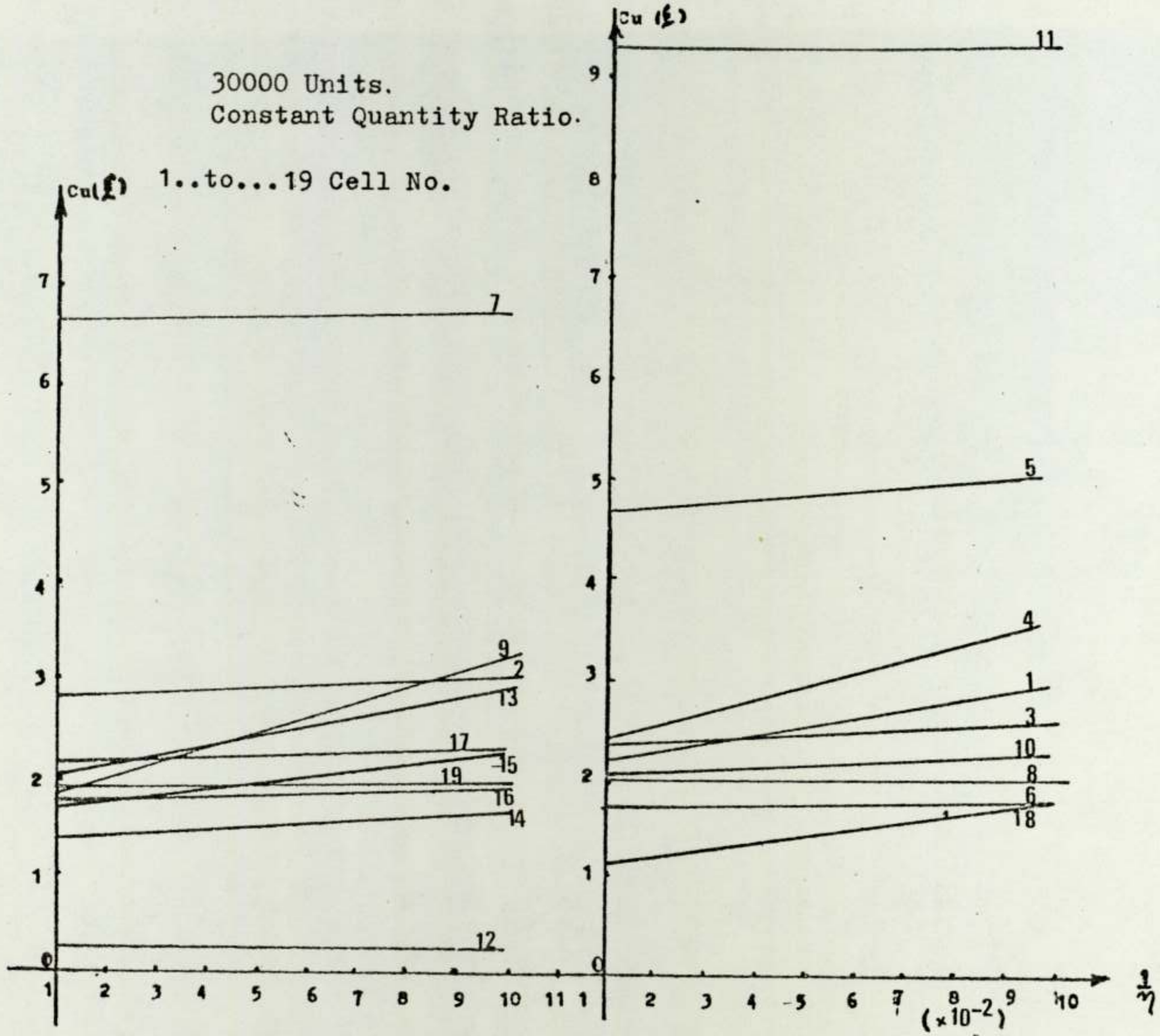


FIG (27) Unit Cost (Cu) To 1/Utilization ($1/\eta$) Test 1, Solution 1.

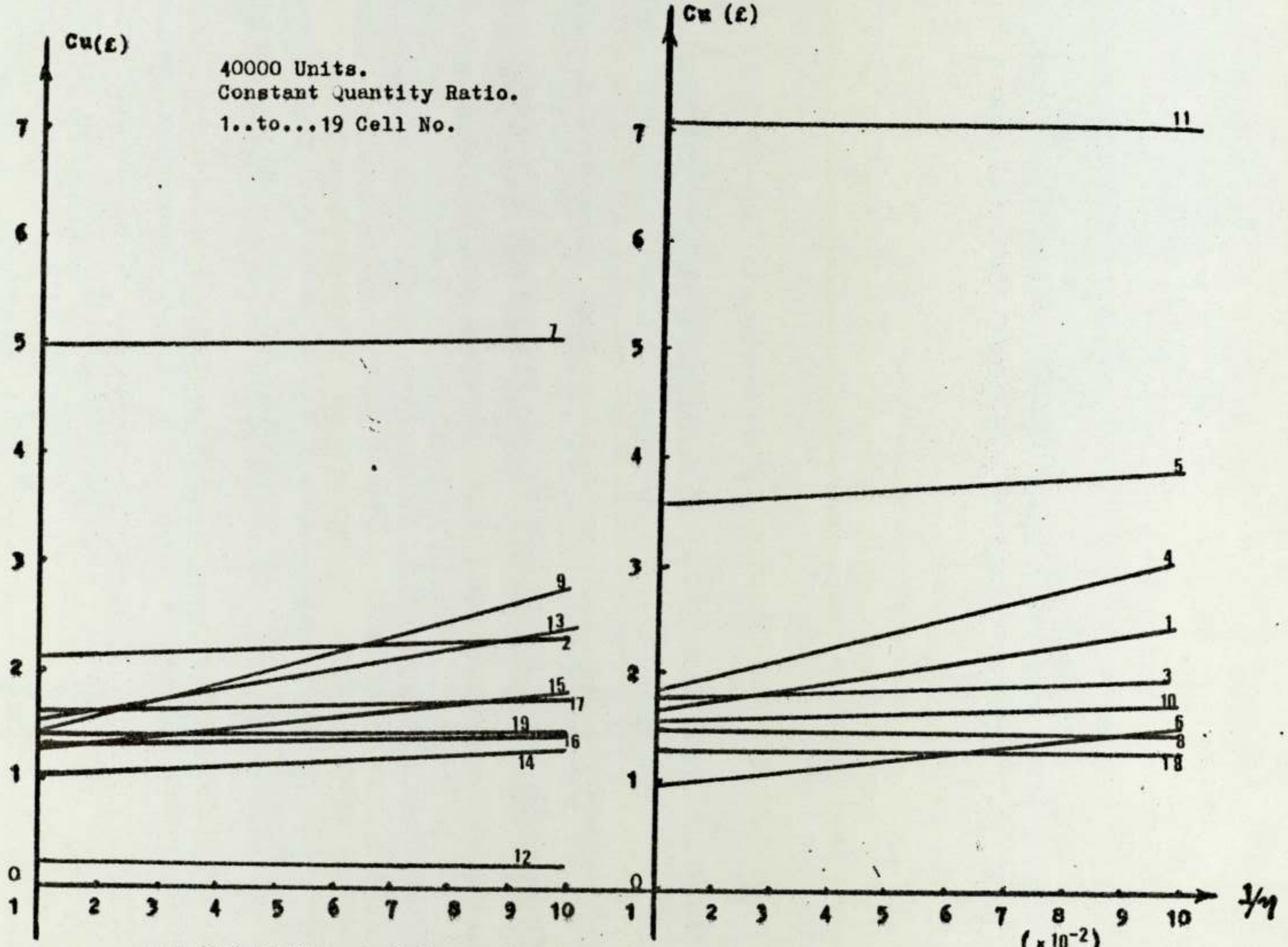


FIG (28) Unit Cost (Cu) To 1/Utilization (1/η) Test 1, Solution 1.

(12) and the relevant results were shown in fig (29).

ii) Changeable Quantity Ratio:-

At 30000 Units:-

It was assumed for simplicity that machine utilization and number of machines will be kept the same as those designed by the company. — Where, $(\sum t_p X)_2 = \frac{N_1}{N_2} (\sum t_p X)_1$ — All new (quantity ratio time) data is recorded in table (13) and appendix (5), quantities, variable cost, fixed cost, and unit cost were established in the same manner described previously in this chapter section 7.5.2, and a relevant representation of the results are shown in fig (30).

At 40000 Units:-

The same methods described above were used, and similar type of data and results are established. The results are recorded in table (14), Appendix (5). For relevant results see fig (31).

At 60000 Units:-

The same methods described above were used and similar type of data and results are established. The results are recorded in table (15) Appendix (5), important results were represented in fig (32).

The first impression from the results in this section suggested that all machines were grouped as one cell represented the lowest unit cost with a reasonable 45% overall utilization

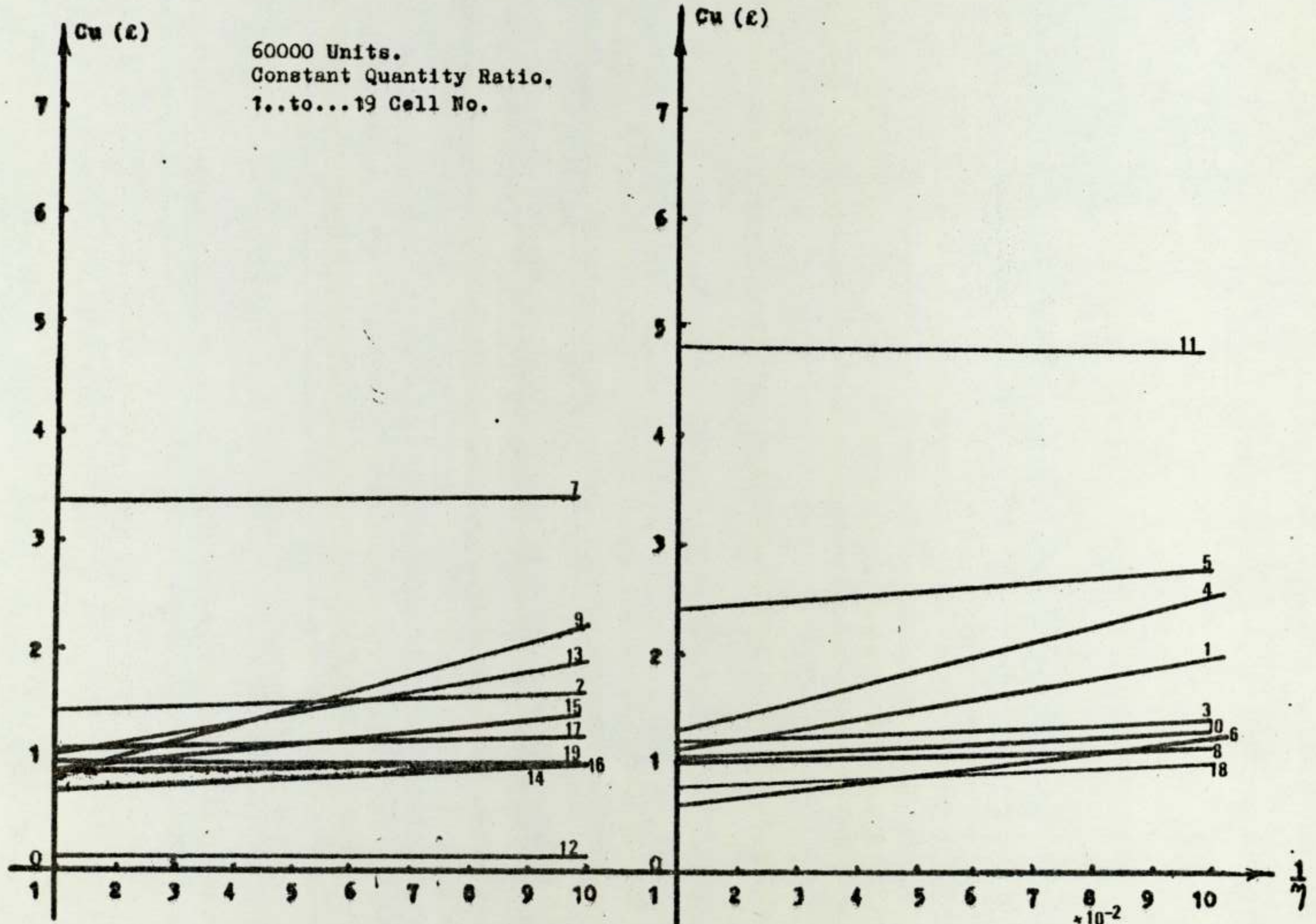


FIG (29) Unit Cost (Cu) To 1/Utilization ($1/\eta$) Test 1, Solution 1.

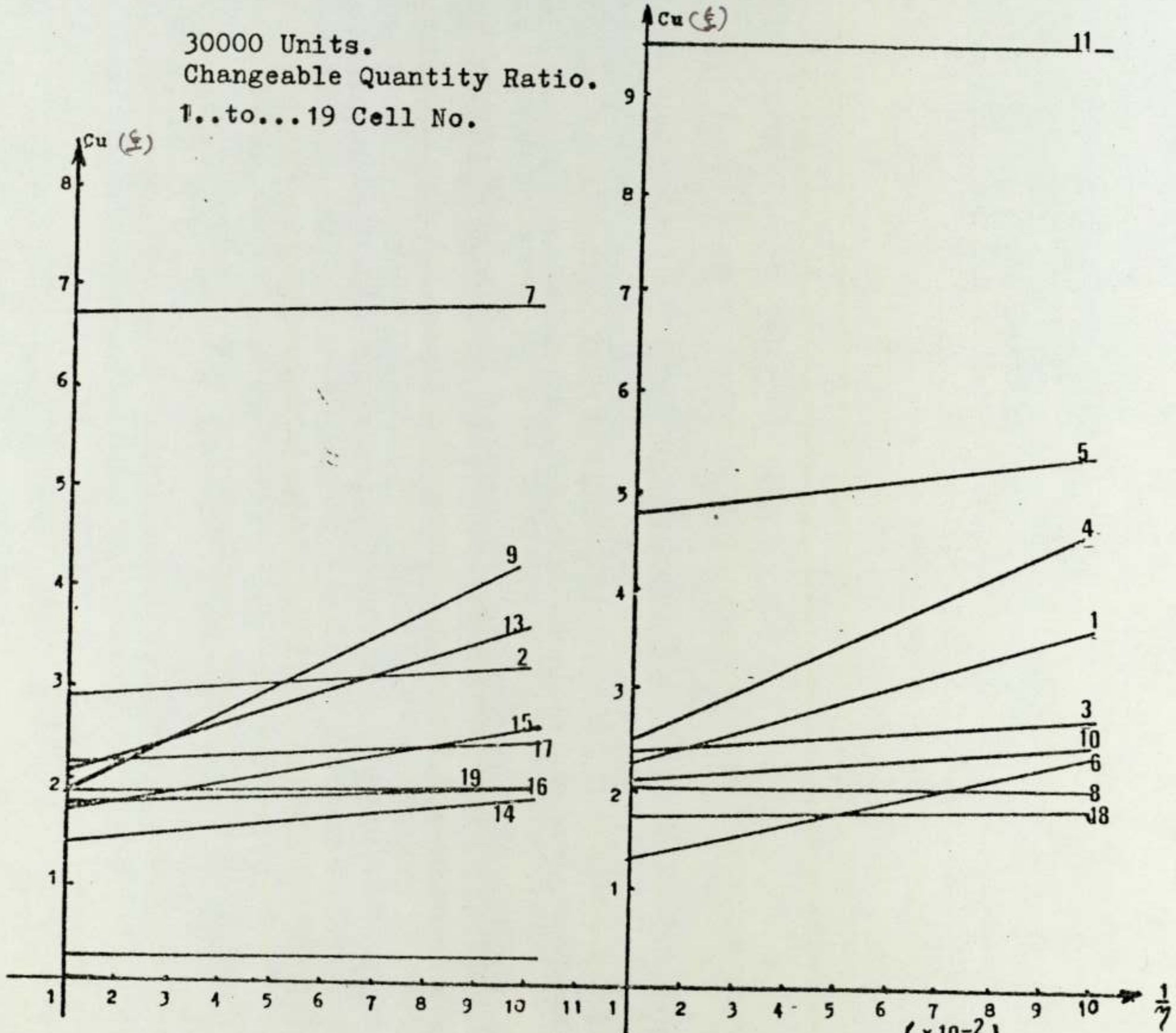


FIG (30) Unit Cost (Cu) To 1/Utilization (1/η) Test 1, Solution 1.

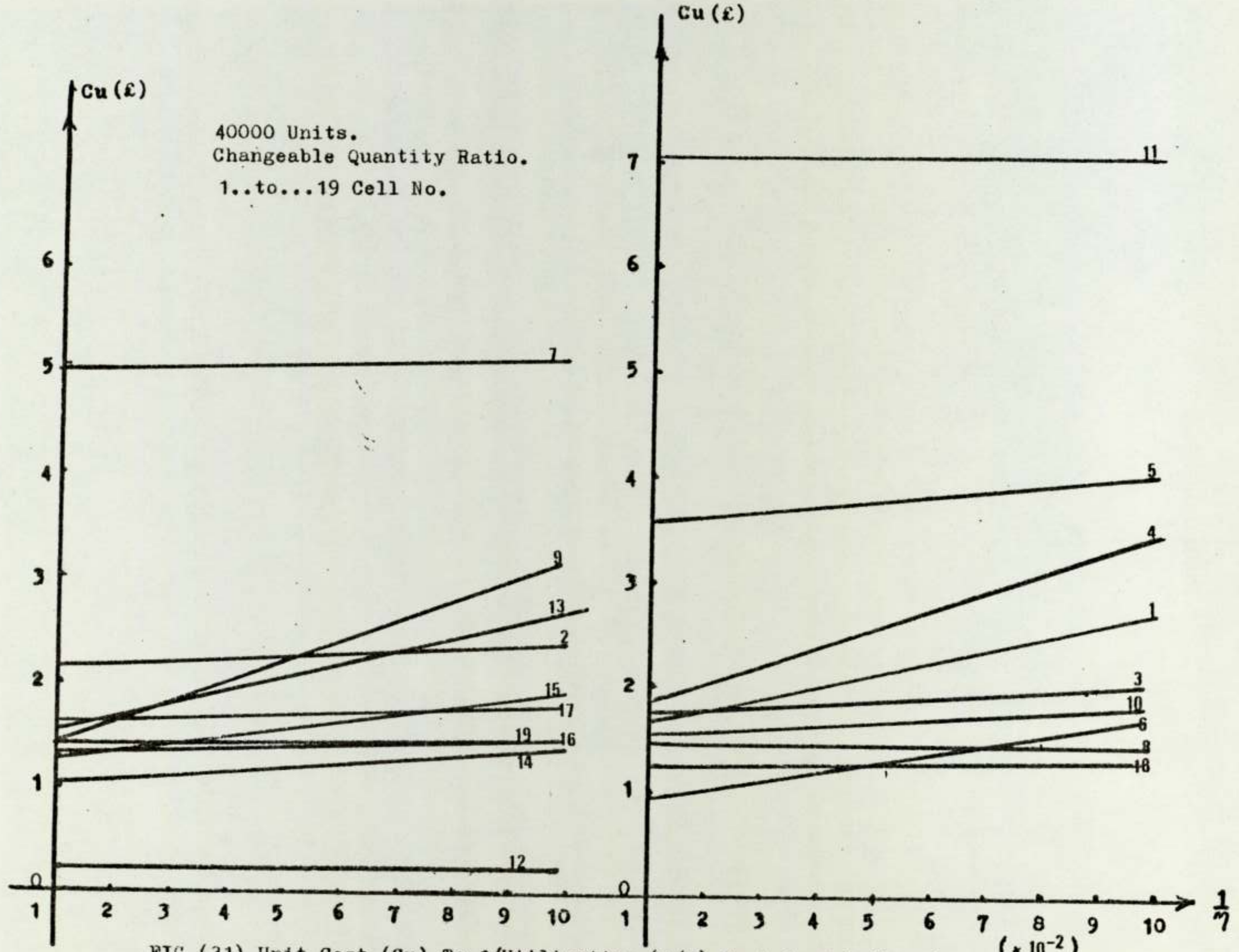


FIG (31) Unit Cost (Cu) To 1/Utilization (1/η) Test 1, Solution 1.

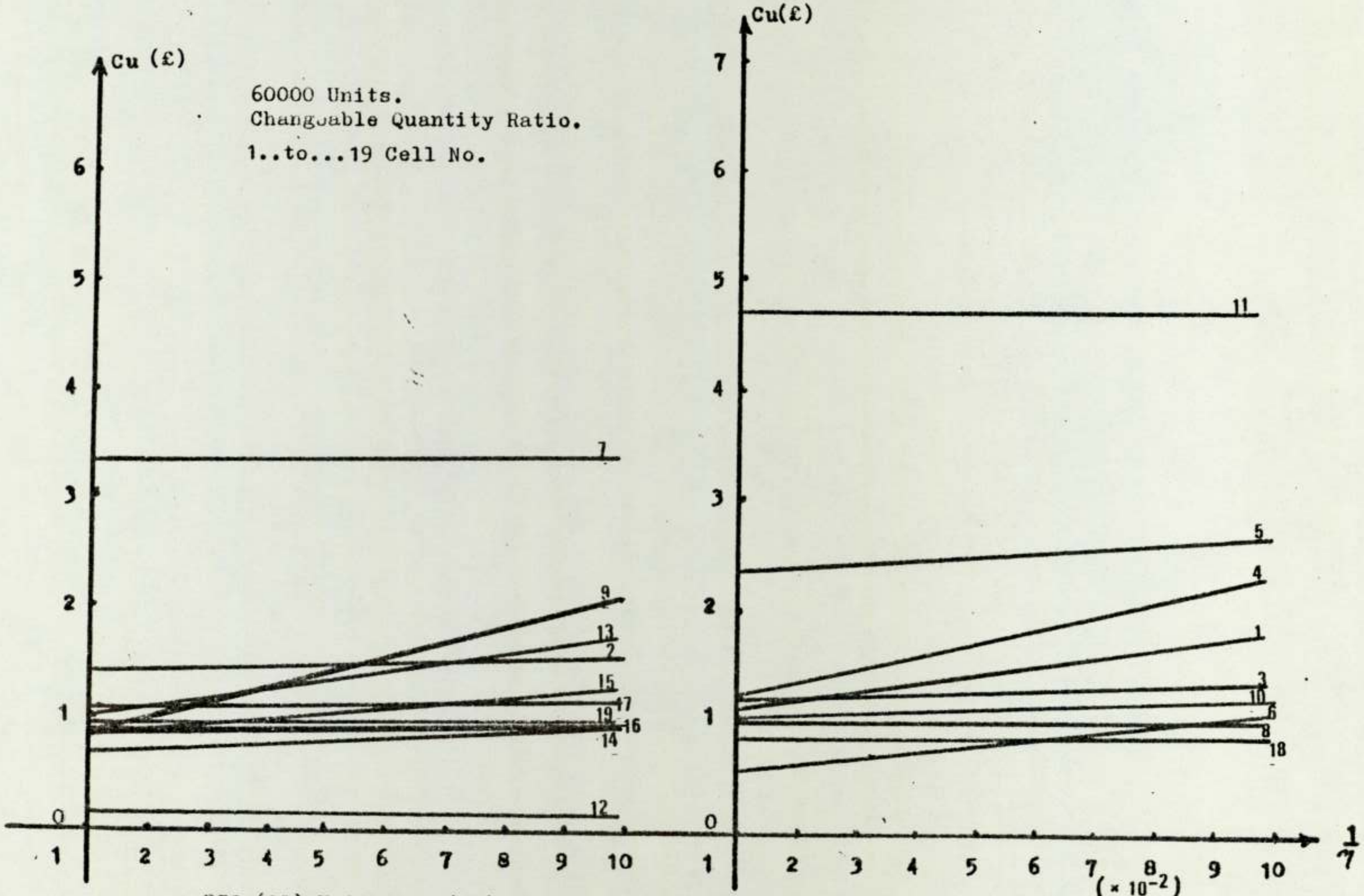


FIG (32) Unit Cost (Cu) To 1/Utilization ($1/\eta$) Test 1, Solution 1.

fig (33). The effect of increasing and decreasing the total quantity input to each cell in relation to the existing company data was significant to indicate the improvements or deterioration of machine utilization in general, a sample from total results were shown in fig (26) through (31).

7.5.3. Results Established From Using Family Formation:-

As described before the boundaries of family formation had already been set by the company previously, which in turn left very little possibility of building and reshuffling families to show any change in a quantitive way. Nevertheless different solutions of family formations were established and unit cost of these formation ascertained and used for comparison and for the choice of the best solution. The same cost procedure described throughout this chapter was followed. Three tests of family grouping were chosen for illustration.

The First Test: Of solutions has already been discussed in section 7.5.2. Where all parts grouped as one family. This family grouping occurs at similarity coefficient of zero. fig (25).

The Second Test: Occurs at the condition when every group of parts is a separate family. Detailed calculations are shown in Appendix (6). This test occurs at a similarity coefficient of 100% and was tested on the five cell solutions as follows;

Solution 1.

Where every machine is an individual cell. To show the

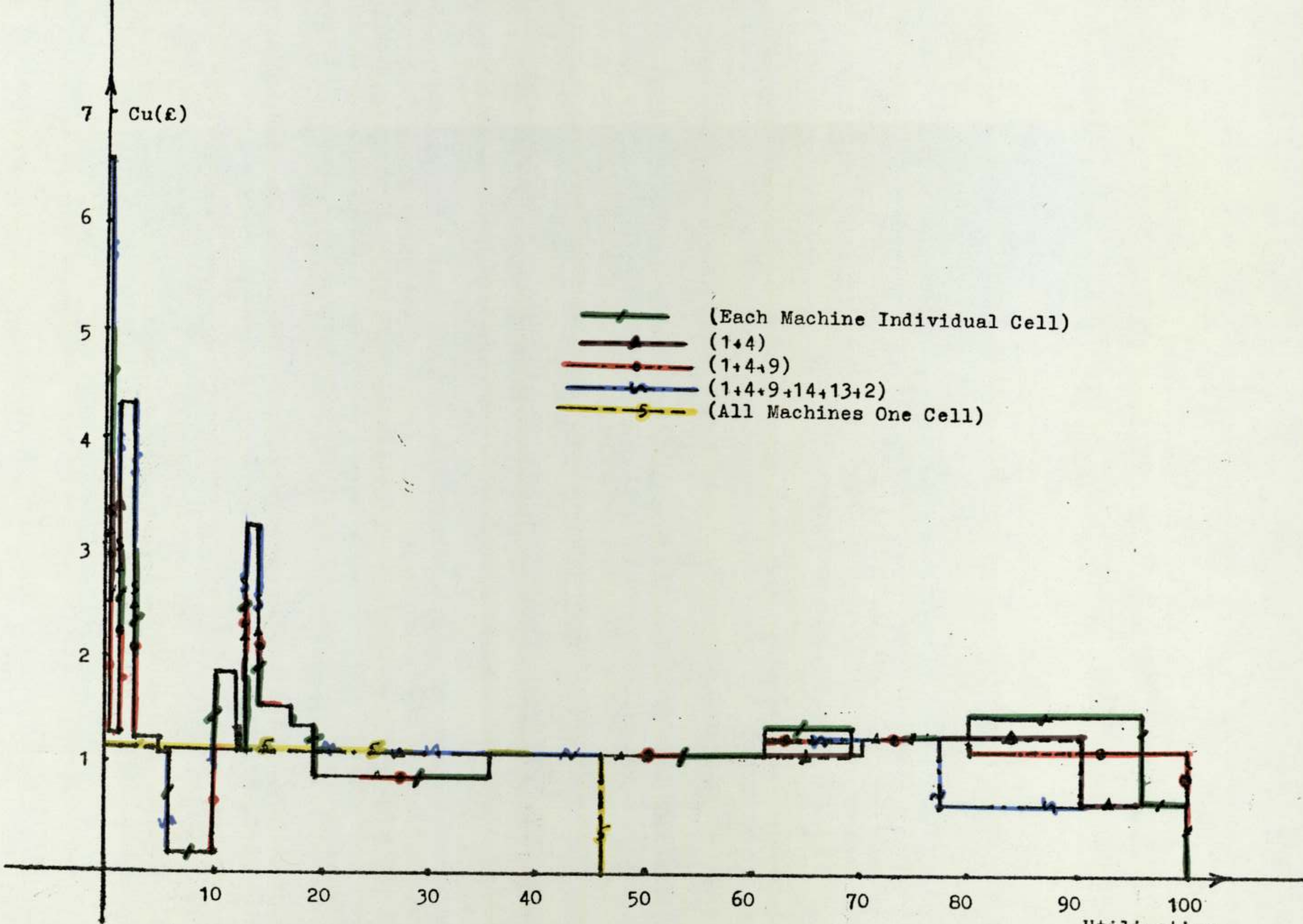
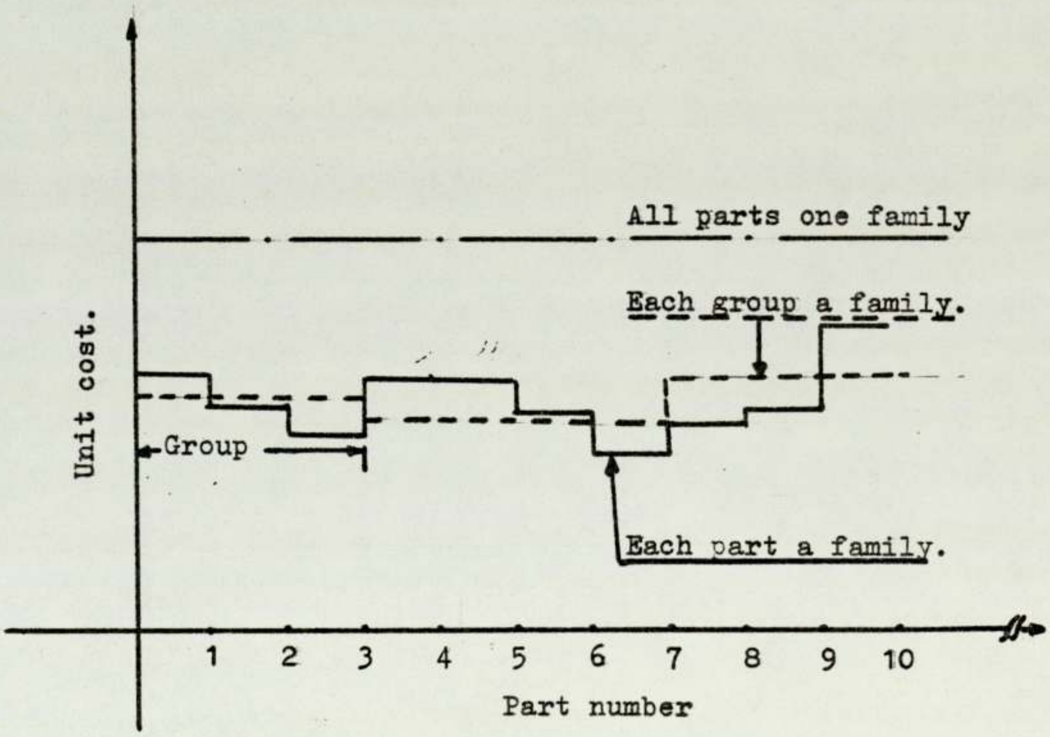


FIG (33) Unit Cost (Cu) To Cell Utilization At The Company Given Quantities.

effect of individual families a maximum and minimum quantity ratio was used to produce unit cost at different utilizations. The effect of unit cost change with utilization was recorded in fig (34). The maximum limit was the most significant to be compared with other solutions, while the lower limit in most of the cases was almost negligible. Therefore only maximum values will appear in the data and graphs. The maximum level of unit cost is the highest to be incurredfor each family or group. The distribution of unit cost for each machine can be illustrated as follows:



Solution 2.

Where machine (1) and machine (4) join together to form a cell while other machines remain as individual cells. Maximum and minimum families where established to show unit cost boundaries

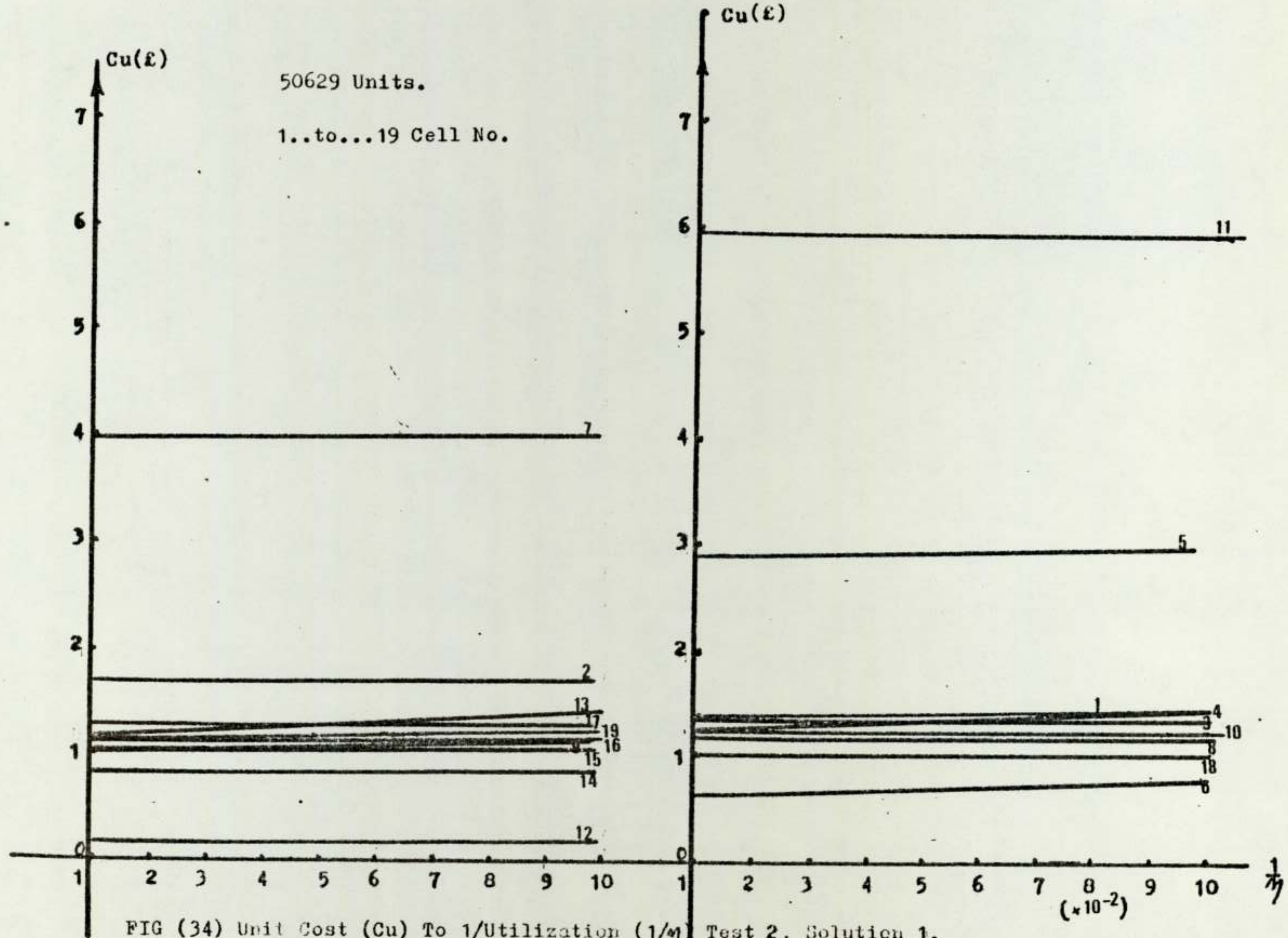


FIG (34) Unit Cost (Cu) To 1/Utilization (1/η) Test 2, Solution 1.

and the effect of family formation at constant quantity input. For summary of useful results see fig (35). There is an improvement in unit cost value of both machines (1 & 4) of the new cell formation.

Solution 3.

Where machines (1,4 & 9) were joined together at a new machine group similarity coefficient to form a cell, and the rest of the machines remain as individual cells. The same procedure described was followed. The relevant results are shown in fig (35). There is an improvement in unit cost value of machines (1,4 & 9) of the new cell.

Solution 4.

Where machines (1,4,9,14,13 & 2) were joined together to form a new enlarged cell while other machines remained as separate cells. Maximum and minimum unit costs were ascertained to be compared to those established with different family informations. For summary of relevant results see fig (35). There is an improvement in unit cost value of machines (1,4,9,13 & 2), while there is no improvement in machine (14) as part of the new cell.

Solution 5.

Where all machines are grouped together to form one big cell. The same procedure was followed and data for comparison ascertained as explained above. see fig (35). There are definite improvements in unit cost of most of the machines involved

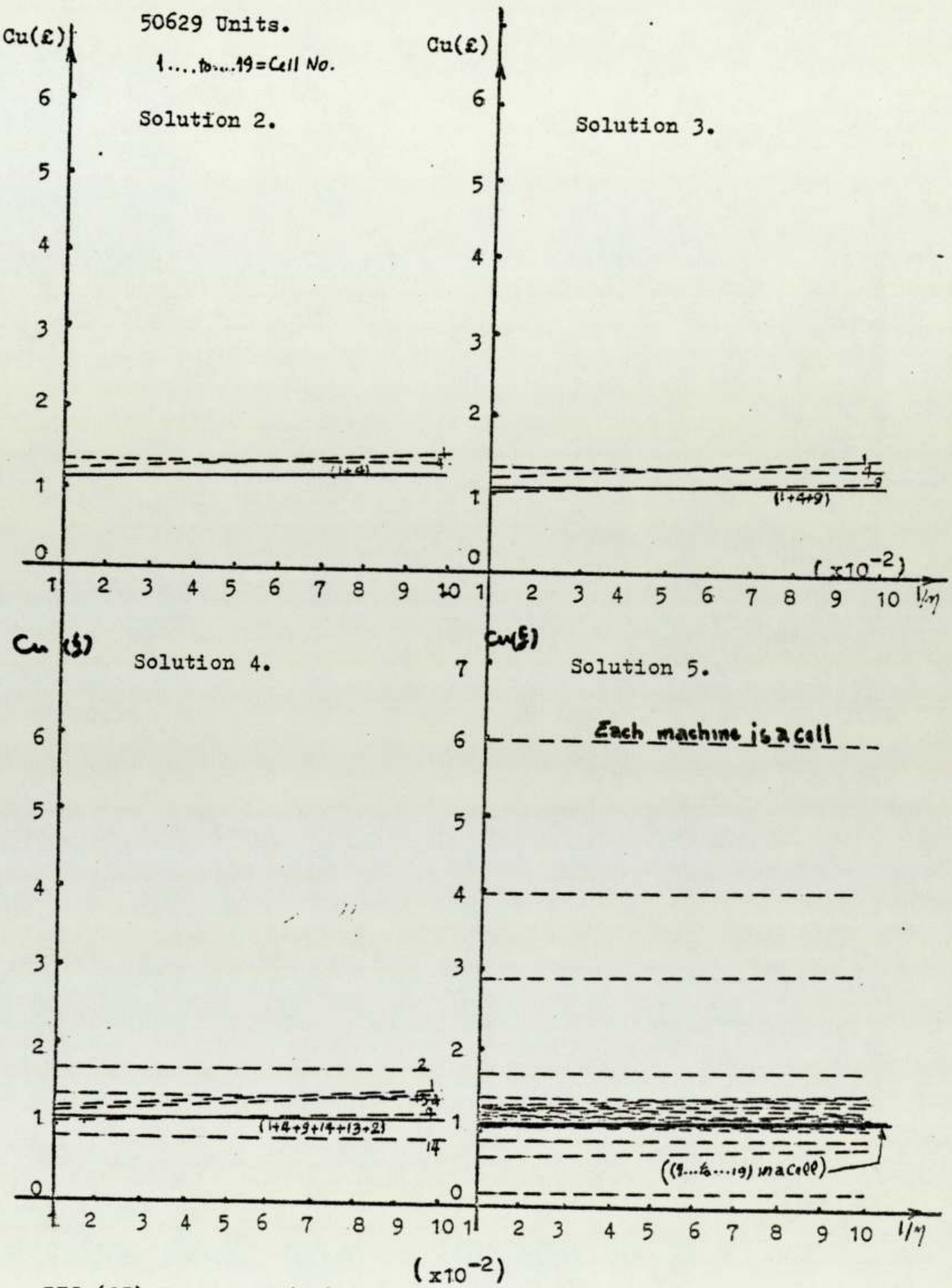


FIG (35) Unit Cost (Cu) To 1/Utilization (1/η) Test 2.

especially those with high unit cost, when machines began to join together to form cells; solutions 1 to 5.

The Third Test:- Of family formations was formed when each part was classified as an individual family. This occured at a similarity coefficient of over 100% (for this particular data sample). Unit cost for comparison for the five chosen machine group solutions was established on the same basis as explained in the second test. For calculations see Appendix (7), and for relevant unit cost data representation of the five solutions see fig (36 & 37).

Solution 2; Cell Comprising Machines (1 & 4).

There is an improvement in unit cost value of both machines 1 and 4 of the new cell.

Solution 3; Cell Comprising Machine (1,4 & 9)

There is an improvement in unit cost value of machines (1,4) as part of the new cell while there is no improvement for machine (9).

Solution 4; Cell Comprising Machines (1,4,9,14,13 & 2).

There is an improvement in unit cost value of machines (1, 4,13 & 2) as part of the new cell while machines (9 & 14) shows no improvement.

Solution 5; Cell Comprising All Machines Involved.

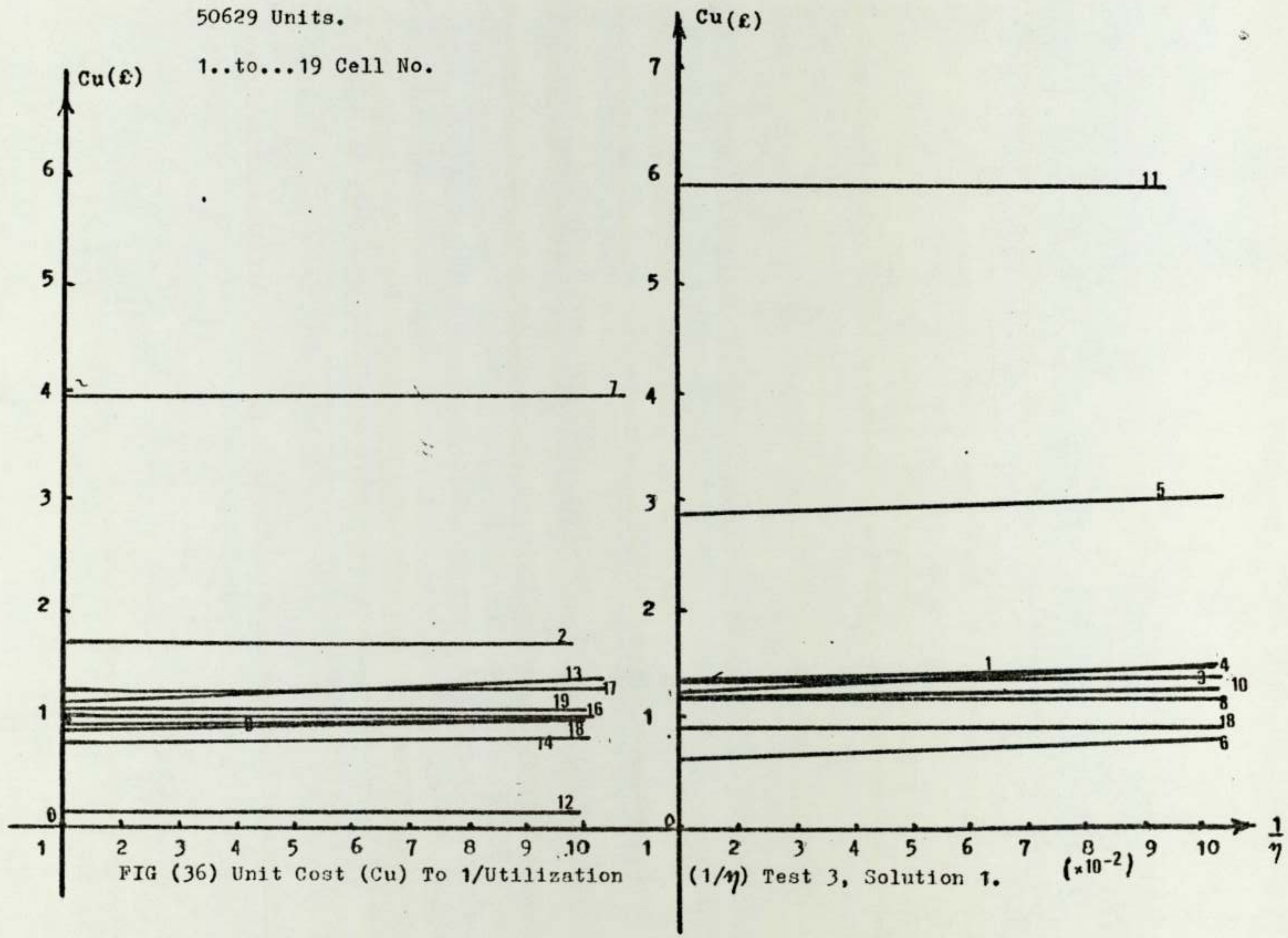


FIG (36) Unit Cost (Cu) To 1/Utilization (1/η) Test 3, Solution 1.

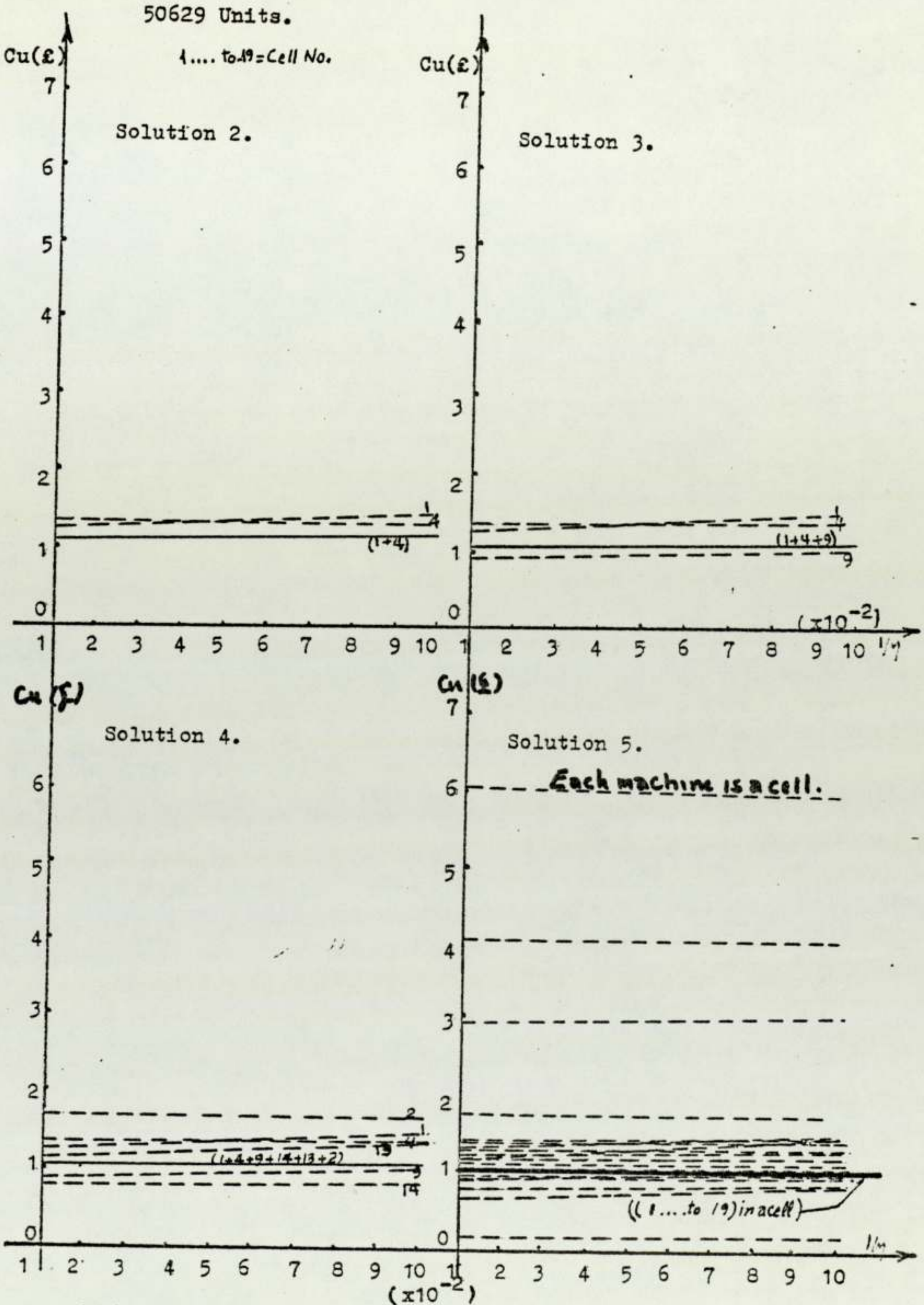


FIG (37) Unit Cost (Cu) To 1/Utilization (1/η) Test 3.

There are definite improvements in unit cost for the vast majority of the machine tools especially those with high unit cost. When machines began to join together in cells, solution 1 to 5.

The results obtained tend to point to the solution where every part is a family fig $(38)_a$ for example and where all the machines are grouped in one cell fig $(38)_b$. It is important to note that for this particular case the variance in unit cost between the second test, (each group of parts classified as a family), and the third test (each part classified as a family), was not as significant as that between these two tests and the first test (all parts classified as one family).

7.6. Summary And Discussion Of Results:-

The investigation carried out was high-lighted by the data and results discussed all through this chapter and recorded in different appendices, tables and graphs. A number of figures can be drawn straight away from the results. fig (39,40 & 41) for example shows the summary relationship between utilization and unit cost of each cell at different total quantities (i.e. 30000, 40000, 50629 and 60000 units), at constant quantity ratio and changeable quantity ratios. It was significantly shown from the figures drawn for all cells that unit cost lines of total quantities above the 50629 units of changeable quantity ratio is lower than those if the ratio was kept constant, and the reverse is true of those under the 50629 units. This provides a state, for this particular case under the given assumptions, that product mix (quantity ratio) should be kept constant if the total quantity is

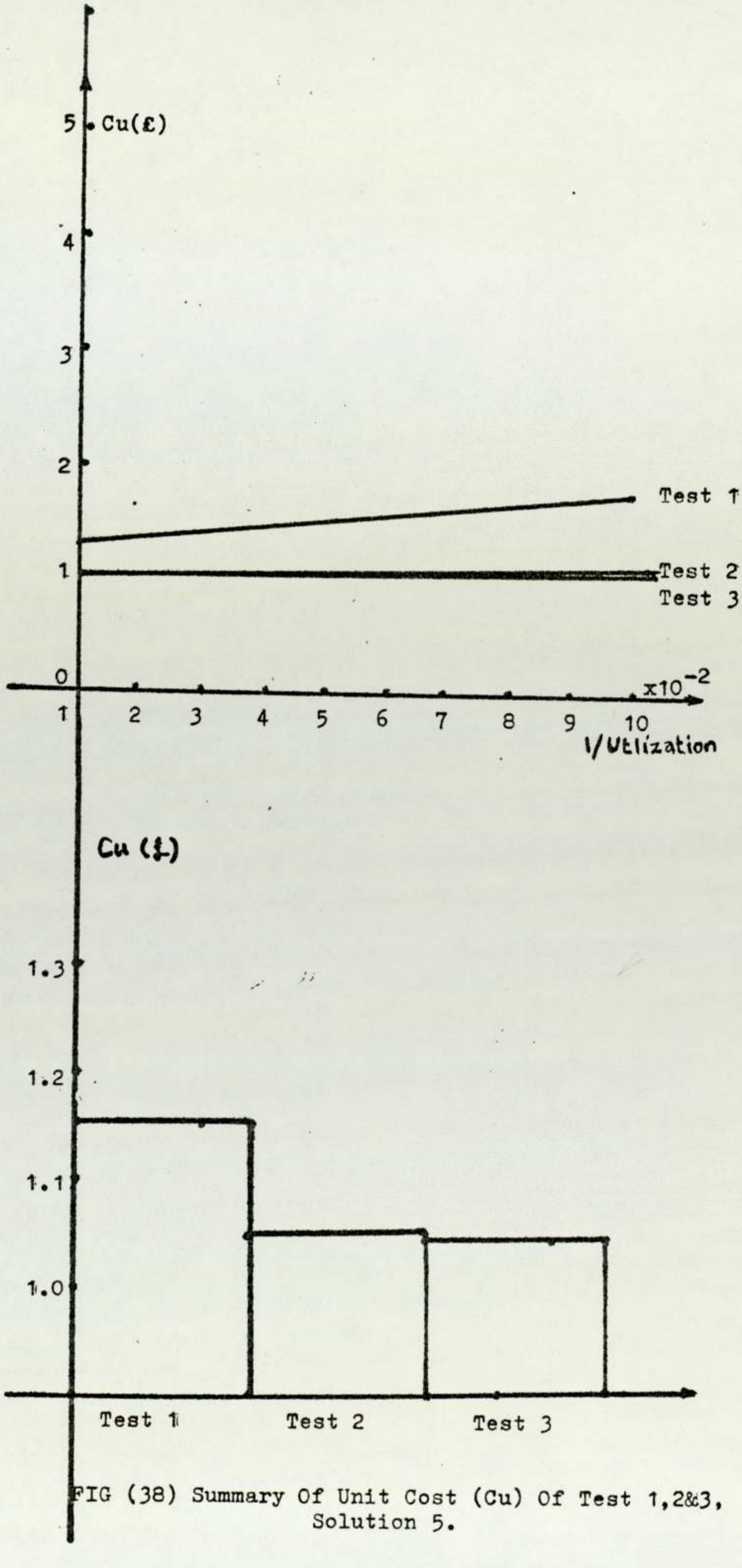


FIG (38) Summary Of Unit Cost (Cu) Of Test 1,2&3, Solution 5.

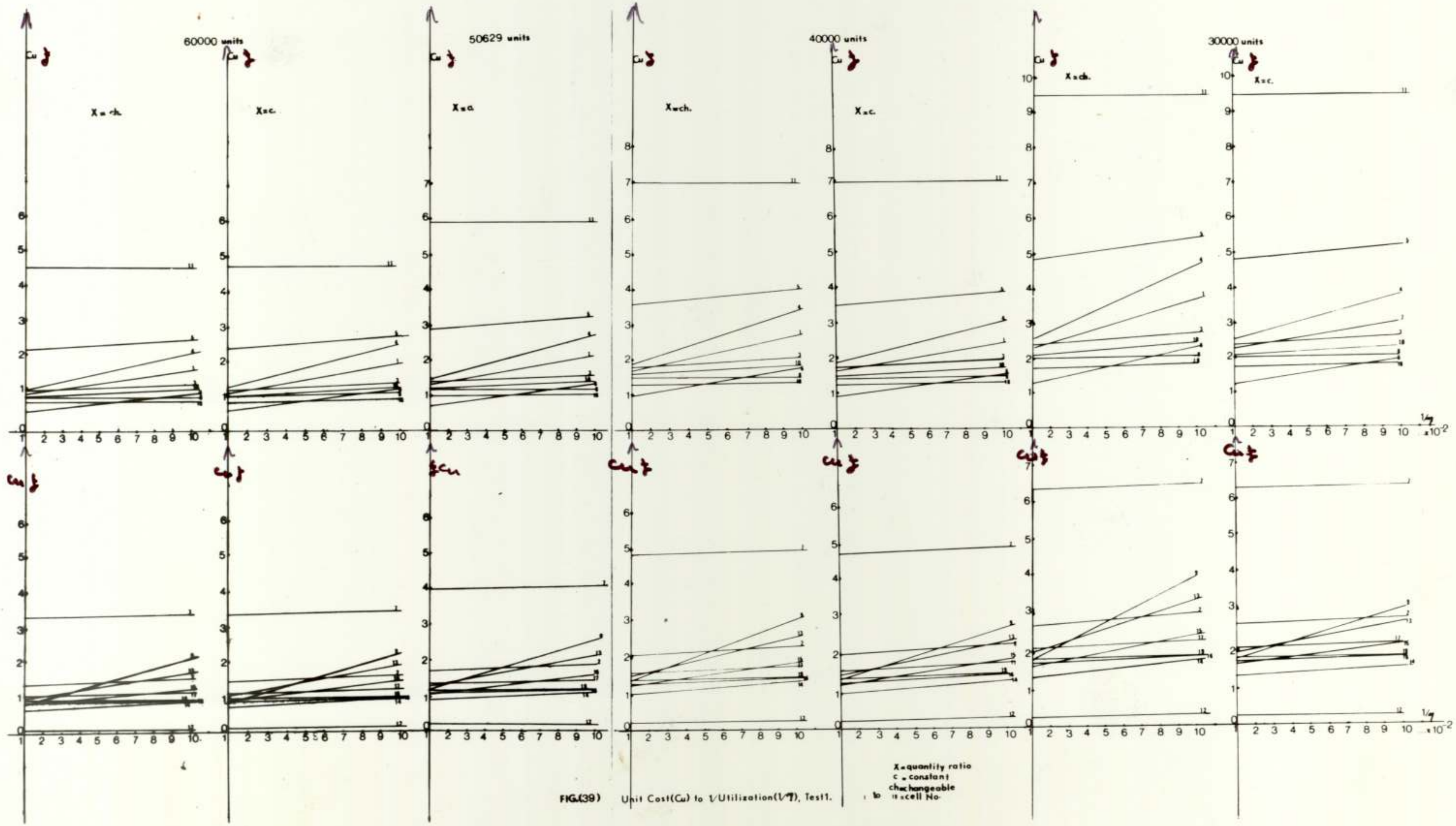
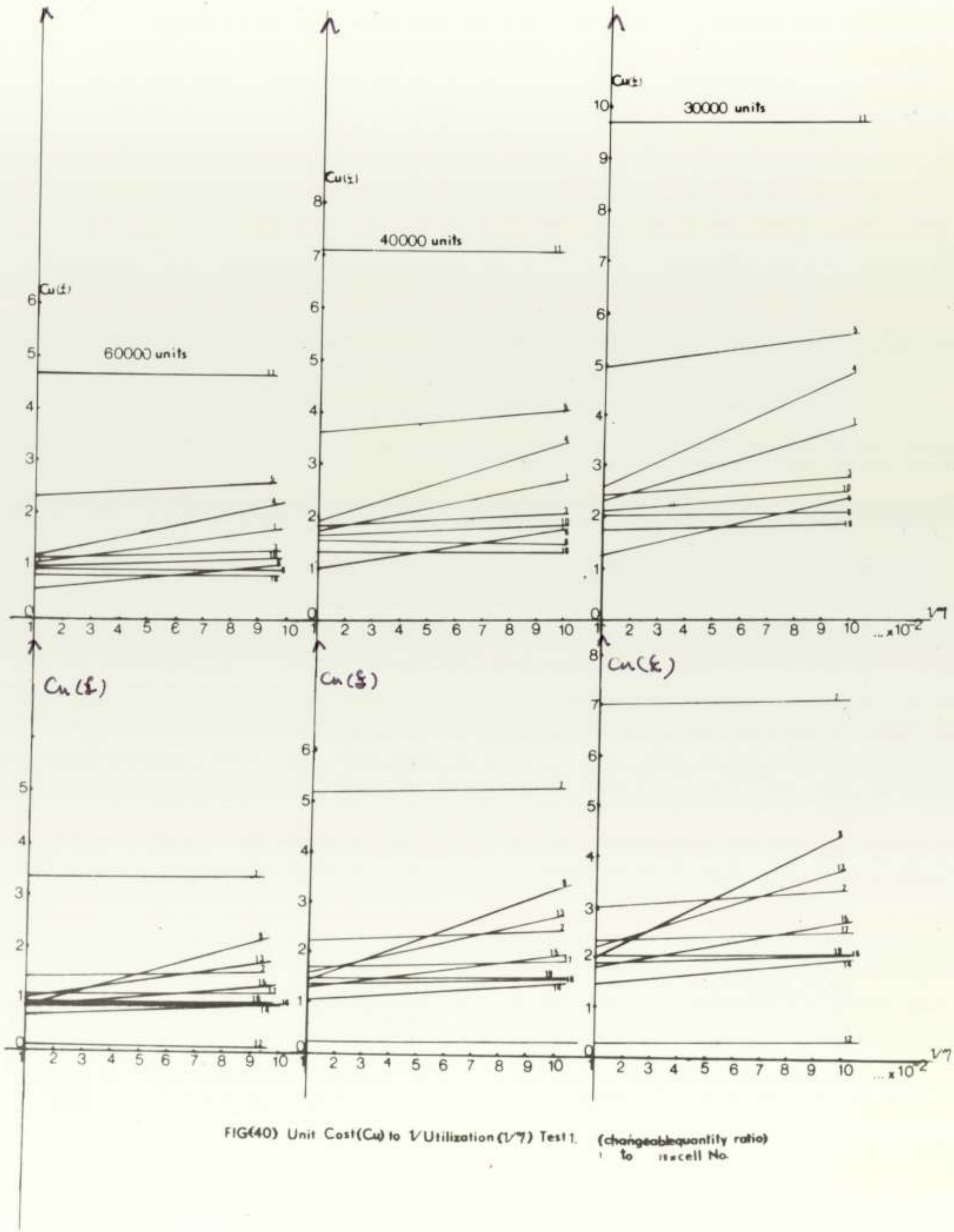


FIG.(39) Unit Cost(C_u) to 1/Utilization($1/\eta$), Test1.

X = quantity ratio
c = constant
ch = changeable
1 to 11 = cell No.



FIG(40) Unit Cost(Cu) to 1/Utilization (1/η) Test 1. (changeable quantity ratio) 1 to 11 = cell No.

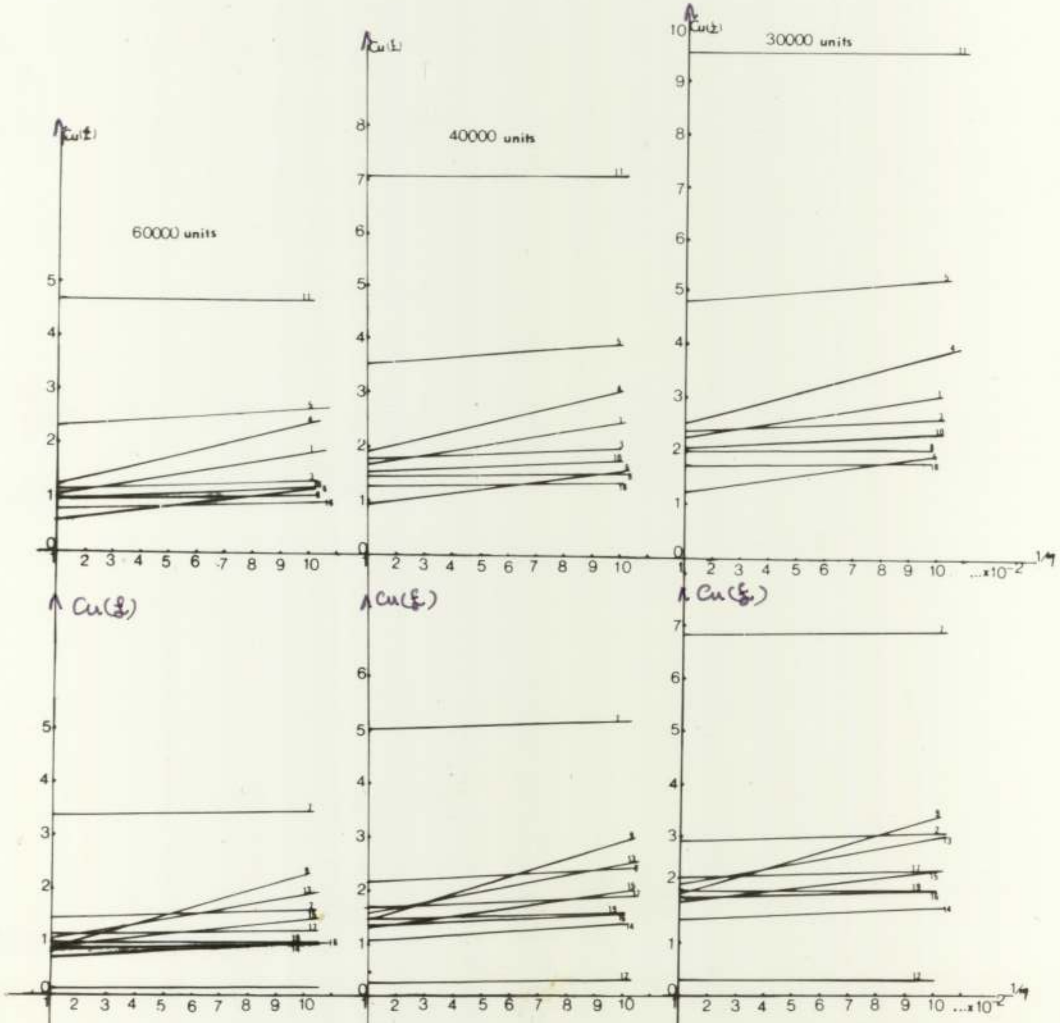


FIG (41) Unit Cost (Cu) to 1/Utilization(1/η) Test 1. (constant quantity ratio) 1 to 19 = cell No.

to be reduced and should be changed if it is going to be increased. As quantities and utilization are related then the same unit cost lines can be drawn from quantities as those from utilization. From the figures drawn of utilization or quantity against unit cost the significance of the cell could be obtained. As can be seen from fig (42), for example, on one hand the large angle clear slope of the cost line indicates that a cell/or (machine) is significant, and any change in utilization or quantity will cause a change to the slope of this line, hence changes the state of the unit cost for the cell. e.g. machine (1,4 & 9). On the other hand for some cells the angle of the unit cost line is very small, that is it is almost horizontal to the base line and any change in utilization or quantity will have very little effect or none at all (e.g.machine 7,12,11..etc). Those cells can be regarded as insignificant and unless the capital cost of the machine is high it can be excluded from the study.

All results of individual machines as separate cells at the given total quantity of 50629 units for the three sets chosen for family formations are shown in fig (25,34 & 36). Also the other solutions of machine grouping at the condition where every part is a family, every group of parts is a family and all the parts are one family is plotted in figs (37,35 & 26). A general comparison between different cell set-ups is shown in fig (43).

From the findings of the calculations and the establishment of the most economical cell and family formation, it can be

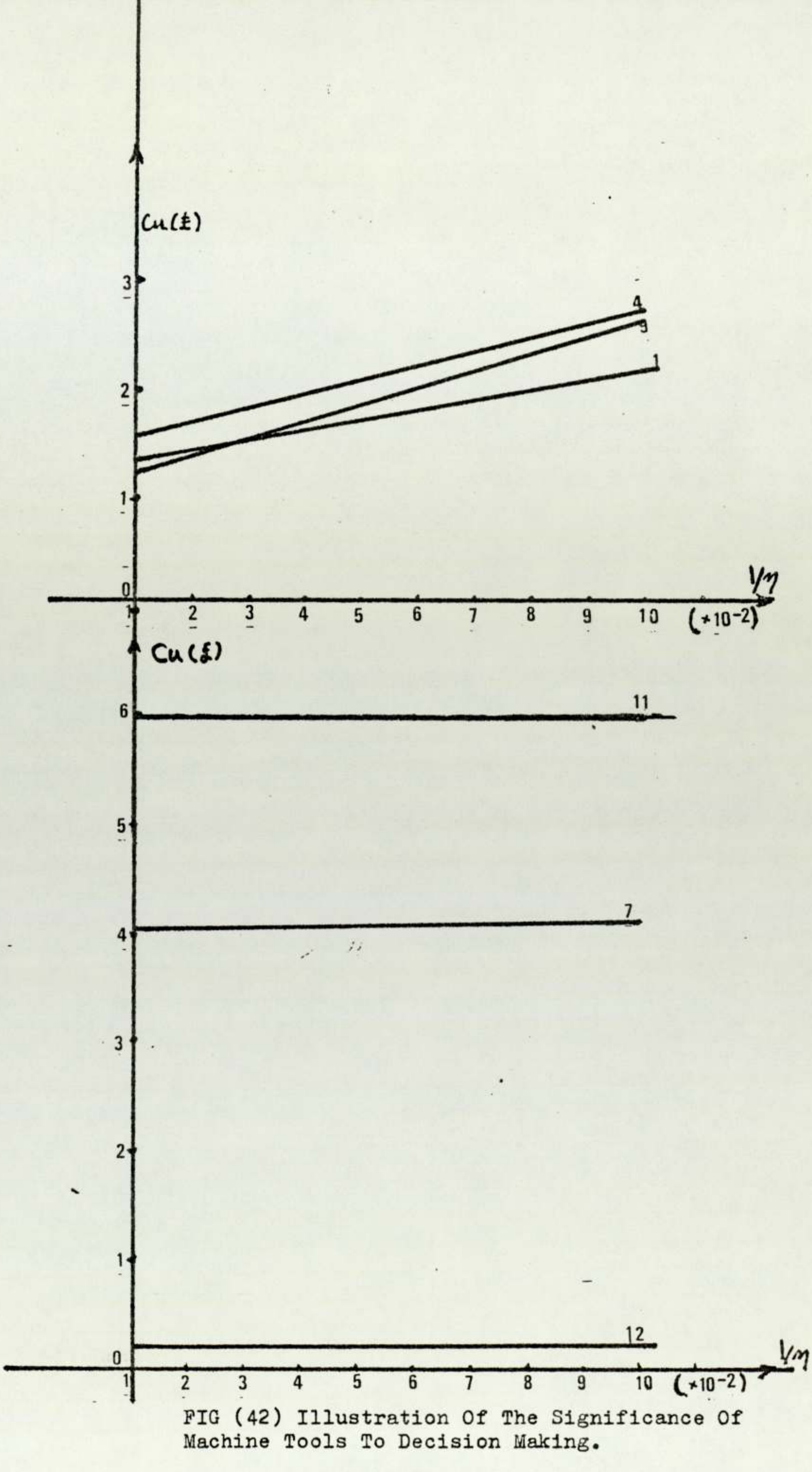


FIG (42) Illustration Of The Significance Of Machine Tools To Decision Making.

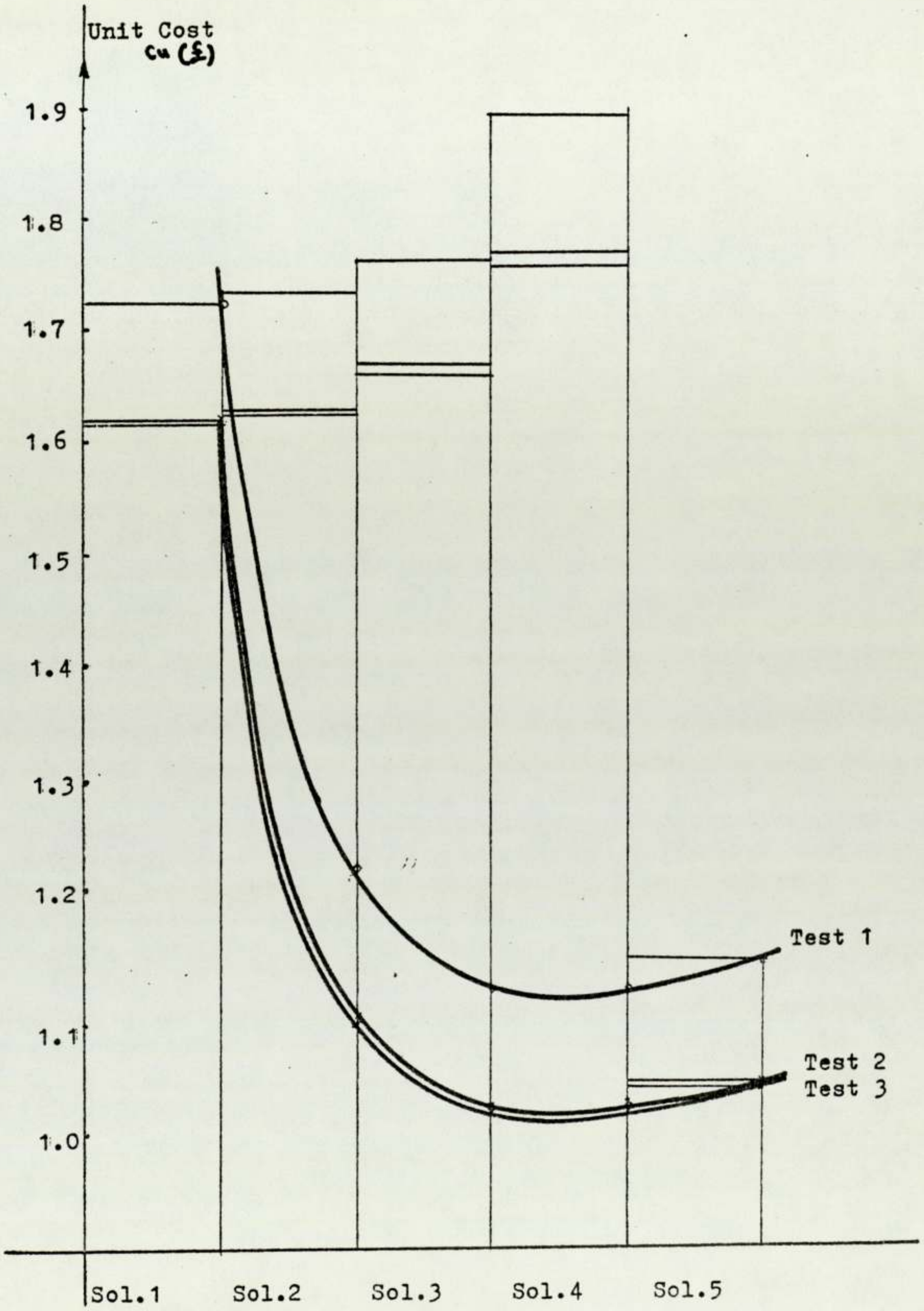


FIG (43) A General Comparison Between All Tests And Solutions Involved.

concluded for this particular case study that the most favourable is where all significant machines are grouped together with each part regarded as separate family fig (43). As far as the machine grouping is concerned the findings resemble those existing on the company's shop floor. The results obtained from part grouping are not as those given by the company, where each group of parts as a separate family is the most favourable. This was so because of the assumption that all basic cost items were left unaltered due to the lack of a useful costing system and the appropriate information. It was found that there was very little significant difference between the unit costs of the set where each part is a separate family or the set where each group of parts is a separate family. The latter is the existing condition in the company.

CHAPTER 8

CONCLUSIONS AND DISCUSSION.

8.0. Conclusion And Discussion.

The object of this project was to study the possibility of introducing a costing procedure to enable comparisons to be made not only between the existing conventional manufacturing system and the proposed GT system, but also to choose the best of many solutions of GT cellular manufacture.

The conclusion of the study can be divided into two main parts.

8.1. Conclusions Related To The General Findings Of The Back Ground Study To Introducing GT As A Total Manufacturing System:-

a) Majority of the results obtained from previous studies of proposing or introducing GT can in general be classified as being special conclusions to specific cases, and to generalize these findings must only be assumed to be an overall guide to future studies.

b) The introduction of GT to the manufacturing industries in many cases was as a specialist tool to overcome certain difficulties in particular section or sections of the company and not as complete solution.

c) As a result of the points above contradictory results and claims were often made. While a section of the company was cured of its problems, in the short term, the possible side effect of this change on other sections, was ignored in many cases. (e.g. Low utilization of minor machines). It is only recently that many people have realized these serious defects and have begun to advocate the introduction and recommendation of GT cellular manufacture as a complete system.

d) The inadequacy of the existing cost data, cost systems and in many cases cost consciousness of the engineers resulted in very limited results being presented in terms of cost.

e) It has been recommended in this thesis that a procedure which can include all or the majority of parameters of introducing GT cellular manufacture as a complete system should be developed to show all benefits in all sections compared to the existing situation.

f) From this particular study a proposed procedure based upon unit cost as a common criteria is put forward where all or most of the items can be expressed in a quantitive way which may be more acceptable by management.

8.2. Conclusions Specifically Related To The Results Of This Case Study:-

i) It was found very difficult to obtain accurate cost information and the company is under-going a major rethink of its cost data system so that future improvement studies can be easily related to cost.

ii) To establish a realistic general procedure of unit cost for comparison and in consultation with the company's needs; a large existing cell was chosen to be studied in order to show if a number of smaller cells are more adequate than one large cell. The result was that from unit cost stand point, and according to the existing condition the large cell should not be broken down into smaller cells.

iii) It was felt that the possibilities of producing only one solution, as it is customary in previous studies, was shortsighted because of the potential capabilities of the existing data to produce more than one solution of cells and families for the same case study.

iv) Using a computer aided system a number of solutions of groups of machines (group of machines ranges from one machine upwards), was developed. Also number of solution of families of parts (a family ranges from each part a separate family up to all parts in one family), was established. see table (6 & 7).

v) A general form of cost procedure was used i.e. unit cost = variable cost + fixed cost/quantity. ref (46). $Cu = V + F/N$.

vi) Because of the importance attached to machine utilizations, products mix, and number of machine the cost procedure was interpreted in terms of those items $Cu = V + \frac{F\ (\sum t_p . X)}{\eta \times R \times W}$;

vii) From the results obtained by applying the unit cost procedure it was found that:-

a) Machine cells:- The unit cost value was at its lowest when all the required machines were grouped in one cell, at zero similarity coefficient, and it progressively increased with the separation of machines into smaller groups. It was at its highest value at the solution where cell (1,4,9,14,13,2) (solution 4) a separate cell fig (46). The the unit cost was progressively reduce i.e. solution 3,2 & 1. Therefore solution 1 is the second best as a whole solution.

b) Part Families:- Unit cost value was at its lowest value when each part is a family (similarity coefficient 100) and it progressively increased to be at its highest value when all parts were in one family. (similarity coefficient 0). The choice of the best solution must be complied to the results of cell formation.

The first part of the result coincides with the existing situation in the company, where all the machines are grouped in one cell, and according to the findings of this study the cell should not be broken down to smaller cells. The second part points to the solution where each part is a family rather than that of the companys, where each group of parts is a family. In practical terms and for this study it was taken that the group is the smallest unit because it includes all identical parts, to save computer time and expense and to use the already existing data, therefore the choice of the test where each part is a family should be the best solution. It can be recommended therefore that the existing situation in the company is the best solution under the given circumstances.

The results have been summarized into fig (44,45,46 &47) for the three tests, at the five proposed solutions. It is clear from the representation that, solution 5, test 3 is the most economical as a whole solution. Comparison of unit cost of different cell formation shows that cells of solution 3 and solution 4 are the most economical. The finding confirms the fact that, solutions have to be considered as a whole and not

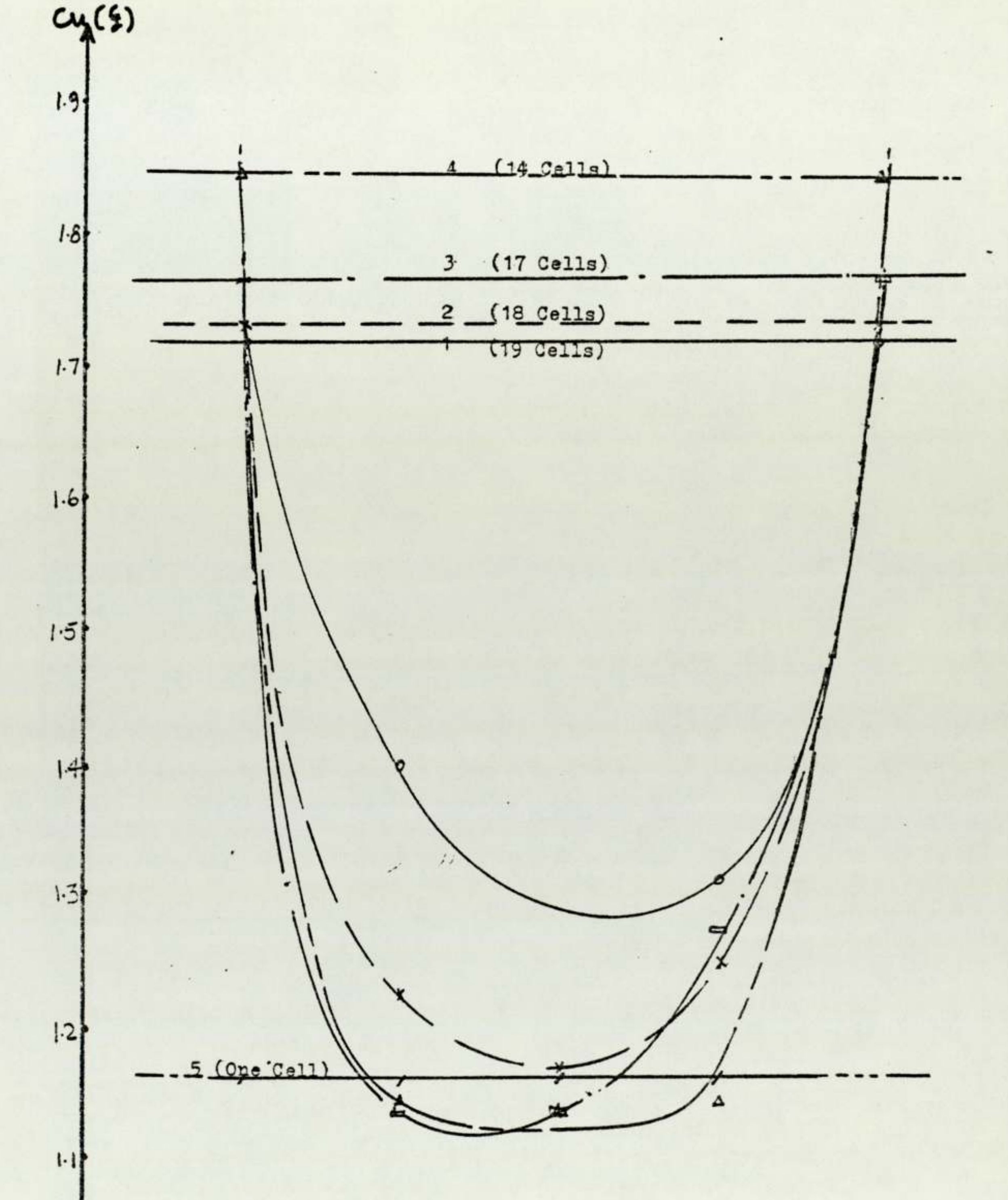


FIG (44) Representation Of Unit Cost (Cu) Of Test 1.Solutions 1,2,3,4,& 5

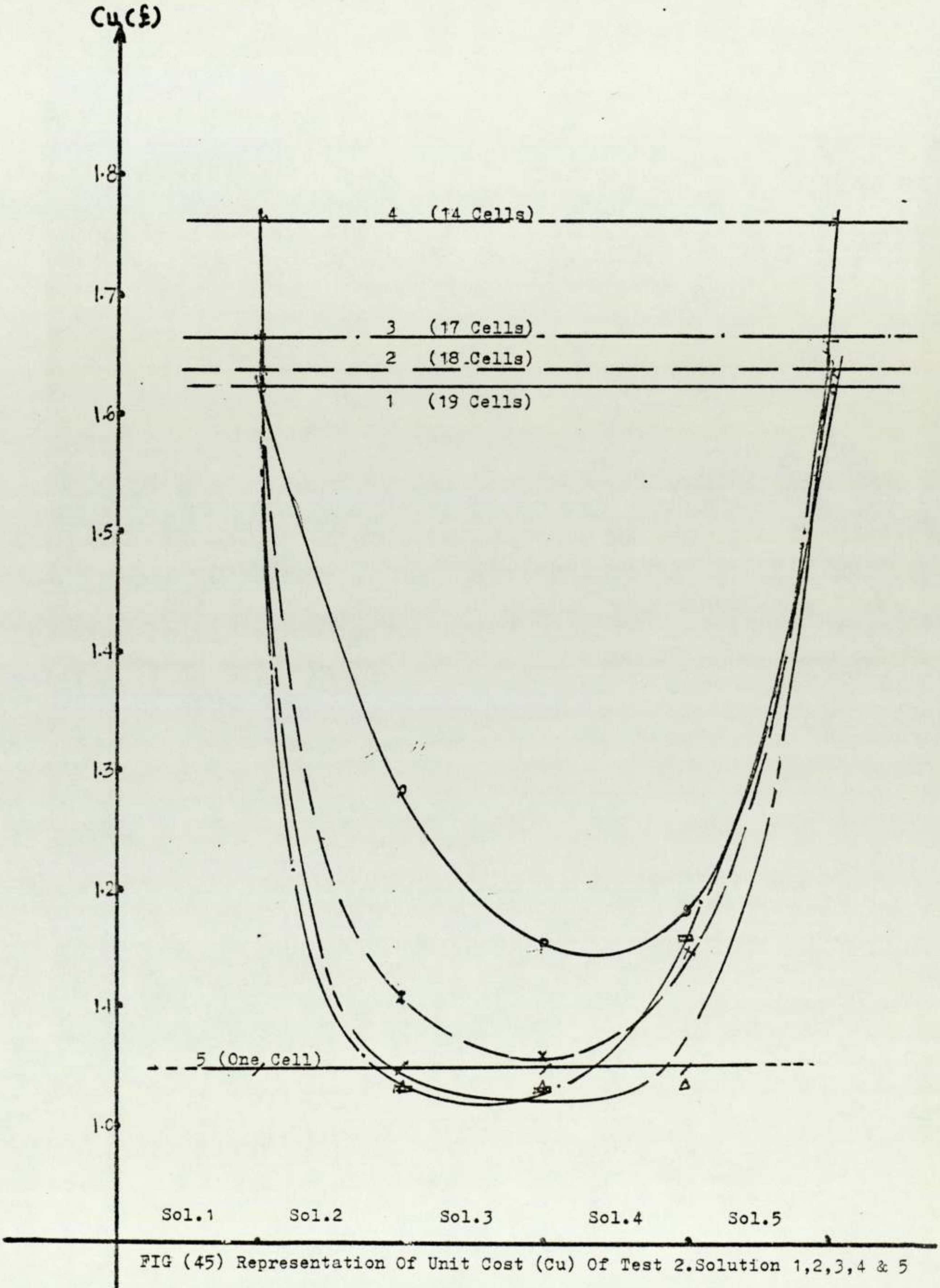


FIG (45) Representation Of Unit Cost (Cu) Of Test 2.Solution 1,2,3,4 & 5

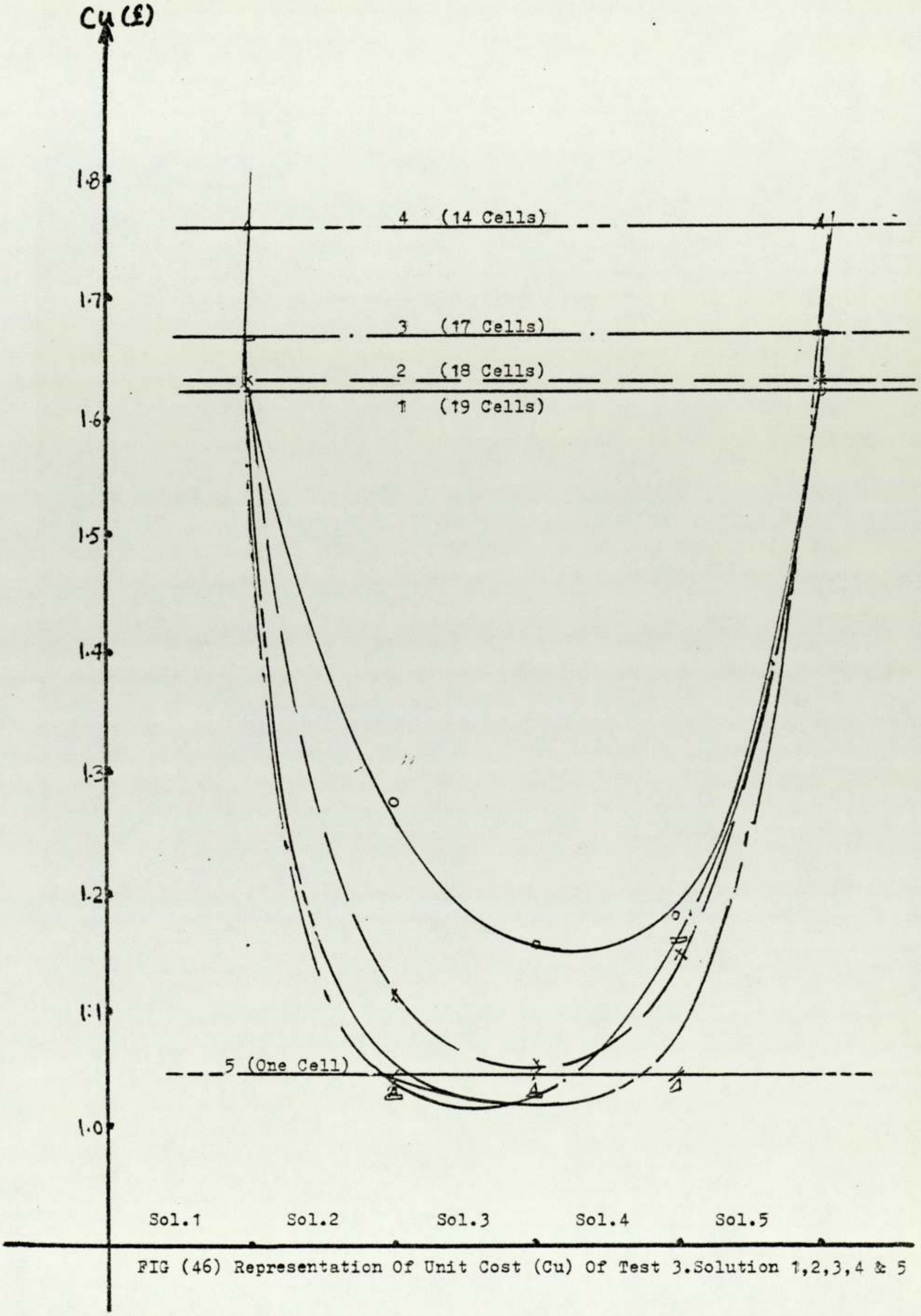


FIG (46) Representation Of Unit Cost (Cu) Of Test 3.Solution 1,2,3,4 & 5

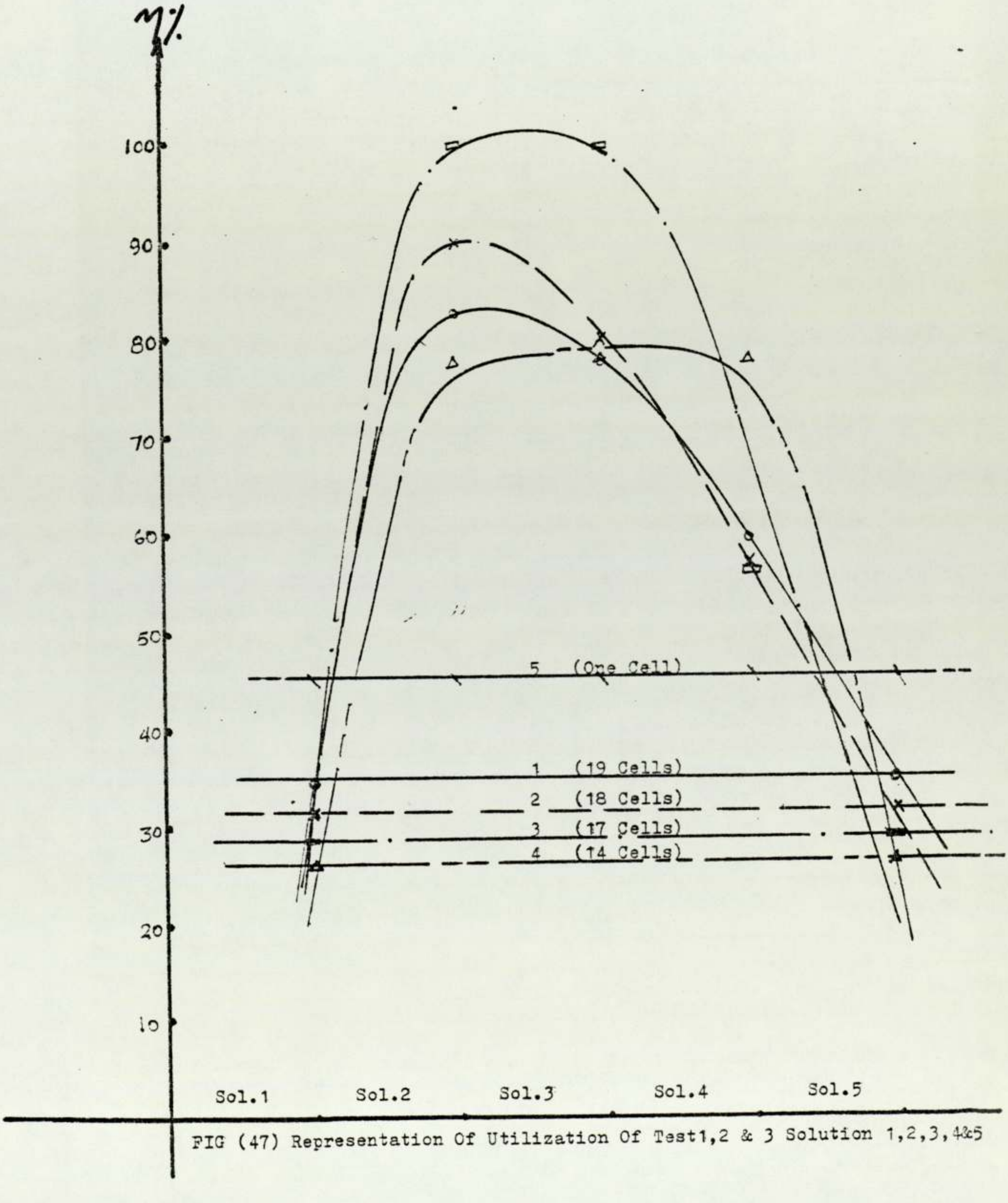


FIG (47) Representation Of Utilization Of Test1,2 & 3 Solution 1,2,3,4&5

just partially to avoid misleading conclusions.

viii) From the results obtained in chapter 4, where in general a reshuffle of family formation resulted in lower unit cost even though the total quantity to the cell had been reduced, it was concluded that, it is not necessary to increase quantities to improve utilizations but equally important is effective product ratio and family formation. Therefore to avoid an increased W.I.P. resulting from increasing quantities, the same products can be manipulated to produce better utilizations of under utilized machines figs (17,18 & 19).

ix) The introduction of quantity ratio made it possible to test the possibilities of increasing and decreasing total quantities.

As it was explained before, the unit cost decreases with an increase in quantity and the results obtained for this study are:-

a) At Constant Quantity Ratio:- The unit cost was reduced progressively with an increasing utilization and total quantity, fig (40). For the same condition given by the company utilization was halved for all quantities with progressive reduction of unit cost tables (10,11 & 12).

b) At changeable quantity ratio:- The unit cost was also reduced with a increasing utilization and total quantity, fig (41). For the same condition given by the company and changed quantity ratio to produce the same utilization, unit cost was progressively reduced, tables (13, 14 & 15).

The above results and reshuffling of data was made to show the possibilities of the use of the procedure to improve utilization by change in quantities.

x) The computer programme to produce similarity coefficient for the purpose of machine and part grouping gives other statistical data which can be very useful in determining items such as scheduling, inter and intra cell organization ..etc. Other methods of grouping can also be used.

xi) Two important features have arisen from the unit cost to utilization representation, one is that when the line is horizontal or almost so to the base line the machine can be described as insignificant to decision making. On the other hand important machines have shown a steep slope in their unit cost to utilization line and the steeper the inclination the more significant is the machine to decision making. A careful consideration should be given to the machine where the lines fall into the boundaries between being significant or not.

To discuss the results mentioned above it is important to stress the need for the introduction of unit cost as a general criteria to show the benefit of GT cellular manufacture. This study has demonstrated and opened the door to using unit cost by establishing a procedure of firstly establishing a number of solutions of machine groups and family formations and then deciding by using unit cost on the optimum solution. The study has also encountered the inadequacy of cost systems and data, also the need for production engineers to become cost conscious so that maximum benefit can be gained.

The main conclusion of this thesis is the establishment of a procedure from which an optimum condition for introducing or improving GT cellular manufacture can be possible and can be over simplified in a summary as follows:-

Part One Preparation:-

a) The status of the case study.
   Existing manufacturing plant.
b) The kind of the plant e.g. (cutting, forming..etc.
c) Existing data; including cost data.
d) Required data; including cost data.

Part Two Technical Consideration:-

a) Part to machine matrix.
b) Number of machine groupings (with determination of the method and criterion of grouping).
c) Number of family groupings (with determination of the method and criterion of grouping).
d) Quantity ratios (product mix).
e) Utilization and quantity calculations.
f) Proposed new plant.

Part Three Economical Consideration:-

a) Determination of cost items to be used as criteria for choosing the optimum solution.
b) Determination of the cost system to be used including the possibility of using the existing system.
c) Calculation of unit cost at different quantities, utilization and any other given conditions.

Part Four Conclusions:-

The determination of the optimumsolution at the given conditions.

a) Using unit cost formula choosen, each solution cost condition should be established.
b) Using cost comparison between the established solutions, the best one can be determined.

Recommendations For Further Work

1) Machine utilization is an important factor in cellular manufacture and many people have accepted the low utilization of second, third and finishing machine tools, which is compensated for by low capital cost or/and highly utilized labour force. The recommendation is to find in practice how many companies really accept this fact, the average level of the acceptable utilization for every machine and methods of over coming this problem.

2) The criterion used to group both machines and parts was related to the P.F.A. system. It will be very valuable to find whether the same method (cluster analysis) can be used for other criterion based on coding and classification system (e.g. Opitz). The author has already begun an investigation into the possibility.

3) As explained in chapter (5), there are more than one method of cluster analysis, and more than one similarity coefficient system; it is highly recommended that research should be undertaken to compare the usefulness of these systems in producing accurate solutions of family and machine groupings.

4) The use of general unit cost form, as has been pointed out before, was only chosen to illustrate the workability of the proposed procedure, and because of the lack of accurate and appropriate cost information. The possibility of using a more accurate method which will include items of importance to the

company concerned can prove vital and a research into cost methods and overall cost items widely used by the majority of the relevant industries should prove fruitful.

5) Investigation into the feasability of establishing a classification method on the same basis as that of Opitz basic code where, a combination of part classification and machine grouping can be carried out by the same programme. The code should be divided into two sections.

a) Geometrical code, which will occupy the first five digits and parts can be classified on the same Opitz system basis.
b) Functional code, where Opitz supplementary code would be replaced by description of the kind of machines and operation sequences from which machine groups can be established.

The facilities of clustan principles would be applied to establish those relevant results.

APPENDIX I

Example of the use of UACLUSTANC computer programme.

Contents:

- The programme.
- Component machine chart as Burbidge presented it.
- Binary data (components) occurence.
- Binary data (machines) occurence.
- Dendrogram of machine results.
- Dendrogram of component results.
- Component machine chart as rearranged by the UACLUSTANC programme.

The Programme:-

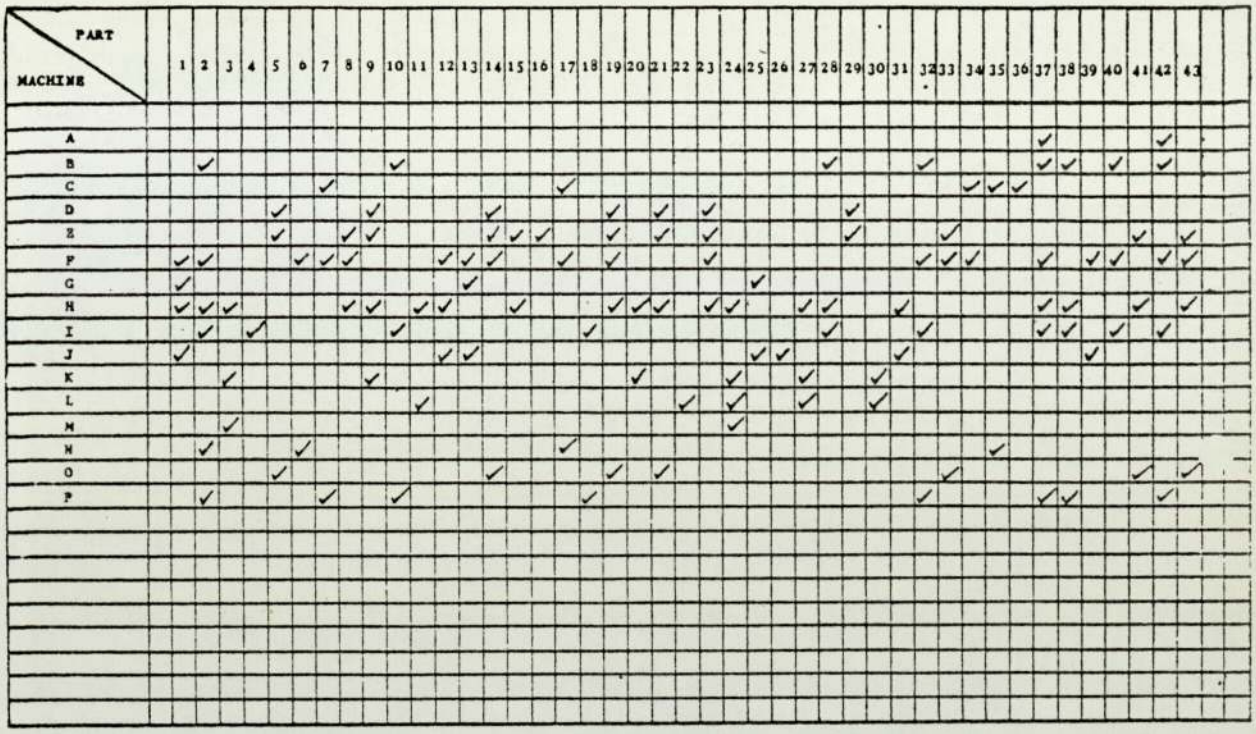
The programme used in this project is UACLUSTANC and (42) basically uses the idea described in section 5.1.1. It is described as a suit of fortran programmes designed for the collective study of several methods of cluster analysis. UNCLUSTANC will allow several programmes to be run within one job. The first programme of this package is A.T.F.I? which reads row observation data and stores it on the common disc-file. It also computes the principal component analysis and other basic statistics. All the input and computed results are stored on the disc file. The row data is listed, read in and may be used for checking purposes. Both continuous and binary data is accepted separately or mixed.

The second programme is A.T.C.O, which computes the similarity matrix and clustan linkage lists from all or part of the data from the data file created by A.T.F.I.

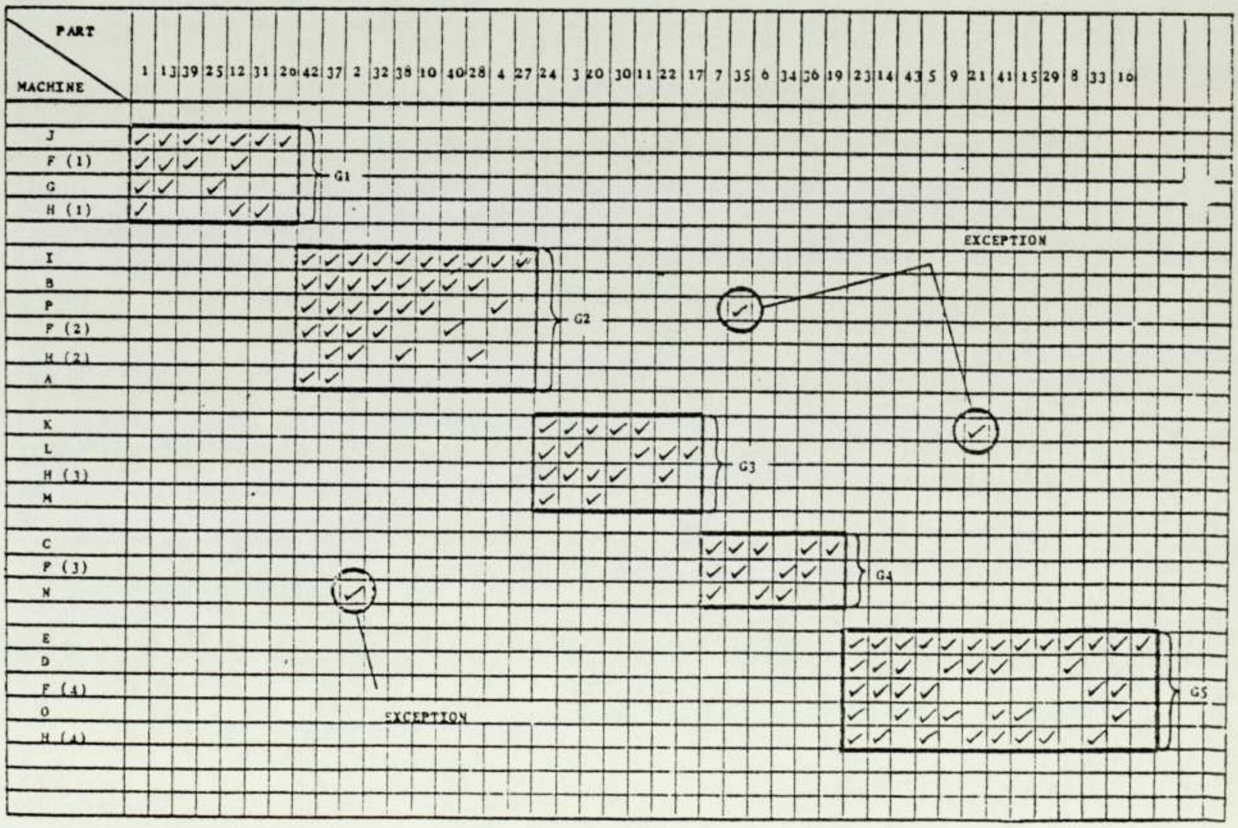
Programme A.T.R.I. is the third programme and is specifically designed to output part of the data, such as computed statistics, coefficient matrix..etc.

The last programme is called A.T.H.A. which consists of two main parts. Firstly the programme starts with N clusters, each containing a single individual, which are numbered according to the input order of the individuals. In each of (N-1) fusion steps, those two clusters which are most "similar" are combined and the resulting union cluster is labelled with the lesser of the two codes of its constituant clusters. Secondly when the programme completes all (N-1) fusion; it summarizes the sequence in a dendrogram graph which is outputed on the graph plotter. The programme works from the similarity matrix data produce by A.T.C.O.

a) COMPONENT MACHINE CHART

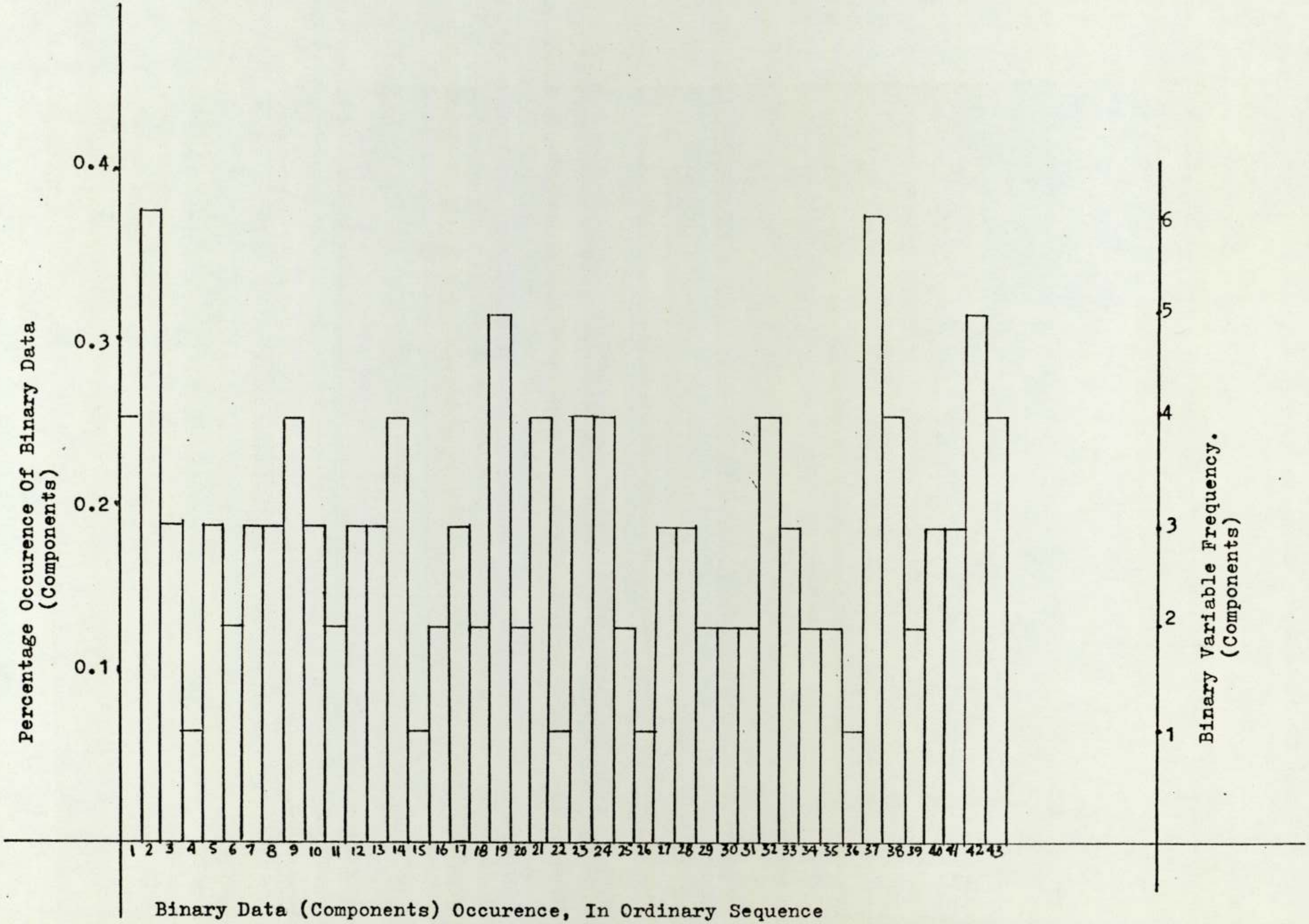


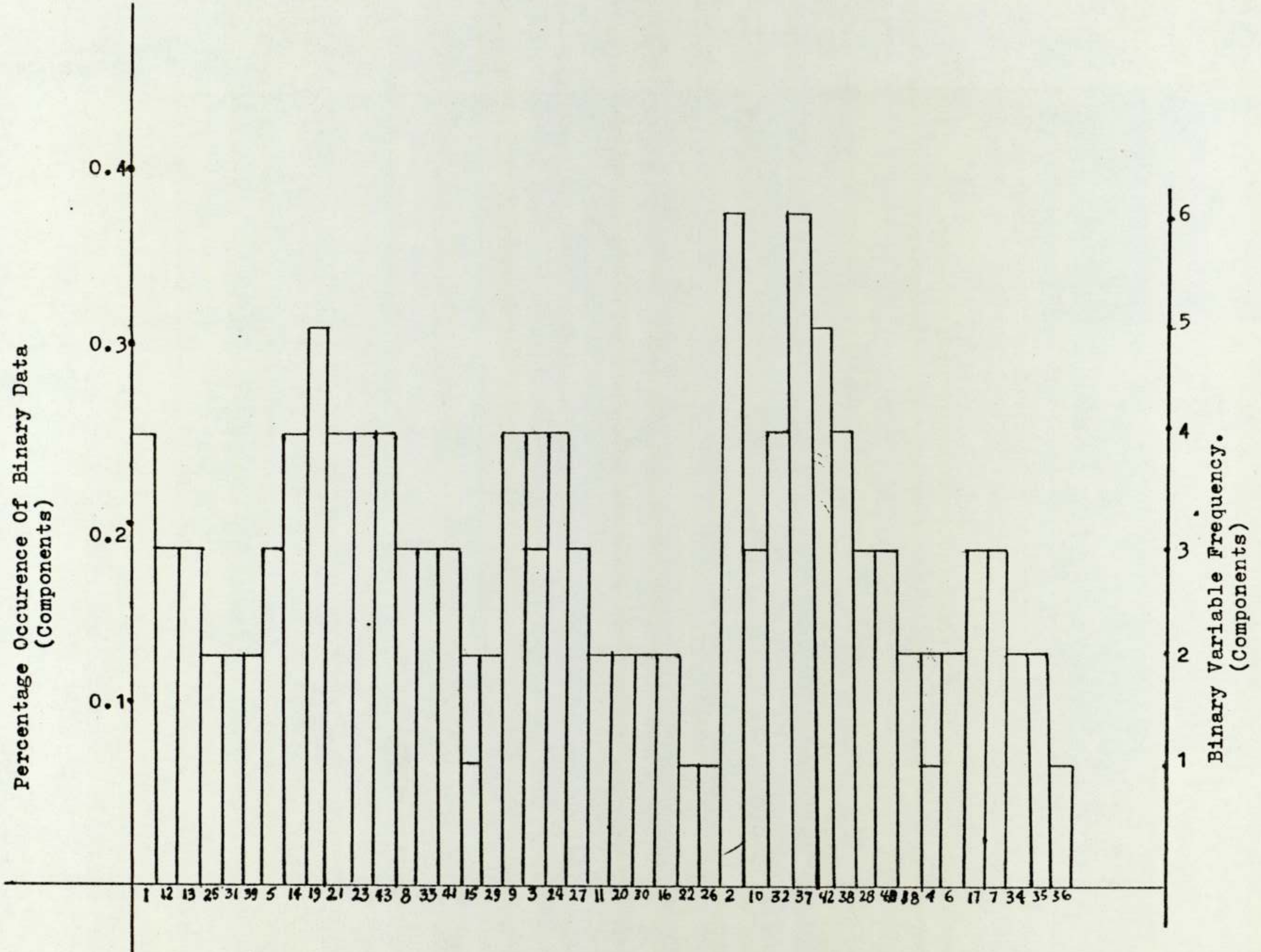
b) DIVISION INTO GROUPS AND FAMILIES



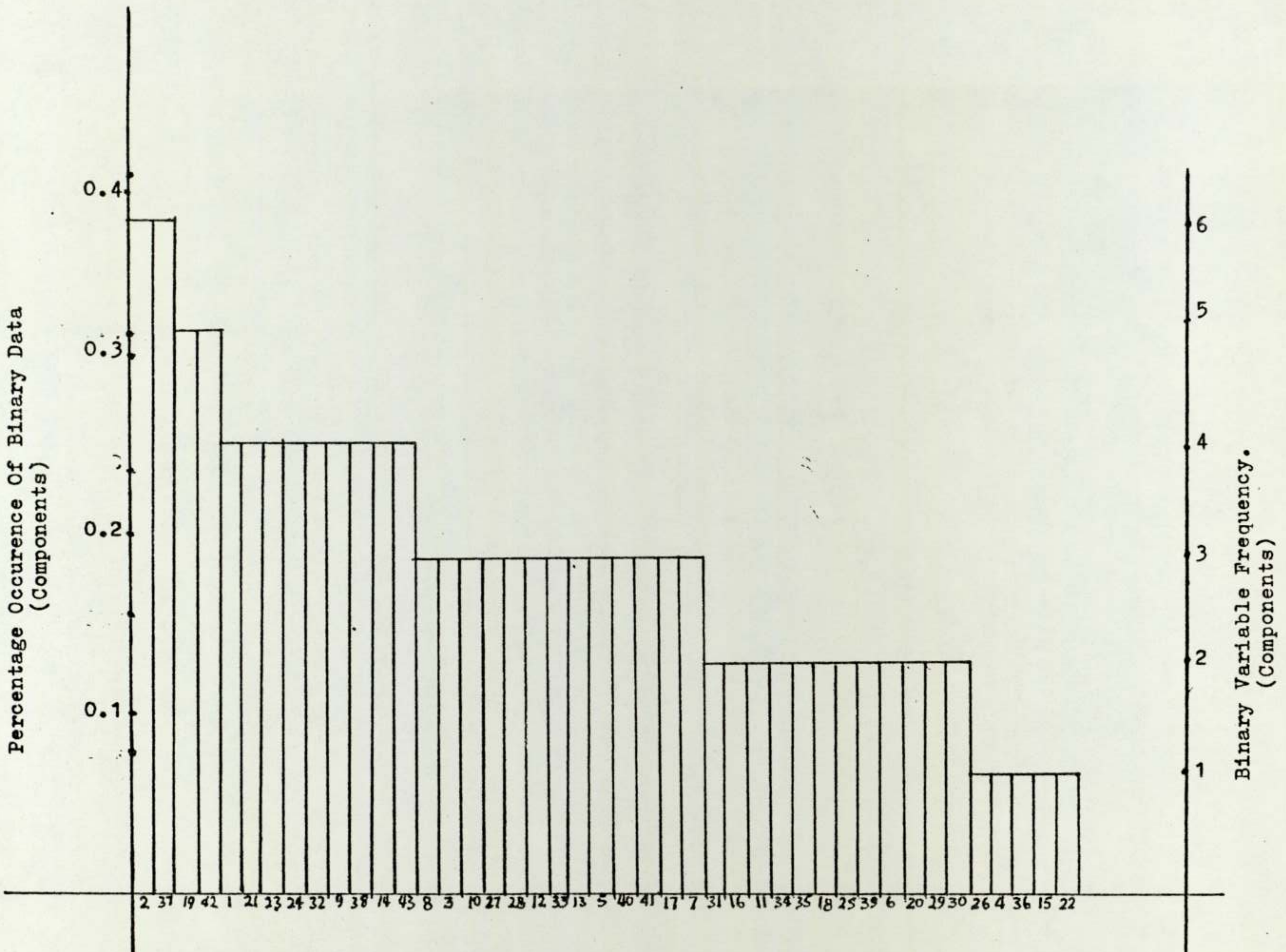
(AFTER BURBIDGE)

Group Analysis

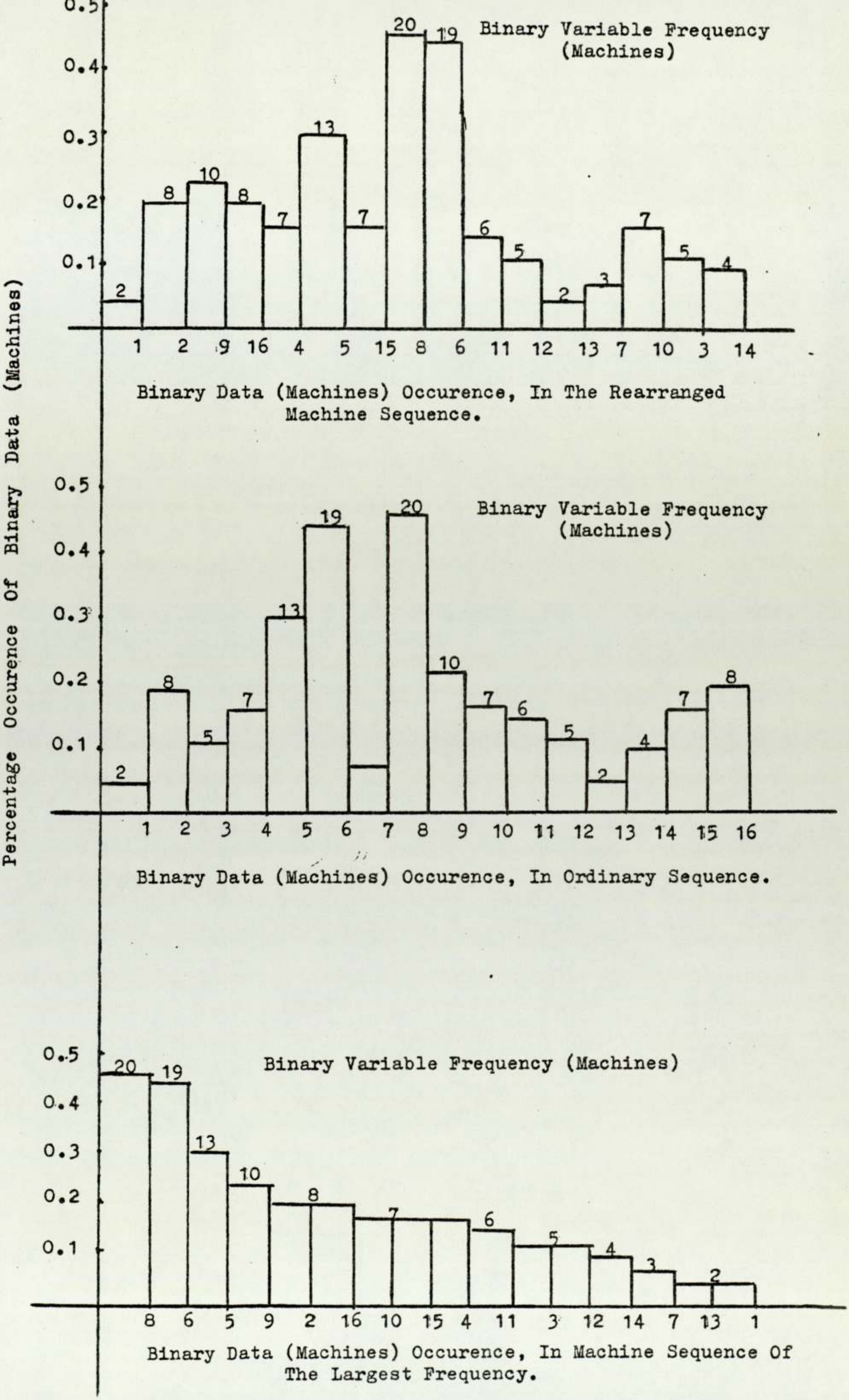

0.4
0.3
0.2
0.1
Percentage Occurence Of Binary Data
(Components)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43
6
5
4
3
2
1
Binary Variable Frequency.
(Components)
Binary Data (Components) Occurence, In Ordinary Sequence

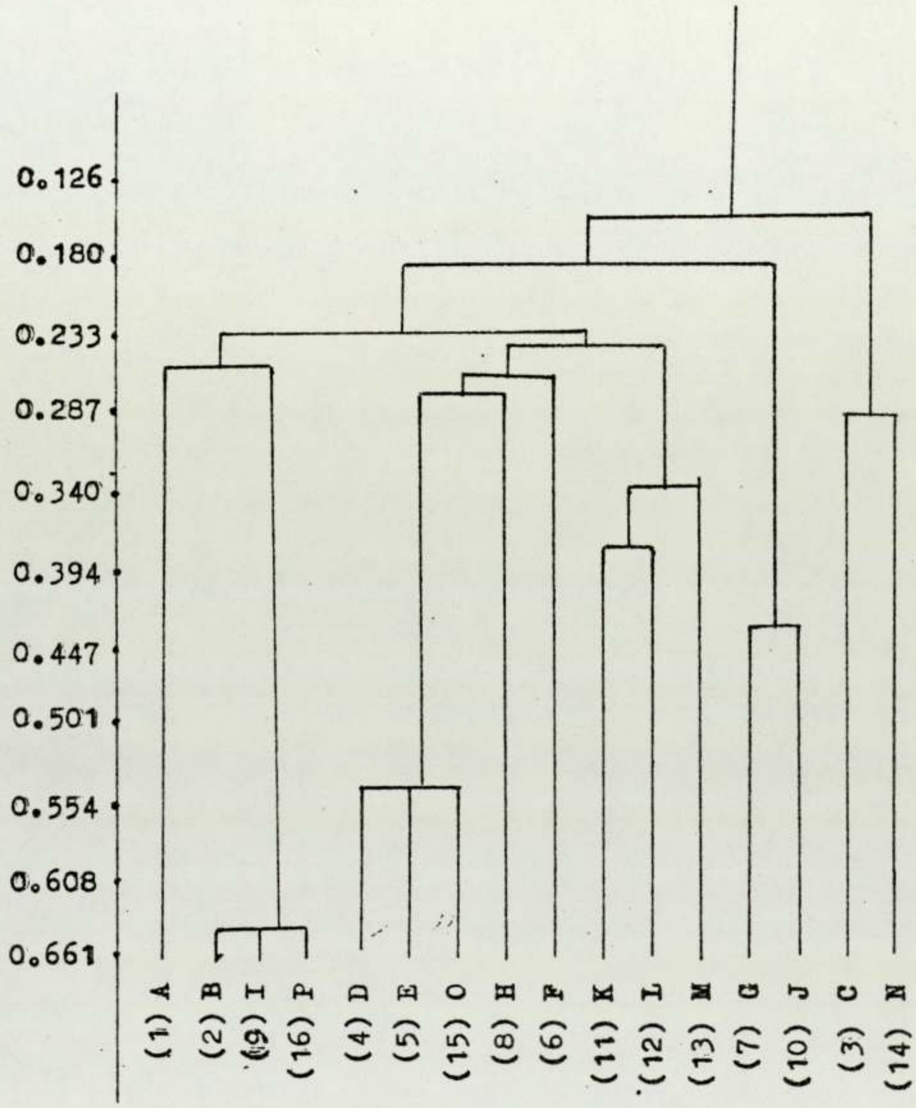


Binary Data (Components) Occurence, In The Rearranged Component Sequence.

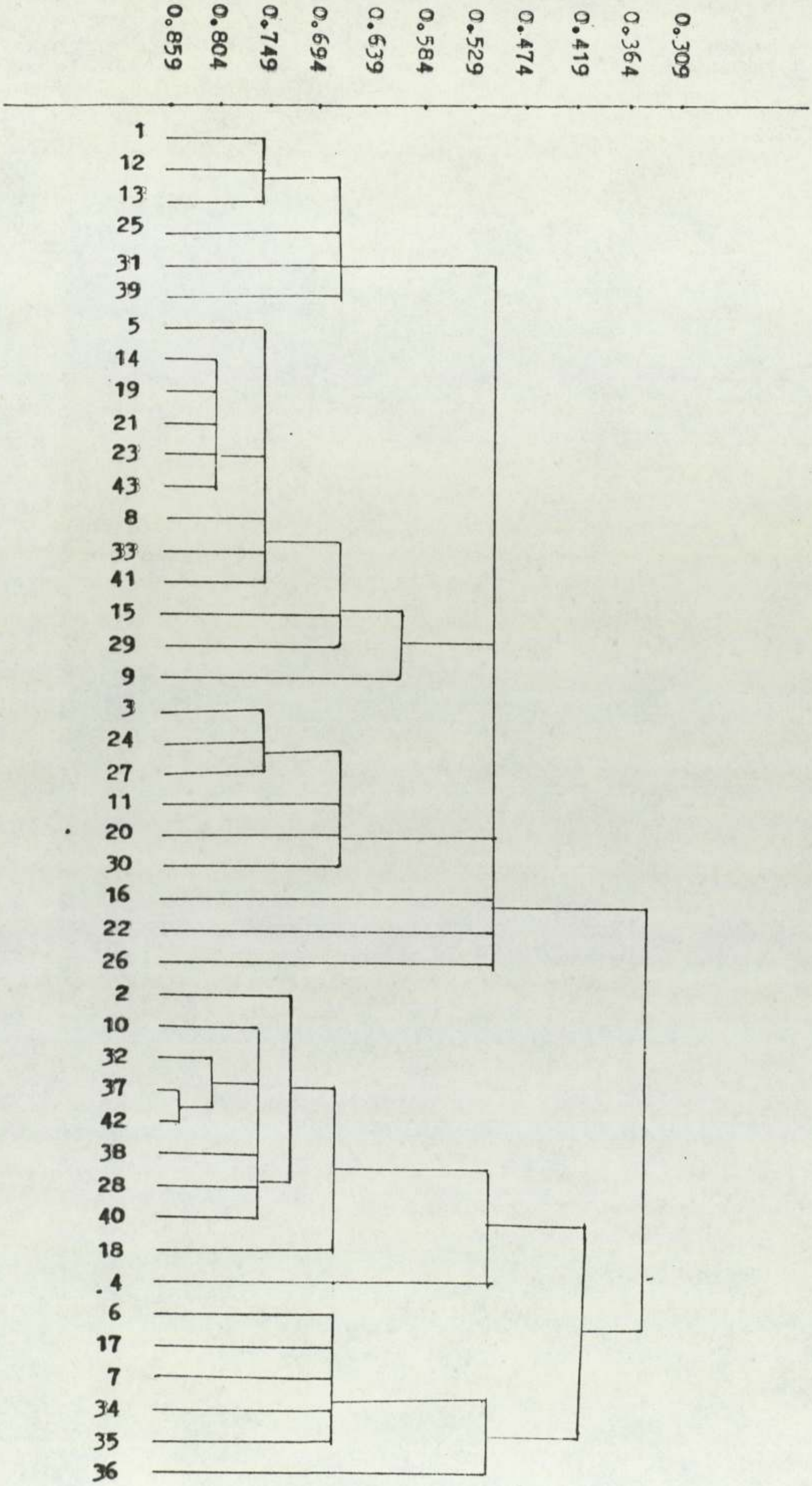


Binary Data (Components) Occurence, In Component Sequence Of The Largest Frequency.


Percentage Occurence Of Binary Data (Machines)
Binary Variable Frequency (Machines)
0.1 0.2 0.3 0.4 0.5
2 8 10 8 7 13 7 20 19 6 5 2 3 7 5 4
1 2 9 16 4 5 15 8 6 11 12 13 7 10 3 14
Binary Data (Machines) Occurence, In The Rearranged Machine Sequence.
Binary Variable Frequency (Machines)
0.1 0.2 0.3 0.4 0.5
2 8 5 7 13 19 20 10 7 6 5 2 4 7 8
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Binary Data (Machines) Occurence, In Ordinary Sequence.
Binary Variable Frequency (Machines)
0.1 0.2 0.3 0.4 0.5
20 19 13 10 8 7 6 5 4 3 2
8 6 5 9 2 16 10 15 4 11 3 12 14 7 13 1
Binary Data (Machines) Occurence, In Machine Sequence Of The Largest Frequency.



Dendrogram Of Machine Results.



Dendrogram of component results.

Part No.

Machine No.	1	12	13	25	31	39	5	14	19	21	23	43	8	33	41	15	29	9	3	24	27	11	20	30	16	22	26	2	10	32	37	42	38	28	40	18	4	6	17	7	34	35	36
A																															X	X											
B												X																X	X	X	X		X	X	X								
I																												X	X	X	X	X	X	X	X	X	X						
P																												X	X	X	X	X	X			X				X			
D							X	X	X	X	X						X	X																									
E							X	X	X	X	X		X	X	X	X	X	X							X																		
O							X	X	X	X		X		X	X																												
H	X	X			X				X	X	X	X			X			X	X	X	X	X	X		X			X			X	X	X	X									
F	X	X	X				X	X	X		X	X	X	X														X		X	X	X			X			X	X	X	X		
K																		X	X	X	X		X	X																			
L																				X	X	X		X		X																	
M																			X	X																							
G	X		X	X																																							
J	X	X	X	X	X	X																					X																
C																																							X	X	X	X	X
N																											X											X	X			X	

Component Machine Chart As Rearranged By The UACLUSTANC Programme.

APPENDIX 2

Unit cost calculations for test 1 (all parts are one family)

<u>Contents:</u>

- Computer programme to calculate quantity ratios and other items.
- Summary of (quantity ratio x time).
- Unit cost calculation at 50,629 units. (The company total quantity).
- Unit cost (simple linear regression formula).

Programme to establish quantity ratio and other important items.
Compiler sequencing.

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IDENTIFICATION DIVISION.
PROGRAM-ID. CXXX99.
AUTHOR. MUSTAFA A BAZELLYA.
DATE-WRITTEN. 6 AUGUST 1975.
REMARKS. TRIAL PROGRAM ONLY.
ENVIRONMENT DIVISION.
CONFIGURATION SECTION.
SOURCE-COMPUTER. ICL-1905.
OBJECT-COMPUTER. ICL-1905 MEMORY 5000 WORDS.
SPECIAL-NAMES.
    CHANNEL-1 IS NEW-PAGE.
INPUT-OUTPUT SECTION.
FILE-CONTROL.
    SELECT CARD-FILE ASSIGN CARD-READER 1.
    SELECT PRINT-FILE ASSIGN PRINTER 1.
DATA DIVISION.
FILE SECTION.
FD  CARD-FILE
    LABEL RECORDS OMITTED
    DATA RECORD IS REC-IN.
01  REC-IN.
    02 COD-NO       PIC 9(9).
    02 FAM-NO       PIC 9(3).
    02 TIME.
       03 TIME1     PIC 99V99.
       03 TIME2     PIC 99V99.
       03 TIME3     PIC 99V99.
       03 TIME4     PIC 99V99.
       03 TIME5     PIC 99V99.
       03 TIME6     PIC 99V99.
       03 TIME7     PIC 99V99.
    02 QTY          PIC 9(5).
FD  PRINT-FILE
    LABEL RECORDS OMITTED
    DATA RECORDS ARE HEADING COMP-REC.
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```
01  HEADING PIC A(120).
01  COMP-REC.
    02 SQ-NO        PIC Z9999
    02 FILLER       PIC X(4).
    02 COD-NO-O     PIC X(9).
    02 FILLER       PIC X(4).
    02 FAM-NO-O     PIC X(3).
    02 FILLER       PIC X(4).
    02 QTYRATIO     PIC ZV.999999.
    02 FILLER       PIC X(5).
    02 LOADRATIO    PIC ZV.999999.
    02 FILLER       PIC X(5).
    02 QTYRXTIME    PIC Z99V.999999.
    02 FILLER       PIC X(4).
    02 TOTALRATIO   PIC Z99V.999999.
    02 FILLER       PIC X(41).
WORKING-STORAGE SECTION.
    77 SQ-NO-O  PIC 9999 COMP.
    77 SUM  PIC 99V9999 COMP.
    77 QTYRATIO-O  PIC V999999 COMP.
    77 LOADRATIO-O  PIC V999999 COMP.
    77 QTYRXTIME-O  PIC 99V999999 COMP.
    77 TOTALRATIO-O  PIC 99V99999 COMP.
PROCEDURE DIVISION.
START.
    OPEN INPUT CARD-FILE  OUTPUT PRINT-FILE.
    MOVE "SQ NO    COD NO        FAM NO    QTYRATIO    LOADRATIO
    "QTYRXTIME     TOTALRATIO"
    TO HEADING
    WRITE HEADING   AFTER NEW-PAGE.
READ-IN.
    READ CARD-FILE   AT END GO TO FINISH.
RATIO-CALC.
    ADD TIME1 TIME2   TIME3 TIME4 TIME5 TIME6 TIME7 GIVING SUM.
    DIVIDE 31578 INTO   QTY GIVING QTYRATIO-O
    MULTIPLY QTYRATIO-O   BY TIME1 GIVING QTYRXTIME-O.
    DIVIDE 439.89 INTO   TIME1 GIVING LOADRATIO-O.
TOTALS.
    ADD QTYRXTIME-O TO   TOTALRATIO-O.
    ADD 1 TO SQ-NO-O.
```

```
PRINT-OUT.
    MOVE SPACES TO COMP-REC
    MOVE SQ-NO-O TO SQ-NO.
    MOVE COD-NO TO COD-NO-O
    MOVE FAM-NO TO FAM-NO-O
    MOVE QTYRATIO-O TO QTYRATIO
    MOVE LOADRATIO-O TO LOADRATIO
    MOVE QTYRXTIME-O TO QTYRXTIME
    MOVE TOTALRATIO-O TO TOTALRATIO.
    WRITE COMP-REC AFTER 2.
    GO TO READ-IN.
FINISH.
    CLOSE CARD-FILE PRINT-FILE
    STOP RUN.
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```

All data are taken from the company records.

Sample of the results.

SQ NO	COD NO	FAM NO	QTYRATIO	LOADRATIO	QTYRXTIME	TOTALRATIO
1	001000220	001	.002280	.001591	00.001596	00.001590
2	001000220	001	.002280	.001136	00.001140	00.002730
3	001000220	001	.000443	.000209	00.000177	00.002900
4	001000220	001	.000443	.001363	00.000265	00.003160
5	001000240	001	.000443	.001363	00.000265	00.003420
6	001000220	001	.000443	.001591	00.000310	00.003730
7	001000220	001	.000443	.000909	00.000177	00.003900
8	001000220	001	.000443	.001136	00.000221	00.004120
9	001000220	001	.000443	.001136	00.000221	00.004340
10	001000220	001	.000443	.001136	00.000221	00.004560
11	001000220	001	.000443	.001136	00.000221	00.004780
12	001000220	001	.001140	.001136	00.000570	00.005350
13	001000220	001	.000380	.001591	00.000266	00.005610
14	001000220	001	.000190	.001591	00.000133	00.005740
15	001000220	001	.000285	.001363	00.000171	00.005910
16	001000220	001	.000095	.001363	00.000057	00.005960
17	001000220	001	.000570	.002955	00.000741	00.006700
18	001010220	002	.002280	.001136	00.001140	00.007840
19	001010220	002	.001868	.001136	00.000934	00.008770

Summary of (Σ quantity ratio x time)

from the computer programme.

Cell No:	(Σt_c x X) (minutes)
1	2.5000
2	2.1000
3	9.25176
4	11.72480
5	24.64660
6	12.42130
7	7.47185
8	3.77321
9	5.88843
10	5.58327
11	2.00625
12	4.80259
13	8.69320
14	5.57995
15	4.17893
16	4.62691
17	1.69201
18	1.96390
19	1.58895

Unit cost calculation at a given quantity of: 50629 units

The companies given data is 639 parts are produced at £91.9311/part

The general formula of unit cost = variable + $\frac{\text{fixed} \times \sum \text{quantity ratio} \times \text{time}}{\text{no of machines} \times 1920 \times \text{utilization}}$

Variable cost is assumed to be 90%

Fixed cost is assumed to be 10%

Cell no	No of parts/cell	Cost/part £	Total cost £	No of components (units)	variable cost £/unit	Fixed cost £	Unit cost £/unit
1	462	91.9311	42472.1	31576	1.21049	4247	1.34507
2	131	91.9311	12042.9	6607	1.64048	1204	1.82275
3	34	91.9311	3125.65	2076	1.35440	313	1.50489
4	450	91.9311	41359.90	28380	1.31162	4136	1.45736
5	21	91.9311	1930.55	631	2.84835	193	3.16484
6	143	91.9311	13146.10	19688	0.60095	1315	0.66772
7	17	91.9311	1562.82	357	3.93990	156	4.37767
8	5	91.9311	459.655	357	1.15879	46	1.28755
9	325	91.9311	29877.6	27194	0.98881	2988	1.09868
10	57	91.9311	5240.0	3967	1.18882	524	1.32091
11	1	91 9311	91.9311	14	5.90985	9	6.56650
12	4	91.9311	367.724	2560	0.12927	37	0.14364
13	143	91.9311	13146.1	10527	1.12392	1315	1.24880
14	69	91.9311	6343.24	7345	0.77725	634	0.86361
15	191	91.9311	17558.8	16839	0.93847	1756	1.04274
16	39	91.9311	3585.31	3190	1.01153	359	1.12392
17	124	91.9311	11399.4	8245	1.24433	1140	1.38259
18	38	91.9311	3493.38	3195	0.98405	349	1.09339
19	47	91.9311	4320.76	3560	1.09232	432	1.21369

Unit cost calculations (Cu)

Test 1   Solution 1

Total quantity: 50629 units

Quantity ratio: As calculated from the company records.

Cell no	Simple linear regression formulas
1	$Cu = 1.21047 + 9.2165 \times \frac{1}{\eta}$
2	$Cu = 1.64047 + 2.1949 \times \frac{1}{\eta}$
3	$Cu = 1.35439 + 2.5258 \times \frac{1}{\eta}$
4	$Cu = 1.31161 + 14.0329 \times \frac{1}{\eta}$
5	$Cu = 2.84834 + 4.1295 \times \frac{1}{\eta}$
6	$Cu = 0.60076 + 7.0901 \times \frac{1}{\eta}$
7	$Cu = 3.93989 + 1.0113 \times \frac{1}{\eta}$
8	$Cu = 1.15878 + 0.1507 \times \frac{1}{\eta}$
9	$Cu = 0.88808 + 15.5807 \times \frac{1}{\eta}$
10	$Cu = 1.18881 + 2.5386 \times \frac{1}{\eta}$
11	$Cu = 5.90984 + 0.0148 \times \frac{1}{\eta}$
12	$Cu = 0.12926 + 0.1554 \times \frac{1}{\eta}$
13	$Cu = 1.12390 + 9.9241 \times \frac{1}{\eta}$
14	$Cu = 0.77724 + 3.0712 \times \frac{1}{\eta}$
15	$Cu = 0.93846 + 6.3697 \times \frac{1}{\eta}$
16	$Cu = 1.01152 + 1.4419 \times \frac{1}{\eta}$
17	$Cu = 1.24432 + 1.6745 \times \frac{1}{\eta}$
18	$Cu = 0.98404 + 0.5950 \times \frac{1}{\eta}$
19	$Cu = 1.09232 + 0.5960 \times \frac{1}{\eta}$

At (η) utilization: 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

APPENDIX 3

Unit cost calculation for test 1.

Tables:

- Unit cost for solution 2.
- Unit cost for solution 3.
- Unit cost for solution 4.
- Unit cost for solution 5.

Unit cost calculations (Cu)

Test 1 Solution 2

Total quantity: 41090 units

Quantity ratio: As calculated from the company records.

1 Machine utilization calculations.

Full 100% load per machine is taken as 1920 hrs/year, and 75% effective performance.

Cell no	Quantity ratio	Quantity	Total hrs	Utilization	No of M/CS
1	10.0593	41090	6888.960	3.588	4

2 Unit cost calculations

Cell no	No of parts/ cell	Cost/part £	Total cost £	No of components (units)	Variable cost £/unit	Fixed cost £	Unit cost £/unit
1	547	91.9311	50286.3	41090	1.10142	5029	1.22380

Cell no	Simple linear regression formular
1	$Cu = 1.10142 + 10.9841 \times \frac{1}{\eta}$

At (η) utilization: 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

The rest of cells as in appendix (2).

This cell consists of machines (1, 4).

Unit cost calculations (Cu)

Test 1 Solution 3

Total quantity: 48322 units

Quantity ratio: As calculated from the company records.

1 Machine utilization calculations.

Full 100% load per machine is taken as 1920 hrs/year, and 75% effective performance.

Cell no	Quantity ratio	Quantity	Total hrs	Utilization	No of M/CS
1	11.83389	48322	9530.63	4.96386	5

2 Unit cost calculations

Cell no	No of parts/ cell	Cost/part £	Total cost £	No of components (units)	Variable cost £/unit	Fixed cost £	Unit cost £/unit
1	598	91.9311	54974.7	48322	1.02390	5497	1.13767

Cell no	Simple linear regression formula
1	$Cu = 1.0239 + 11.2945 \times \frac{1}{\eta}$

At (η) utilization: 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

The rest of cells as in appendix (2).

This cell consists of machines (1, 4, 9).

Unit cost calculations (Cu)

Test 1   Solution 4

Total quantity: 48460 units

Quantity ratio: As calculated from the company records.

1 Machine utilization calculations

Full 100% load per machine is taken as 1920 hrs/year, and 75% effective performance.

Cell no	Quantity ratio	Quantity	Total hrs	Utilization	No of M/CS
1	14.82020	48460	11969.8	6.23429	8

2 Unit cost calculations

Cell no	No of parts/cell	Cost/part £	Total cost £	No of components (units)	Variable cost £/unit	Fixed cost £	Unit cost £/unit
1	602	91.9311	55342.5	48460	1.02782	5534	1.14202

Cell no	Simple linear regression formula
1	$Cu = 1.0278 + 8.8999 \times \frac{1}{\eta}$

At (η) utilization: 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

The rest of cells as in appendix (2)

This cell consists of machines (1, 4, 9, 14, 13, 2).

Unit cost calculations (Cu)

Test 1 Solution 5

Total quantity: 50629 units

Quantity ratio: As calculated from the company records.

1 Machine utilization calculations.

Full 100% load per machine is taken as 1920 hrs/year, and 75% effective performance.

Cell no	Quantity ratio	Quantity	Total hrs	Utilization	No of M/CS
1	22.6536	50629	19115.4	9.95598	22

2 Unit cost calculations

Cell no	No of parts/cell	Cost/part £	Total cost £	No of components (units)	Variable cost £/unit	Fixed cost £	Unit cost £/unit
1	639	91.9311	58744	50629	1.04425	5874	1.16028

Cell	Simple linear regression formula
1	$Cu = 1.0442 + 5.2509 \times \frac{1}{\eta}$

At (η) utilization: 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

This cell consists of machines (all machines).

APPENDIX 4

Unit cost calculations for the new proposed data at the given quantity ratio (constant).

Tables:

- Proposed variations in quantities calculated for comparison for total quantities of 30000; 40000 and 60000 units.
- Machine utilization calculations for total quantities 30000; 40000 and 60000 units.
- Unit cost calculation for test 1. For total quantities 30000; 40000 and 60000 (simple linear regression formulas).

Proposed variation in quantities calculated in relation to the companys existing condition, to establish realistic comparisons.

Cell no	Companys total quantity 50629	Percentage from total	Quantity/cell for different total quantities(units)		
			30000	40000	60000
1	31576	0.62371	18711	24948	37422
2	6607	0.13040	3912	5216	7824
3	2076	0.04100	1230	1640	2460
4	28380	0.56054	16815	22420	33630
5	631	0.01246	375	500	750
6	19688	0.38886	11667	15556	23334
7	357	0.00705	213	284	426
8	357	0.00705	213	284	426
9	27199	0.53722	16167	21489	32233
10	3967	0.07891	2367	3156	4734
11	14	0.00027	9	12	18
12	2560	0.050926	1528	2037	3056
13	10527	0.20941	6282	8377	12565
14	7345	0.14611	4383	5845	8767
15	16839	0.33257	9978	13304	19956
16	3190	0.06300	1890	2520	3780
17	8245	0.16285	4886	6514	9771
18	3195	0.06310	1893	2524	3786
19	3560	0.07031	2109	2812	4218

Machine utilization calculations:

Total quantity 30000 units;

Full 100% load per machine is taken as 1920 hrs/year,

and 75% effective performance.

Cell no	Quantity ratio	Quantity	Total hrs	Utilization	No of M/CS
1	2.50000	18711	779.625	0.40605	1
2	2.10000	3912	136.920	0.07131	1
3	9.25176	1230	205.080	0.10681	1
4	11.7248	16815	3285.870	1.71139	2
5	24.6466	375	154.041	0.08022	1
6	12.4213	11667	2415.320	1.25798	2
7	7.47185	213	26.520	0.01381	1
8	3.77321	213	13.3948	0.00697	1
9	5.88843	16167	1586.63	0.82637	1
10	5.58327	2367	220.26	0.11471	1
11	2.00625	9	0.3009	0.00015	1
12	4.80259	1528	122.305	0.06370	1
13	8.69320	6282	910.178	0.47405	1
14	5.57995	4383	407.615	0.21229	1
15	4.17893	9978	694.956	0.36195	1
16	4.62691	1890	145.747	0.07591	1
17	1.69201	4886	137.786	0.07176	1
18	1.96390	1893	61.961	0.03227	1
19	1.58895	2109	55.8515	0.02908	1

Machine utilization calculations:

Total quantity 40000 units;

Full 100% load per machine is taken as 1920 hrs/year,

and 75% effective performance.

Cell no	Quantity ratio	Quantity	Total hrs	Utilization	No of M/CS
1	2.5000	24984	1041.00	0.54218	1
2	2.1000	5216	182.56	0.09508	1
3	9.25176	1640	252.881	0.13170	1
4	11.72480	22420	4381.160	2.28185	3
5	24.64660	500	205.388	0.10697	1
6	12.42130	15556	3220.420	1.67730	2
7	7.47185	284	35.3667	0.01842	1
8	3.77321	284	17.8598	0.00930	1
9	5.88843	21489	2108.94	1.0984	1
10	5.58327	3156	293.68	0.15245	1
11	2.00625	9	0.40125	0.00020	1
12	4.80259	2037	163.047	0.08492	1
13	8.69320	8377	1213.710	0.63214	1
14	5.57995	5845	543.580	0.28311	1
15	4.17893	13304	926.608	0.48260	1
16	4.62691	2520	194.330	0.10121	1
17	1.69201	6514	183.695	0.09567	1
18	1.96390	3195	104.577	0.05446	1
19	1.58895	2812	74.4687	0.03878	1

Machine utilization calculations:

Total quantity 60000 units;

Full 100% load per machine is taken as 1920 hrs/year,

and 75% effective performance.

Cell no	Quantity ratio	Quantity	Total hrs	Utilization	No of M/CS
1	2.5000	37422	1559.25	0.81210	1
2	2.1000	7824	273.84	0.14262	1
3	9.25176	2460	379.322	0.19756	1
4	11.7248	33630	6571.750	3.42278	4
5	24.6466	750	308.082	0.16045	1
6	12.4213	23334	4830.640	2.51596	3
7	7.47185	426	53.0501	0.02763	1
8	3.77321	426	26.7897	0.01395	1
9	5.88843	32233	3163.36	1.64758	2
10	5.58327	4734	440.52	0.22943	1
11	2.00625	18	0.60187	0.00031	1
12	4.80259	3056	244.611	0.12740	1
13	8.69320	12565	1820.500	0.94817	1
14	5.57995	8767	815.323	0.42464	1
15	4.17893	19956	1389.91	0.72391	1
16	4.72791	3780	291.495	0.15182	1
17	1.69201	9771	275.543	0.14351	1
18	1.96390	.3786	123.922	0.06454	1
19	1.58895	4218	111.7030	0.05817	1

Unit cost calculation at a given quantity of : 30000 units

The companies given data is 639 parts are produced at £91.9311/part

The general formula of unit cost = variable + $\frac{\text{fixed} \times \sum \text{quantity ratio} \times \text{time}}{\text{no of machines} \times 1920 \times \text{utilization}}$

Variable cost is assumed to be 90%

Fixed cost is assumed to be 10%

Cell no	No of parts/ cell	Cost/part £	Total cost £	No of components (units)	variable cost £/unit	Fixed cost £	Unit cost £/unit
1	462	91.9311	42472.1	18711	2.04291	4247	2.26990
2	131	91.9311	12042.9	3912	2.77060	1204	3.07845
3	34	91.9311	3125.65	1230	2.28706	313	2.54117
4	450	91.9311	41359.9	16815	2.21373	4136	2.4597
5	21	91.9311	1930.55	375	4.63331	193	5.14813
6	143	91.9311	13146.1	11667	1.01409	1315	1.12677
7	17	91.9311	1562.82	213	6.60346	156	7.33718
8	5	91.9311	459.655	213	1.94220	46	2.15800
9	325	91.9311	29877.6	16167	1.66325	2988	1.84806
10	57	91.9311	5240.0	2367	1.99239	524	2.21377
11	1	91.9311	91.9311	9	9.39310	9	9.39310
12	4	91.9311	367.724	1528	0.21659	37	0.24065
13	143	91.9311	13146.1	6282	1.88340	1315	2.09266
14	69	91.9311	6343.24	4383	1.30251	634	1.44723
15	191	91.9311	17558.8	9978	1.58377	1756	1.75975
16	39	91.9311	3585.31	1890	1.70729	359	1.89699
17	124	91.9311	11399.40	4886	2.09977	1140	2.33308
18	38	91.9311	3493.38	349	1.66087	349	1.84542
19	47	91.9311	4320.76	2109	1.84385	432	2.04872

Unit cost calculation at a given quantity of: 40000 units

The companies given data is 639 parts are produced at £91.9311/part

The general formula of unit cost = variable + $\frac{\text{fixed} \times \sum \text{quantity ratio} \times \text{time}}{\text{no of machines} \times 1920 \times \text{utilization}}$

Variable cost is assumed to be 90%

Fixed cost is assumed to be 10%

Cell no	No of parts/ cell	Cost/part £	Total cost £	No of components (units)	variable cost £/unit	Fixed cost £	Unit cost £/unit
1	462	91.9311	42472.1	24948	1.53217	4247	1.70242
2	131	91.9311	12042.9	5216	2.07779	1204	2.38866
3	34	91.9311	3125.65	1640	1.71529	313	1.90588
4	450	91.9311	41359.9	22420	1.66029	4136	1.84477
5	21	91.9311	1930.55	500	3.47499	193	3.86110
6	143	91.9311	13146.1	15556	0.76057	1315	0.86508
7	17	91.9311	1562.82	284	4.95259	156	5.50218
8	5	91.9311	459.655	284	1.45665	46	1.61850
9	325	91.9311	29877.6	21489	1.25133	2988	1.39036
10	57	91.9311	5240.0	3156	1.49429	524	1.66032
11	1	91.9311	91.9311	12	6.89483	9	7.66092
12	4	91.9311	367.724	2037	0.16247	37	0.18052
13	143	91.9311	13146.1	8377	1.41238	1315	1.56931
14	69	91.9311	6343.24	5845	0.97671	634	1.08524
15	191	91.9311	17558.8	13304	1.18783	1756	1.31981
16	39	91.9311	3585.31	2520	1.28046	359	1.42274
17	124	91.9311	11399.4	6514	1.57499	1140	1.74999
18	38	91.9311	3493.38	2524	1.24565	349	1.38406
19	47	91.9311	4320.76	2812	1.38288	432	1.53654

Unit cost calculation at a given quantity of : 60000 units

The companies given data is 639 parts are produced at £91.9311/part

The general formula of unit cost = variable + $\frac{\text{fixed} \times \sum \text{quantity ratio} \times \text{time}}{\text{no of machines} \times 1920 \times \text{utilization}}$

Variable cost is assumed to be 90%

Fixed cost is assumed to be 10%

Cell no	No of parts/ cell	Cost/part £	Total cost £	No of components (units)	variable cost £/unit	Fixed cost £	Unit cost £/unit
1	462	91.9311	42472.1	37422	1.02145	4247	1.13495
2	131	91.9311	12042.9	7824	1.38530	1204	1.53922
3	34	91.9311	3125.65	2460	1.14353	313	1.27058
4	450	91.9311	41359.9	33630	1.10685	4136	1.22985
5	21	91.9311	1930.55	750	2.31665	193	2.57406
6	143	91.9311	13146.1	23334	0.50704	1315	0.56338
7	17	91.9311	1562.82	426	3.30173	156	3.66859
8	5	91.9311	459.655	426	0.97110	46	1.07900
9	325	91.9311	29877.6	32233	0.83423	988	0.92692
10	57	91.9311	5240.0	4734	0.99619	524	1.1068
11	1	91.9311	91.9311	18	4.59655	9	5.10728
12	4	91.9311	367.724	3056	0.10829	37	0.12032
13	143	91.9311	13146.1	12565	0.94162	1315	1.04624
14	69	91.9311	6343.24	8767	0.65118	634	0.72353
15	191	91.9311	17558.8	19956	0.79188	1756	0.87987
16	39	91.9311	3585.31	3780	0.85364	359	0.94849
17	124	91.9311	11399.4	9771	1.04999	1140	1.16666
18	38	91.9311	3493.38	3786	0.83043	349	0.92271
19	47	91.9311	4320.76	4218	0.92192	432	1.02436

Unit cost calculations (Cu)

Test 1 Solution 1

Total quantity: 30000 units

Quantity ratio: As calculated from the company records.

Cell no	Simple linear regression formulas
1	$Cu = 2.0429 + 9.2173 \times \frac{1}{\eta}$
2	$Cu = 2.7706 + 2.1949 \times \frac{1}{\eta}$
3	$Cu = 2.2863 + 2.5258 \times \frac{1}{\eta}$
4	$Cu = 2.2137 + 14.0329 \times \frac{1}{\eta}$
5	$Cu = 4.6333 + 4.1295 \times \frac{1}{\eta}$
6	$Cu = 1.0141 + 7.09005 \times \frac{1}{\eta}$
7	$Cu = 6.6035 + 1.01134 \times \frac{1}{\eta}$
8	$Cu = 1.9422 + 0.15065 \times \frac{1}{\eta}$
9	$Cu = 1.6272 + 15.58070 \times \frac{1}{\eta}$
10	$Cu = 1.9925 + 2.53860 \times \frac{1}{\eta}$
11	$Cu = 9.3931 + 0.01483 \times \frac{1}{\eta}$
12	$Cu = 0.2166 + 0.15425 \times \frac{1}{\eta}$
13	$Cu = 1.8834 + 9.92410 \times \frac{1}{\eta}$
14	$Cu = 1.3025 + 3.07120 \times \frac{1}{\eta}$
15	$Cu = 1.5837 + 6.36970 \times \frac{1}{\eta}$
16	$Cu = 1.7073 + 1.44190 \times \frac{1}{\eta}$
17	$Cu = 2.0998 + 1.67450 \times \frac{1}{\eta}$
18	$Cu = 1.6609 + 0.59500 \times \frac{1}{\eta}$
19	$Cu = 1.8438 + 0.59600 \times \frac{1}{\eta}$

At (η) utilization: 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

Unit cost calculations (Cu)

Test 1 Solution 1

Total quantity: 40000 units

Quantity ratio: As calculated from the company records.

Cell no	Simple linear regression formulas
1	$Cu = 1.5321 + 9.21731 \times \frac{1}{\eta}$
2	$Cu = 2.0778 + 2.19421 \times \frac{1}{\eta}$
3	$Cu = 1.7153 + 2.51330 \times \frac{1}{\eta}$
4	$Cu = 1.6602 + 14.03300 \times \frac{1}{\eta}$
5	$Cu = 3.4750 + 4.12950 \times \frac{1}{\eta}$
6	$Cu = 0.8447 + 7.09890 \times \frac{1}{\eta}$
7	$Cu = 4.9526 + 1.01195 \times \frac{1}{\eta}$
8	$Cu = 1.4566 + 0.15082 \times \frac{1}{\eta}$
9	$Cu = 1.2513 + 15.27440 \times \frac{1}{\eta}$
10	$Cu = 1.4945 + 2.53610 \times \frac{1}{\eta}$
11	$Cu = 6.8948 + 0.01590 \times \frac{1}{\eta}$
12	$Cu = 0.16242 + 0.15426 \times \frac{1}{\eta}$
13	$Cu = 1.4124 + 9.92390 \times \frac{1}{\eta}$
14	$Cu = 0.9767 + 3.07120 \times \frac{1}{\eta}$
15	$Cu = 1.1878 + 6.37050 \times \frac{1}{\eta}$
16	$Cu = 1.2636 + 1.46070 \times \frac{1}{\eta}$
17	$Cu = 1.5780 + 1.67450 \times \frac{1}{\eta}$
18	$Cu = 1.2450 + 0.62570 \times \frac{1}{\eta}$
19	$Cu = 1.3829 + 0.59590 \times \frac{1}{\eta}$

At (η) utilization: 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

Unit cost calculations (Cu)

Test 1 Solution 1

Total quantity: 60000 units

Quantity ratio: As calculated from the company records.

Cell no	Simple linear regression formulas
1	$Cu = 1.0199 + 9.2368 \times \frac{1}{\eta}$
2	$Cu = 1.3853 + 2.1949 \times \frac{1}{\eta}$
3	$Cu = 1.1435 + 2.5139 \times \frac{1}{\eta}$
4	$Cu = 1.1067 + 14.0337 \times \frac{1}{\eta}$
5	$Cu = 2.3166 + 4.1295 \times \frac{1}{\eta}$
6	$Cu = 0.5070 + 7.0900 \times \frac{1}{\eta}$
7	$Cu = 3.3017 + 1.0121 \times \frac{1}{\eta}$
8	$Cu = 0.9711 + 0.1508 \times \frac{1}{\eta}$
9	$Cu = 0.8342 + 15.2744 \times \frac{1}{\eta}$
10	$Cu = 0.9962 + 2.5398 \times \frac{1}{\eta}$
11	$Cu = 4.5965 + 0.0156 \times \frac{1}{\eta}$
12	$Cu = 0.1083 + 0.1543 \times \frac{1}{\eta}$
13	$Cu = 0.9409 + 9.9333 \times \frac{1}{\eta}$
14	$Cu = 0.6512 + 3.0712 \times \frac{1}{\eta}$
15	$Cu = 0.7919 + 6.3705 \times \frac{1}{\eta}$
16	$Cu = 0.8536 + 1.4419 \times \frac{1}{\eta}$
17	$Cu = 1.0500 + 1.6945 \times \frac{1}{\eta}$
18	$Cu = 0.8304 + 0.5950 \times \frac{1}{\eta}$
19	$Cu = 0.9219 + 0.5960 \times \frac{1}{\eta}$

At (η) utilization: 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

APPENDIX 5

Unit cost calculations for the new proposed data at the new calculated quantity ratio (changeable).

Tables:

- Data of new (quantity ratio x time).
- Machine utilization calculations for (total quantities) 30000; 40000 and 60000 units.
- Unit cost calculation for test 1. For total quantities simple linearregression formulas 30000; 40000 and 60000.

Calculations of $(\Sigma t_\rho . X)$ for different total quantities:
Assumption; machine utilization (η), machines per cell, number of machines (W) are the same as given by the company records.

$$N_1 = \frac{\eta \times R \times W}{(\Sigma t_\rho . X)_1} \quad \text{and} \quad N_2 = \frac{\eta \times R \times W}{(\Sigma t_\rho . X)_2} \quad ; R = 1920 \text{ hrs/year}$$

therefore

$$(\Sigma t_\rho . X)_2 = \left(\frac{N_1}{N_2}\right) (\Sigma t_c . X)_1$$

Where N = quantity ; t_ρ = production time ; X = quantity ratio

Cell no.	$(\Sigma t_\rho . X)_1$	30000 units		40000 units		60000 units	
		$\frac{N_1}{N_2}$	$(\Sigma t_\rho . X)_2$	$\frac{N_1}{N_2}$	$(\Sigma t_\rho . X)_2$	$\frac{N_1}{N_2}$	$(\Sigma t_\rho . X)_2$
1	2.5000	1.68767	4.2191	1.2657	3.1643	0.8441	2.1096
2	2.1000	1.68767	3.5441	1.2657	2.6581	0.8441	1.7721
3	9.2518	1.68767	15.6139	1.2657	11.7104	0.8441	7.8069
4	11.7248	1.68767	19.7875	1.2657	14.8406	0.8441	9.8069
5	24.6466	1.68767	41.5953	1.2657	31.1964	0.8441	20.7976
6	12.4213	1.68767	20.9630	1.2657	15.7203	0.8441	10.4815
7	7.4719	1.68767	12.6139	1.2657	9.4575	0.8441	6.3070
8	3.7732	1.68767	6.3679	1.2657	4.7759	0.8441	3.1850
9	5.8884	1.68767	9.9377	1.2657	7.4533	0.8441	4.9704
10	5.5833	1.68767	9.4227	1.2657	7.0670	0.8441	4.7120
11	2.0062	1.68767	3.3860	1.2657	2.5394	0.8441	1.6935
12	4.8026	1.68767	8.1052	1.2657	6.0789	0.8441	4.0539
13	8.6932	1.68767	14.6712	1.2657	11.0034	0.8441	7.3379
14	5.5799	1.68767	9.4171	1.2657	7.0628	0.8441	4.7100
15	4.1789	1.68767	7.0526	1.2657	5.2895	0.8441	3.5274
16	4.6069	1.68767	7.8087	1.2657	5.8565	0.8441	3.9056
17	1.6920	1.68767	2.8555	1.2657	2.1417	0.8441	1.4282
18	1.9639	1.68767	3.3144	1.2657	2.4858	0.8441	1.6577
19	1.5889	1.68767	2.6816	1.2657	2.0112	0.8441	1.3412

Machine utilization calculations:

Total quantity 30000 units;

Full 100%load per machine is taken as 1920 hrs/year,

and 75% effective performance.

Cell no	Quantity ratio	Quantity	Total hrs	Utilization	No of M/CS
1	4.21917	18711	1315.460	0.69	1
2	3.54410	3912	231.280	0.12	1
3	15.6139	1230	320.100	0.17	1
4	19.7875	16815	5545.910	2.89	3
5	41.5953	375	263.910	0.14	1
6	20.9630	11667	4075.860	2.12	2
7	12.6139	213	44.458	0.023	1
8	6.36793	213	22.606	0.01177	1
9	9.93772	16167	2677.710	1.39464	2
10	9.42271	2367	371.725	0.19360	1
11	3.38588	9	0.508	0.00026	1
12	8.10518	1528	206.411	0.10750	1
13	14.6712	6282	1535.960	0.79998	1
14	9.41711	4383	687.919	0.35829	1
15	7.05265	9978	1172.850	0.61086	1
16	7.80869	1890	245.973	0.12811	1
17	2.85555	4886	232.536	0.12111	1
18	3.31441	1893	104.569	0.05446	1
19	2.68162	2109	94.259	0.04909	1

Machine utilization calculations;

Total quantity 40000 units;

Full 100%load per machine is taken as 1920 hrs/year, and 75% effective performance.

Cell no	Quantity ratio	Quantity	Total hrs	Utilization	No of M/CS
1	3.1643	24948	1315.460	0.69	1
2	2.6581	5216	231.280	0.12	1
3	11.7104	1640	320.100	0.17	1
4	14.8406	22420	5545.910	2.89	3
5	31.1964	500	263.910	0.14	1
6	15.7203	15556	4075.860	2.12	2
7	9.4575	284	44.458	0.023	1
8	4.7759	284	22.613	0.01177	1
9	7.4533	21489	2670.190	1.39072	2
10	7.0670	3156	371.779	0.19363	1
11	2.5394	12	0.508	0.00026	1
12	6.0670	2037	206.476	0.10753	1
13	11.0034	8377	1536.680	0.80035	1
14	7.0628	5845	688.213	0.35844	1
15	5.2895	13304	1173.270	0.61105	1
16	5.8565	2520	246.050	0.12815	1
17	2.14170	6514	232.585	0.12113	1
18	2.48580	2524	104.602	0.05448	1
19	2.01120	2812	94.289	0.4910	1

Machine utilization calculations:

Total quantity 60000 units;

Full 100%load per machine is taken as 1920 hrs/year, and 75% effective performance.

Cell no	Quantity ratio	Quantity	Total hrs	Utilization	No of M/CS
1	2.10958	37422	1315.460	0.69	1
2	1.77205	7824	231.280	0.12	1
3	7.80695	2460	320.100	0.17	1
4	9.89379	33630	5545.910	2.89	3
5	20.7976	750	263.910	0.14	1
6	10.4815	23334	4075.860	2.12	2
7	6.30698	426	44.458	0.023	1
8	3.18496	426	22.613	0.01177	1
9	4.97042	32233	2670.190	1.39072	2
10	4.71203	4734	371.779	0.19363	1
11	1.69347	18	0.508	0.00026	1
12	4.05386	3056	206.476	0.10753	1
13	7.33793	12565	1536.680	0.80035	1
14	4.71003	8767	688.213	0.35844	1
15	3.52743	19956	1173.270	0.61105	1
16	3.90556	3780	246.050	0.12815	1
17	1.42822	9771	232.585	0.12113	1
18	1.65772	3786	104.602	0.05448	1
19	1.34123	4218	94.289	0.4910	1

Unit cost calculations (Cu)

Test 1 Solution 1

Total quantity: 30000 units

Quantity ratio: As calculated for the proposed new data (changeable).

Cell no	Simple linear regression formulas
1	$Cu = 2.0429 + 15.5556 \times \frac{1}{\eta}$
2	$Cu = 2.7706 + 3.7043 \times \frac{1}{\eta}$
3	$Cu = 2.2871 + 4.2425 \times \frac{1}{\eta}$
4	$Cu = 2.2136 + 23.6829 \times \frac{1}{\eta}$
5	$Cu = 4.6333 + 6.9292 \times \frac{1}{\eta}$
6	$Cu = 1.1262 + 11.9731 \times \frac{1}{\eta}$
7	$Cu = 6.6035 + 1.7083 \times \frac{1}{\eta}$
8	$Cu = 1.94219 + 0.2543 \times \frac{1}{\eta}$
9	$Cu = 1.6332 + 25.7781 \times \frac{1}{\eta}$
10	$Cu = 1.9924 + 4.2864 \times \frac{1}{\eta}$
11	$Cu = 9.3930 + 0.0264 \times \frac{1}{\eta}$
12	$Cu = 0.2166 + 0.2604 \times \frac{1}{\eta}$
13	$Cu = 1.8833 + 16.7484 \times \frac{1}{\eta}$
14	$Cu = 1.3025 + 5.1831 \times \frac{1}{\eta}$
15	$Cu = 1.5837 + 9.6488 \times \frac{1}{\eta}$
16	$Cu = 1.7073 + 2.4336 \times \frac{1}{\eta}$
17	$Cu = 2.0998 + 2.8261 \times \frac{1}{\eta}$
18	$Cu = 1.6607 + 1.0088 \times \frac{1}{\eta}$
19	$Cu = 1.8439 + 1.0058 \times \frac{1}{\eta}$

At (η) utilization: 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

Unit cost calculations (Cu)

Test 1 Solution 1

Total quantity: 40000 units

Quantity ratio: As calculated for the proposed new data (changeable).

Cell no	Simple linear regression formulas
1	$Cu = 1.5321 + 11.6667 \times \frac{1}{\eta}$
2	$Cu = 2.0779 + 2.7783 \times \frac{1}{\eta}$
3	$Cu = 1.71538 + 3.1805 \times \frac{1}{\eta}$
4	$Cu = 1.6602 + 17.7621 \times \frac{1}{\eta}$
5	$Cu = 3.4750 + 5.2269 \times \frac{1}{\eta}$
6	$Cu = 0.8447 + 8.9798 \times \frac{1}{\eta}$
7	$Cu = 4.9526 + 1.2812 \times \frac{1}{\eta}$
8	$Cu = 1.4567 + 0.1901 \times \frac{1}{\eta}$
9	$Cu = 1.2248 + 19.3336 \times \frac{1}{\eta}$
10	$Cu = 1.4943 + 3.2148 \times \frac{1}{\eta}$
11	$Cu = 7.0448 + 0.0198 \times \frac{1}{\eta}$
12	$Cu = 0.16242 + 0.1954 \times \frac{1}{\eta}$
13	$Cu = 1.4125 + 12.5613 \times \frac{1}{\eta}$
14	$Cu = 0.9769 + 3.8869 \times \frac{1}{\eta}$
15	$Cu = 1.1878 + 7.2366 \times \frac{1}{\eta}$
16	$Cu = 1.2801 + 1.8297 \times \frac{1}{\eta}$
17	$Cu = 1.5747 + 2.1191 \times \frac{1}{\eta}$
18	$Cu = 1.2456 + 0.7570 \times \frac{1}{\eta}$
19	$Cu = 1.3829 + 0.7542 \times \frac{1}{\eta}$

At (η) utilization: 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

Unit cost calculations (Cu)

Test 1 Solution 1

Total quantity: 60000 units

Quantity ratio: As calculated for the proposed new data (changeable).

Cell no	Simple linear regression formulas
1	$Cu = 1.0214 + 7.7779 \times \frac{1}{\eta}$
2	$Cu = 1.3853 + 1.8522 \times \frac{1}{\eta}$
3	$Cu = 1.1435 + 2.1212 \times \frac{1}{\eta}$
4	$Cu = 1.1068 + 11.8414 \times \frac{1}{\eta}$
5	$Cu = 2.3166 + 3.4846 \times \frac{1}{\eta}$
6	$Cu = 0.5070 + 5.9865 \times \frac{1}{\eta}$
7	$Cu = 3.3017 + 0.8541 \times \frac{1}{\eta}$
8	$Cu = 0.9711 + 0.1272 \times \frac{1}{\eta}$
9	$Cu = 0.8165 + 12.8890 \times \frac{1}{\eta}$
10	$Cu = 0.9962 + 2.1432 \times \frac{1}{\eta}$
11	$Cu = 4.6965 + 0.0132 \times \frac{1}{\eta}$
12	$Cu = 0.1083 + 0.1302 \times \frac{1}{\eta}$
13	$Cu = 0.9417 + 8.3742 \times \frac{1}{\eta}$
14	$Cu = 0.6515 + 2.5900 \times \frac{1}{\eta}$
15	$Cu = 0.7919 + 4.8244 \times \frac{1}{\eta}$
16	$Cu = 0.8536 + 1.2168 \times \frac{1}{\eta}$
17	$Cu = 1.0499 + 1.4130 \times \frac{1}{\eta}$
18	$Cu = 0.8304 + 0.5047 \times \frac{1}{\eta}$
19	$Cu = 0.9219 + 0.5028 \times \frac{1}{\eta}$

At (η) utilization: 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

APPENDIX 6

Unit cost calculations for :

Test 2. Where every group is a family.

Tables:

- Simple linear regression formulas for solution 1.
- Summary of utilization; (Σquantity ratio x time) and the relevent unit cost.
- Unit cost calculations for solution 2;3;4 and 5.

Unit cost calculations (Cu)

Test 2 Solution 1

Total quantity: 50629 units

Quantity ratio: As calculated from the company records.

Cell no	Simple linear regression formulas
1	$Cu = 1.21047 + 2.7282 \times \frac{1}{\eta}$
2	$Cu = 1.64047 + 0.5768 \times \frac{1}{\eta}$
3	$Cu = 1.35439 + 0.6038 \times \frac{1}{\eta}$
4	$Cu = 1.31161 + 0.7504 \times \frac{1}{\eta}$
5	$Cu = 2.84834 + 1.6303 \times \frac{1}{\eta}$
6	$Cu = 0.60076 + 1.8611 \times \frac{1}{\eta}$
7	$Cu = 3.93989 + 0.4505 \times \frac{1}{\eta}$
8	$Cu = 1.15878 + 0.0575 \times \frac{1}{\eta}$
9	$Cu = 0.88808 + 1.5433 \times \frac{1}{\eta}$
10	$Cu = 1.18881 + 0.6527 \times \frac{1}{\eta}$
11	$Cu = 5.90484 + 0.0156 \times \frac{1}{\eta}$
12	$Cu = 0.12926 + 0.1509 \times \frac{1}{\eta}$
13	$Cu = 1.12390 + 2.5924 \times \frac{1}{\eta}$
14	$Cu = 0.77724 + 0.7046 \times \frac{1}{\eta}$
15	$Cu = 0.93846 + 0.8492 \times \frac{1}{\eta}$
16	$Cu = 1.01152 + 0.3119 \times \frac{1}{\eta}$
17	$Cu = 1.24432 + 0.5514 \times \frac{1}{\eta}$
18	$Cu = 0.98404 + 0.1047 \times \frac{1}{\eta}$
19	$Cu = 1.09231 + 0.2688 \times \frac{1}{\eta}$

At (η) utilization: 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

Summary of, utilization (η); (Σquantity ratio x time) $(\Sigma t_{\rho} \cdot X)_{max}$, and the relevent unit cost (Cu).

Test 2 Solution 1

Cell no	Utilization	(Σquantity ratio x time)	Unit cost
1	0.69	0.73996	1.24949
2	0.12	0.40275	1.68870
3	0.17	2.22221	1.38991
4	0.96	0.62700	1.31943
5	0.14	9.73050	2.96478
6	1.00	3.25926	0.61955
7	0.023	3.32771	4.13576
8	0.012	1.44190	1.20670
9	0.70	0.59496	0.91014
10	0.19	1.43513	1.22316
11	0.00024	2.00620	6.56290
12	0.106	4.69602	0.14349
13	0.80	2.27092	1.15632
14	0.355	1.28022	0.79709
15	0.61	0.62072	0.95238
16	0.128	0.76246	1.03589
17	0.121	0.55711	1.29027
18	0.054	0.34541	1.00342
19	0.049	0.71670	1.14715

Unit cost calculations (Cu):

Test 2 Solution 2

Total quantity: 41090 units

Quantity ratio: As calculated from the company records.

Cell utilization is 90%

Cell no	Machine utilization (η)	(Σquantity ratio x time) $(\Sigma t_{\rho} \cdot X)_{max}$.	Unit cost (Cu) £
1	0.90	0.56862	1.10831

Simple linear regression formula: $Cu = 1.10141 + 0.6206 \times \frac{1}{\eta}$

Test 2 Solution 3

Total quantity: 48322 units

Quantity ratio: As calculated from the company records.

Cell utilization is 100%

Cell no	Machine utilization (η)	(Σquantity ratio x time $(\Sigma t_{\rho} \cdot X)_{max}$.	Unit cost (Cu) £
1	1.00	0.48352	1.02851

Simple linear regression formula: $Cu = 1.02389 + 0.4613 \times \frac{1}{\eta}$

Test 2 Solution 4

Total quantity: 48460 units

Quantity ratio: As calculated from the company records.

Cell utlization is 78%

Cell no	Machine utilization (η)	Σquantity ratio x time $(\Sigma t_{\rho} \cdot X)_{max}$.	Unit cost (Cu) £
1	0.78	0.49331	1.03162

Simple linear regression formula: $Cu = 1.02781 + 0.2963 \times \frac{1}{\eta}$

Test 2   Solution 5

Total quantity: 50629 units

Quantity ratio: As calculated from the company records.

Cell utilization is 45%

Cell no	Machine utilization (η)	(Σquantity ratio x time) $(\Sigma t_{\rho}.X)_{max}$.	Unit cost (Cu) £
1	0.45	1.26739	1.05073

Simple linear regression formula: $Cu = 1.04424 + 0.2936 \times \frac{1}{\eta}$

At (η) utilization; 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

APPENDIX 7

Unit cost calculations for:

<u>Test 3.</u> Where every part is a family.

<u>Tables:</u>

- Simple linear regression formulas for solution 1.
- Summary of utilization; (Σquantity ratio x time) and the relevent unit cost.
- Unit cost calculation for solution 2;3;4 and 5.

Unit cost calculations (Cu)

Test 3 Solution 1

Total quantity: 50629 units

Quantity ratio: As calculated from the company records.

Cell no	Simple linear regression formulas
1	$Cu = 1.2105 + 2.2755 \times \frac{1}{\eta}$
2	$Cu = 1.6404 + 0.3073 \times \frac{1}{\eta}$
3	$Cu = 1.3544 + 0.5896 \times \frac{1}{\eta}$
4	$Cu = 1.3116 + 0.3537 \times \frac{1}{\eta}$
5	$Cu = 2.8483 + 1.0754 \times \frac{1}{\eta}$
6	$Cu = 0.6009 + 1.6931 \times \frac{1}{\eta}$
7	$Cu = 3.9398 + 0.4505 \times \frac{1}{\eta}$
8	$Cu = 1.1588 + 0.0575 \times \frac{1}{\eta}$
9	$Cu = 0.9887 + 1.4311 \times \frac{1}{\eta}$
10	$Cu = 1.1888 + 0.2345 \times \frac{1}{\eta}$
11	$Cu = 5.9099 + 0.0156 \times \frac{1}{\eta}$
12	$Cu = 0.1293 + 0.0754 \times \frac{1}{\eta}$
13	$Cu = 1.1239 + 2.5924 \times \frac{1}{\eta}$
14	$Cu = 0.7772 + 0.3693 \times \frac{1}{\eta}$
15	$Cu = 0.9385 + 0.3549 \times \frac{1}{\eta}$
16	$Cu = 1.0115 + 0.1517 \times \frac{1}{\eta}$
17	$Cu = 1.2443 + 0.1567 \times \frac{1}{\eta}$
18	$Cu = 0.9840 + 0.1047 \times \frac{1}{\eta}$
19	$Cu = 1.0923 + 0.2688 \times \frac{1}{\eta}$

At (η) utilization: 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

Summary of, utilization (η); (Σquantity ratio x time) $(\Sigma t_p.X)_{max}$.
and the relevent unit cost (Cu).
Test 3 Solution 1

Cell no	Utilization	(Σquantity ratio x time)	Unit cost
1	0.69	0.61716	1.24346
2	0.12	0.29398	1.66608
3	0.17	2.16976	1.38407
4	0.96	0.29562	1.31530
5	0.14	6.41867	2.92515
6	1.00	2.96628	0.61788
7	0.023	3.32771	4.13576
8	0.012	1.44190	1.20670
9	0.70	0.55172	0.90925
10	0.19	0.51538	1.20115
11	0.00024	2.00620	6.56290
12	0.106	2.34487	0.13637
13	0.80	2.27092	1.15632
14	0.355	0.67092	0.78765
15	0.61	0.25938	0.94428
16	0.128	0.48651	1.02330
17	0.121	0.11219	1.25728
18	0.054	0.34541	1.00342
19	0.049	0.71670	1.14715

Unit cost calculations (Cu):

Test 3 Solution 2

Total quantity: 41090 units

Quantity ratio: As calculated from the company records.

Cell utilization is 90%

Cell no	Machine utilization (η)	(Σquantity ratio x time) $(\Sigma t_{\rho}.X)_{max}$.	Unit cost (Cu) £
1	0.90	0.47425	1.10716

Simple linear regression formula: $Cu = 1.10141 + 0.5175 \times \frac{1}{\eta}$

Test 3 Solution 3

Total quantity: 48322 units

Quantity ratio: As calculated from the company records.

Cell utilization is 100%

Cell no	Machine utilization (η)	(Σquantity ratio x time) $(\Sigma t_{\rho}.X)_{max}$.	Unit cost (Cu) £
1	1.00	0.40328	1.02775

Simple linear regression formula: $Cu = 1.02389 + 0.3847 \times \frac{1}{\eta}$

Test 3 Solution 4

Total quantity: 48460 units

Quantity ratio: As calculated from the company records.

Cell utilization is 78%

Cell no	Machine utilization (η)	(Σquantity ratio x time) $(\Sigma t_{\rho}.X)_{max}$.	Unit cost (Cu) £
1	0.78	0.49331	1.03162

Simple linear regression formula: $Cu = 1.02781 + 0.2963 \times \frac{1}{\eta}$

Test 3 Solution 5

Total quantity: 50629 units.

Quantity ratio: As calculated from the company records.

Cell utilization is 45%

Cell no	Machine utilization (η)	(Σquantity ratio x time) $(\Sigma t_{\rho}.X)_{max}$.	Unit cost (Cu) £
1	0.45	1.15346	1.05015

Simple linear regression formula: $Cu = 1.0442 + 0.2674 \times \frac{1}{\eta}$

At (η) utilization; 10; 20; 30; 40; 50; 60; 70; 80; 90; 100%

APPENDIX 8

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APPENDIX 9

TABLES.

Source, Year Author	Set-Up Time	Lead And Through-Put Time	Work In Progress	Stocks	Manpower	Comments.
The Production Engineering 1970; F.R.E.Durie.	- 66%	-89%				From Material & Finished Products.
Metal Working Production 1974; W.A.Hawkins.		-53%	- 38%		+ 17%	Reductions Of Queues & Size Of Jobs. Increase In Manpower To Reduce Queues.
Design Engineering; 1971; Mark Crook.	- 80%	-80%	- 50%			Homogeneous Families Of Components. 10-15% Reduction In Machining Time Due To Rationalization.
Machine Tool Review; ; F.W.Craven.	- 99%	- 83%	- 72-92%			Operations Reduced From 3-2. Tooling Reduced From 28-24. Varies From One Cell To The Other. Reduction In Batch Size Resulted in Reduction Stocks.
Machinary & Production Eng. 1968;J.J.Marlew	-95%		-89%			
Metal Working Production		-84%	-100%		- 20%	Decrease In Manpower Without Drop In Out Put.
Turine Inter.Centre; 1969; J.L.Burbidge.		-77%		-44%		

— Reduced
+ Increased

Table (1) Average Benefits Of GT In The U.K.

Manufacturing costs (£) for producing equivalent numbers and types of components by conventional methods and GT

	Conventional		GT	
	Cost	Cost per piece	Cost	Cost per piece
Capital Cost	300,000	3.00	183,000	1.83
Pre-Production Costs				
Planning	2,830		3,680	
Data preparation	250		250	
Jig and tool design	21,250		12,750	
Jig and tool production	37,370		18,685	
	61,700	1.23	35,375	0.71
Annual Running Costs				
(i) Direct labour	150,000		60,000	
(ii) Indirect labour	38,500		21,000	
(iii) Maintenance	9,000		9,150	
(iv) Consumables	30,000		25,400	
(v) Tool and fixture maintenance	11,724		6,287	
(vi) Tool and work preparation	2,166		1,334	
(vii) Tool setting and grinding	5,000		5,000	
(viii) Space occupied	15,000		9,150	
(ix) Power and heating	8,000		6,000	
(x) Inspection	1,500		1,500	
(xi) Insurances	750		480	
(xii) Transport between operations	4,130		750	
	275,770	27.58	145,051	14.50
Material cost per piece		5.0		5.0
Approximate cost per piece		36.71		22.04
(xiii) Scrap	7,336		4,404	
(xiv) Work in progress	8,070		3,130	
Total Running Cost	291,181	29.12	153,585	15.36
Final Cost/Piece		38.35		22.80

TABLE (2)

(AFTER KNIGHT)

Quantity (Units)	Trial 1.			Trial 2.		
N	$\eta_1\%$	$\eta_2\%$	$\eta_3\%$	$\eta_1\%$	$\eta_2\%$	$\eta_3\%$
20000	16	12	12	8.4	26	36
40000	32	24	24	16.8	52	72
60000	48	36	36	25.2	78	108
80000	64	48	48	33.0	100	140

Table (3) Summary Of Quantity And Machine Utilization Trials 1 & 2

Machines	Parts 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	
2	X		X	X	X															
3													X							
4	X	X			X			X		X	X	X		X				X	X	
5															X					X
6			X	X		X			X							X	X	X		
7																				
8																				
9				X		X		X	X		X			X		X	X	X	X	
10	X																			
11																				
12																				
13	X			X							X	X								
14	X																X	X		
15	X									X	X	X		X		X	X		X	
16							X											X		
17	X	X	X	X	X	X		X					X		X		X	X		X
18									X											
19	X										X	X		X						

Table (4) Machine To Part Matrix

Analysis of groups from machine/part matrix

(Machining time, part number and quantities)

Group (31)

Turning machine	1	2	3	4	5	6	7	
Part no	Machining time (min)							Quantity (units)
6411280	0.6	0.5		4.9				36
6411276	0.7	0.5		5.5				36
6220603	0.6	0.5		6.1				18
6044103	5.4	5.1		11.2				66
7120850	0.5	0.5		18.7				61
6248068	0.7	1.2		15.0				3
8522532	0.5	0.5		16.7				59

Group (5)

Drilling machine	8	9	10	
6043040		0.33		66
6445065		0.33		66
6042514		0.60		260

Group (12)

Milling machine	11	12	13	
8400444			2.3	72
6211091			0.7	126

Group (69)

Grinding machine	14	15	16	17	18	
6062352				1.2		259
6110752				1.0		100

Group (174)

Extra machine	19	
6445419	2.0	14

Table (5)

Cell Formation

Solution no	Description of cells in the solution	Similarity coefficient (S.C.)	No of cells
1	Every machine is an individual cell.	55%	19
2	(1, 4); Every other machine is a separate cell.	50%	18
3	(1, 4, 9); 14; 13; 2; 6; 15; 17; 19; 10; 18; 16; 3; 8; 5; 7; 11; 12.	38%	17
4	(1, 4, 9, 14, 13, 2); 6; 15; 17; 19; 10; 18; 16; 3; 8; 5; 7; 11; 12.	27%	14
5	All machines are grouped in one cell.	0%	1

Table (6)

More solutions can be obtained from fig (22), at different levels of similarity coefficients.

Family Formation

Test no	Description of families in the test	Similarity coefficient (S.C.)	No of families
1	Each part is an individual family		639
2	Each group is an individual family	100%	233
3	All parts are grouped in one family	0%	1

Table (7)

More tests can be obtained from fig (23), at different levels of similarity coefficients.

Machine utilization calculations:

Total quantity 50629 units;

Full 100% load per machine is taken as 1920 hrs/year, and 75% effective performance.

Cell no	Quantity ratio	Quantity	Total hrs	Utilization	No of M/CS
1	2.5000	31576	1315.460	0.69	1
2	2.1000	6607	231.280	0.12	1
3	9.25176	2076	320.100	0.17	1
4	11.72480	28380	5545.850	2.89	3
5	24.6466	631	263.910	0.14	1
6	12.4213	19688	4075.860	2.12	2
7	7.47185	357	44.760	0.023	1
8	3.77321	357	22.451	0.012	1
9	5.88843	27184	2669.320	1.39	2
10	5.58327	3967	369.150	0.19	1
11	2.00625	14	00.468	0.00024	1
12	4.80259	2560	204.910	0.10672	1
13	8.69320	10527	1525.220	0.79438	1
14	5.57995	7345	683.079	0.35577	1
15	4.17893	16839	1172.810	0.61084	1
16	4.62691	3190	245.977	0.12812	1
17	1.69201	8245	232.510	0.12109	1
18	1.96390	3195	104.577	0.05446	1
19	1.58895	3560	94.278	0.04910	1

Table (8)

Summary of relevant results of utilization (η); Unit cost (Cu); and quantity (N).

Total quantity: 50629 units

Quantity ratio: As calculated from the company records.

	Cu_1	N_1	Cu_2	N_2	Cu_3	N_3	Cu_4	N_4
10	2.13214	4608	1.85995	5486	1.60577	1245	2.71490	2948
20	1.67131	9216	1.75018	10971	1.48005	2490	2.01317	5895
30	1.51770	13824	1.71361	16457	1.43816	3736	1.77932	8843
40	1.44090	18432	1.69533	21942	1.41722	4981	1.66239	11790
50	1.39482	23040	1.68436	27429	1.40466	6226	1.59224	14738
60	1.36409	27648	1.67704	32914	1.39628	7471	1.54547	17686
70	1.34216	32256	1.67182	38400	1.39030	8716	1.51206	20633
80	1.32569	36864	1.66790	43886	1.38581	9962	1.48760	23581
90	1.31289	41472	1.66485	49371	1.38232	11207	1.46752	26528
100	1.30265	46080	1.66242	54857	1.37953	12452	1.45192	29476

	Cu_5	N_5	Cu_6	N_6	Cu_7	N_7	Cu_8	N_8
10	3.26126	467	1.30989	1855	4.04108	1542	1.17385	3053
20	3.05480	935	0.95540	3710	3.99045	3084	1.16632	6106
30	2.98598	1402	0.83725	5565	3.97360	4625	1.16381	9159
40	2.95157	1870	0.77817	7420	3.96517	6167	1.16255	12212
50	2.93093	2337	0.74273	9275	3.96012	7709	1.16180	15266
60	2.91716	2804	0.71910	11129	3.95675	9251	1.16130	18319
70	2.90733	3272	0.70222	12984	3.95434	10793	1.16094	21372
80	2.89996	3732	0.68956	14839	3.95253	12334	1.16067	24425
90	2.89422	4207	0.67971	16694	3.95113	13876	1.16046	27478
100	2.88964	4674	0.67184	18549	3.95001	15418	1.16029	30531

	Cu_9	N_9	Cu_{10}	N_{10}	Cu_{11}	N_{11}	Cu_{12}	N N_{12}
10	2.51612	1956	1.44278	2063	5.91141	5742	0.14469	2399
20	1.75246	3912	1.31580	4126	5.91063	11484	0.13698	4797
30	1.49791	5868	1.27347	6189	5.91037	17226	0.13441	7196
40	1.37063	7824	1.25231	8252	5.91024	22968	0.13312	9595
50	1.29427	9780	1.23961	10315	5.91016	28710	0.13235	11994
60	1.16130	11730	1.23114	12378	5.91011	34452	0.13184	14392
70	1.16094	13648	1.22510	14441	5.91007	40194	0.13147	16791
80	1.17972	15648	1.22056	16504	5.91004	45936	0.13119	19190
90	1.15851	17604	1.21706	18567	5.91002	51678	0.13098	21588
100	1.16029	19564	1.21421	20633	5.91000	57421	0.13081	23987

	Cu_{13}	N_{13}	Cu_{14}	N_{14}	Cu_{15}	N_{15}	Cu_{16}	N_{16}
10	2.11624	1325	1.08434	2065	1.57546	2757	1.15571	2490
20	1.62008	2650	0.93079	4129	1.25696	5513	1.08362	4980
30	1.45469	3976	0.87961	6194	1.15080	8270	1.05959	7469
40	1.37200	5301	0.85402	8258	1.09771	11027	1.04757	9959
50	1.32238	6626	0.83866	10323	1.06586	13783	1.04036	12449
60	1.28930	7951	0.82843	12387	1.04463	16540	1.03556	14939
70	1.26567	9276	0.82112	14452	1.02946	19297	1.03212	17428
80	1.24796	10601	0.81563	16516	1.01809	22053	1.02955	19918
90	1.23417	11927	0.81137	18581	1.00924	24810	1.02755	22408
100	1.22315	13252	0.80795	20645	1.00216	27567	1.02595	24898

	Cu_{17}	N_{17}	Cu_{18}	N_{18}	Cu_{19}	N_{19}
10	1.41176	6808	1.04354	5866	1.15190	7250
20	1.32804	13617	1.01379	11732	1.12211	14500
30	1.30014	20425	1.00388	17598	1.11218	21750
40	1.28618	27234	0.99892	23464	1.10721	29000
50	1.27781	34042	0.99594	29329	1.10423	36250
60	1.27223	40851	0.99396	35195	1.10225	43500
70	1.26824	47659	0.99254	41061	1.10083	50750
80	1.26525	54468	0.99148	46927	1.09976	58000
90	1.26293	61276	0.99066	52793	1.09894	65251
100	1.26107	68085	0.99000	58659	1.09828	72500

Table (9)

Summary of relevant results of utilization (η); Unit cost (Cu); and quantity (N).

Total quantity: 30000 units

Quantity ratio: As calculated from the company records.

	Cu_1	N_1	Cu_2	N_2	Cu_3	N_3	Cu_4	N_4
10	2.96456	4608	2.99007	5486	2.53843	1245	3.61690	2948
20	2.50373	9216	2.88033	10971	2.41274	2490	2.91531	5895
30	2.35012	13824	2.84375	16457	2.37085	3736	2.68145	8843
40	2.27332	18432	2.82546	21942	2.34990	4981	2.56452	11790
50	2.22724	23040	2.81449	27429	2.33733	6226	2.49436	14738
60	2.19651	27648	2.80717	32914	2.32895	7471	2.44759	17686
70	2.17457	32256	2.80195	38400	2.32297	8716	2.41418	20633
80	2.15811	36864	2.79803	43886	2.31848	9962	2.38912	23581
90	2.14531	41472	2.79498	49371	2.311499	11207	2.36963	26528
100	2.13507	46080	2.79254	54857	2.311219	12452	2.35404	29476

	Cu_5	N_5	Cu_6	N_6	Cu_7	N_7	Cu_8	N_8
10	5.04622	467	1.72303	1855	6.70458	1542	1.95726	3053
20	4.83976	935	1.36856	3710	6.65405	3084	1.94973	6106
30	4.77054	1402	1.25040	5565	6.63718	4625	1.94722	9159
40	4.76653	1870	1.19132	7420	6.62875	6167	1.94596	12212
50	4.71588	2337	1.15587	9275	6.62369	7709	1.94521	15266
60	4.70212	2804	1.13224	11129	6.62032	9256	1.94471	18319
70	4.69229	3272	1.11536	12984	6.61791	10793	1.94435	21319
80	4.68492	3739	1.10270	14839	6.61610	12334	1.94408	24425
90	4.67918	4207	1.09286	16694	6.61470	13876	1.94387	27478
100	4.67460	4674	1.08498	18549	6.61357	15418	1.94370	30531

	Cu_9	N_9	Cu_{10}	N_{10}	Cu_{11}	N_{11}	Cu_{12}	N_{12}
10	3.19055	1956	2.24635	2063	9.39466	5742	0.23201	2399
20	2.39675	3912	2.11937	4126	9.39362	11484	0.22430	4797
30	2.14235	5868	2.07704	6189	9.39362	17226	0.22173	7196
40	2.01507	7824	2.05588	8252	9.39349	22968	0.22044	9595
50	1.93871	9780	2.04318	10315	9.39341	28710	0.21967	11994
60	1.88780	11736	2.03471	12378	9.39336	34452	0.21916	14392
70	1.85143	13692	2.02867	14441	9.39331	40194	0.21879	16791
80	1.82416	15648	2.02467	16504	9.39329	45936	0.21851	19190
90	1.80295	17604	2.02060	18567	9.39327	51678	0.21830	21588
100	1.78590	19564	2.01778	20633	9.39326	57421	0.21813	23987

	Cu_{13}	N_{13}	Cu_{14}	N_{14}	Cu_{15}	N_{15}	Cu_{16}	N_{16}
10	2.87572	1325	1.60960	2065	2.22076	2557	1.85147	2490
20	2.37956	2650	1.45605	4129	1.90198	5513	1.77938	4980
30	2.21417	3976	1.40487	6194	1.79610	88270	1.75535	7469
40	2.13148	5301	1.37928	8258	1.74301	11027	1.74333	9959
50	2.08186	6626	1.36392	10323	1.71116	13783	1.73612	12449
60	2.04878	7951	1.35369	12387	1.68993	16540	1.73132	14939
70	2.02515	9276	1.34638	14452	1.67476	19297	1.72788	17428
80	2.00744	10601	1.34089	16516	1.66339	22053	1.72531	19918
90	1.99365	11927	1.33663	18581	1.65454	24810	1.72331	22408
100	1.98263	13252	1.33321	20645	1.64746	27567	1.72171	24898

	Cu_{17}	N_{17}	Cu_{18}	N_{18}	Cu_{19}	N_{19}
10	2.26720	6808	1.72036	5866	1.90343	7250
20	2.18348	13617	1.69061	11732	1.87364	14500
30	2.15558	20425	1.68070	17598	1.86371	21750
40	2.14162	27234	1.67574	23464	1.85874	29000
50	2.13325	34042	1.67276	29329	1.85576	36250
60	2.12767	40851	1.67078	35195	1.85378	43500
70	2.12368	47659	1.66936	41061	1.85236	50750
80	2.12069	54468	1.66830	46927	1.85129	58000
90	2.11837	61276	1.66748	52793	1.85047	65251
100	2.11651	68085	1.66682	58659	1.84981	72500

Table (10)

Summary of relevant results of utilization (η); Unit cost (Cu); and quantity (N).

Total quantity: 40000 units

Quantity ratio: As calculated from the company records.

	Cu_1	N_1	Cu_2	N_2	Cu_3	N_3	Cu_4	N_4
10	2.45382	4608	2.29726	5486	1.96666	1245	3.06346	2948
20	1.99299	9216	2.18752	10971	1.84097	2490	2.36187	5895
30	1.83938	13824	2.15094	16457	1.79908	3736	2.12801	8843
40	1.76258	18432	2.13265	21942	1.77813	4981	2.01108	11790
50	1.71650	23040	2.12168	27429	1.76556	6226	1.94092	14738
60	1.68577	27648	2.11436	32914	1.75718	7471	1.89415	17686
70	1.66383	32256	2.10914	38400	1.75120	8716	1.86074	20633
80	1.64737	36864	2.10552	43886	1.74671	9962	1.83568	23581
90	1.63457	41472	2.10217	49371	1.74322	11207	1.81619	26528
100	1.62433	46080	2.09973	54857	1.74042	12452	1.80060	29476

	Cu_5	N_5	Cu_6	N_6	Cu_7	N_7	Cu_8	N_8
10	3.8879	467	1.46451	1855	5.05377	1542	1.47171	3053
20	3.68144	935	1.11504	3710	5.00318	3084	1.46418	6106
30	3.61262	1402	0.99688	5565	4.98634	4625	1.46167	9159
40	3.57821	1870	0.93780	7420	4.97788	6167	1.46041	12212
50	3.55757	2337	0.90235	9275	4.97282	7709	1.45966	15266
60	3.54380	2804	0.87872	11129	4.96945	9251	1.45916	18319
70	3.53397	3272	0.86184	12984	4.96704	10793	1.45880	21319
80	3.52660	3739	0.84918	14839	4.96523	12334	1.45848	24425
90	3.52086	4207	0.83934	16694	4.96383	13876	1.45832	27478
100	3.51628	4674	0.83146	18549	4.96270	15418	1.45815	30531

	Cu_9	N_9	Cu_{10}	N_{10}	Cu_{11}	N_{11}	Cu_{12}	N_{12}
10	2.77864	1956	1.74825	2063	6.89639	5742	0.17789	2399
20	2.01498	3912	1.62127	4126	6.89561	11484	0.17018	4797
30	1.76043	5868	1.57894	6189	6.89535	17226	0.16761	7196
40	1.63315	7824	1.55778	8252	6.89522	22968	0.16632	9595
50	1.55679	9780	1.54508	10315	6.89514	28710	0.16555	11994
60	1.50588	11736	1.53661	12378	6.89509	34452	0.16504	14392
70	1.46951	13692	1.53057	14441	6.89505	40194	0.16467	16791
80	1.44224	15642	1.52576	16504	6.89502	45936	0.16439	19190
90	1.42103	17604	1.52250	18567	6.89500	51678	0.16418	21588
100	1.40406	19564	1.51968	20633	6.89488	57421	0.16401	23987

	Cu_{13}	N_{13}	Cu_{14}	N_{14}	Cu_{15}	N_{15}	Cu_{16}	N_{16}
10	2.4047	1325	1.28380	2065	1.82482	2757	1.42469	2490
20	1.90854	2650	1.13025	4129	1.50632	5513	1.31020	4980
30	1.74315	3976	1.07907	6194	1.40016	8270	1.30029	7469
40	1.66046	5301	1.05348	8258	1.34707	11270	1.29533	9959
50	1.61084	6626	1.03812	10323	1.31522	13783	1.29235	12449
60	1.57776	7951	1.02789	12387	1.29037	16540	1.29037	14939
70	1.55413	9276	1.02058	14452	1.27882	19297	1.28895	17428
80	1.53642	10601	1.01509	16516	1.26745	22053	1.28789	19918
90	1.52263	11927	1.01083	18581	1.25860	24810	1.28707	22408
100	1.51167	13252	1.00741	20645	1.25152	27567	1.28641	24898

	Cu_{17}	N_{17}	Cu_{18}	N_{18}	Cu_{19}	N_{19}
10	1.74242	6808	1.30514	5866	1.44246	7250
20	1.65870	13617	1.27539	11732	1.41267	14500
30	1.63080	20425	1.26548	17598	1.40274	21750
40	1.61684	27234	1.26052	23464	1.39777	29000
50	1.60847	34042	1.25754	29329	1.39479	36250
60	1.60289	40851	1.25556	35195	1.39281	43500
70	1.59890	47659	1.25414	41061	1.39139	50750
80	1.59591	54468	1.25308	46927	1.39032	58000
90	1.28707	61276	1.59359	52793	1.25226	65251
100	1.59173	68085	1.25160	58659	1.38884	72500

Table (11)

Summary of relevant results of utilization (η); Unit cost (Cu); and quantity (N).

Total quantity: 60000 units

Quantity ratio: As calculated from the company records.

	Cu_1	N_1	Cu_2	N_2	Cu_3	N_3	Cu_4	N_4
10	1.9431	4608	1.60477	5486	1.39490	1245	2.51002	2948
20	1.48227	9216	1.49503	10971	1.26921	2490	1.8084	5895
30	1.32866	13824	1.45845	16457	1.22732	3736	1.57457	8843
40	1.25186	18432	1.44016	21942	1.20637	4981	1.45764	11790
50	1.20578	23040	1.42919	27429	1.19380	6226	1.38748	14738
60	1.17505	27648	1.42187	32914	1.18542	7471	1.34071	17686
70	1.14411	32256	1.41665	38400	1.17944	8716	1.30730	20633
80	1.13665	36864	1.41273	43886	1.17495	9962	1.28224	23581
90	1.12385	41472	1.40968	49371	1.17146	11207	1.26275	26528
100	1.11361	46080	1.40724	54857	1.16866	12452	1.24681	29476

	Cu_5	N_5	Cu_6	N_6	Cu_7	N_7	Cu_8	N_8
10	2.72956	467	1.21598	1855	3.40291	1542	0.98616	3053
20	2.52310	935	0.86151	3710	3.35232	3084	0.97863	6106
30	2.45428	1402	0.74335	5565	3.33545	4625	0.97612	9159
40	2.41987	1870	0.68427	7420	3.32702	6167	0.97486	12212
50	2.39923	2337	0.64882	9275	3.32195	7709	0.97411	15266
60	2.38546	2804	0.62519	11129	3.31858	9251	0.97361	18319
70	2.37563	3272	0.60831	12984	3.31617	10793	0.97325	21319
80	2.36826	3739	0.59565	14839	3.31436	12334	0.97298	24425
90	2.36252	4207	0.58581	16694	3.31296	13876	0.97277	27478
100	2.35794	4674	0.57793	18549	3.31183	15418	0.97260	30531

	Cu_9	N_9	Cu_{10}	N_{10}	Cu_{11}	N_{11}	Cu_{12}	N_{12}
10	2.36154	1956	1.25015	2063	4.59811	5742	0.12371	2399
20	1.59788	3912	1.12317	4126	4.59733	11484	0.11600	4797
30	1.34333	5868	1.08075	6189	4.59707	17226	0.11343	7196
40	1.21605	7824	1.05968	8252	4.59694	22968	0.11214	9595
50	1.13969	9780	1.04698	10315	4.59686	28710	0.11137	11994
60	1.08878	11736	1.03851	12378	4.59681	34452	0.11086	14392
70	1.05241	13692	1.03247	14441	4.59677	40194	0.11049	16791
80	1.02514	15648	1.02793	16504	4.59674	45936	0.11021	19190
90	1.00393	17604	1.02440	18567	4.59672	51678	0.11000	21588
100	0.98696	19564	1.02158	20633	4.59671	57421	0.10983	23987

	Cu_{13}	N_{13}	Cu_{14}	N_{14}	Cu_{15}	N_{15}	Cu_{16}	N_{16}
10	1.93394	1325	0.95827	2065	1.42887	2757	0.99782	2490
20	1.43778	2650	0.80472	4129	1.11037	5513	0.92573	4980
30	1.27239	3976	0.75354	6194	1.00421	8270	0.90170	7469
40	1.18970	5301	0.72795	8258	0.95112	11027	0.88968	9959
50	1.14008	6626	0.71259	10323	0.91927	13783	0.88247	12449
60	1.10700	7951	0.70236	12387	0.89804	16540	0.87767	14939
70	1.08337	9276	0.69505	14452	0.88287	19297	0.87423	17428
80	1.06187	10601	0.68956	16516	0.87150	22053	0.87166	19918
90	1.05187	11927	0.68530	18581	0.86265	24810	0.86966	22408
100	1.04085	13252	0.68188	20645	0.85557	27567	0.86806	24898

	Cu_{17}	N_{17}	Cu_{18}	N_{18}	Cu_{19}	N_{19}
10	1.21742	6808	0.88992	5866	0.9815	7250
20	1.13370	13617	0.86017	11732	0.95171	14500
30	1.10580	20425	0.85026	17598	0.94178	21750
40	1.09184	27234	0.84530	23464	0.93681	29000
50	1.08347	34042	0.84232	29329	0.93383	36250
60	1.07789	40851	0.84034	35195	0.93185	43500
70	1.07390	47659	0.83892	41061	0.93043	50750
80	1.07091	54468	0.83786	46927	0.92936	58000
90	1.06859	61276	0.83704	52793	0.92854	65251
100	1.06673	68085	0.83638	58659	0.92788	72500

Table (12)

Summary of relevant results of utilization (η); Unit cost (Cu); and quantity (N).

Total quantity: 30000 units

Quantity ratio: As calculated for the proposed new data.

	Cu_1	N_1	Cu_2	N_2	Cu_3	N_3	Cu_4	N_4
10	3.54836	2730	3.1410	3251	2.71129	738	4.58181	11746
20	2.82063	5460	2.95580	6502	2.49917	1476	3.39777	3493
30	2.56139	8191	2.89406	9753	2.42847	2213	3.00306	5240
40	2.43177	13001	2.86320	2951	2.39311	6986	2.80573	1108
50	2.35400	13651	2.84468	16252	2.37190	3689	2.68733	8733
60	2.30215	16381	2.83233	19503	2.35776	4427	2.60839	10479
70	2.26511	19111	2.82351	22753	2.34776	5165	2.55201	12226
80	2.23734	21842	2.81690	26004	2.34008	5902	2.50973	13972
90	2.21573	24572	2.81175	29254	2.33419	6640	2.47684	15719
100	2.19845	27302	2.80764	32505	2.32948	7378	2.45053	17466

	Cu_5	N_5	Cu_6	N_6	Cu_7	N_7	Cu_8	N_8
10	5.33017	277	2.32322	1099	6.77427	913	1.96762	1809
20	4.98171	554	1.72499	2198	6.68886	1826	1.95491	3618
30	4.86557	831	1.52558	3297	6.66039	2739	1.95067	5427
40	4.80751	1108	1.42588	4396	6.64616	3652	1.94855	7236
50	4.77267	1385	1.36606	5495	6.63762	4565	1.94728	9045
60	4.74944	1662	1.32617	6594	6.63192	5478	1.94643	10854
70	4.73285	1939	1.29769	7693	6.62786	6393	1.94583	12663
80	4.72041	2216	1.27632	8793	6.62481	7304	1.94537	14473
90	4.71073	2493	1.25970	9892	6.62243	8217	1.94502	16282
100	4.70299	2770	1.24371	10991	6.62054	9133	1.94474	18091

	Cu_9	N_9	Cu_{10}	N_{10}	Cu_{11}	N_{11}	Cu_{12}	N_{12}
10	4.21084	1159	2.42099	1223	9.39574	3402	0.24262	1421
20	2.92204	2318	2.20669	2445	9.39442	6805	0.22960	2843
30	2.49244	3477	2.13525	3668	9.39398	10207	0.22526	4264
40	2.27764	4636	2.09954	4890	9.39376	13609	0.22309	5685
50	2.14876	5795	2.07811	6113	9.39362	17012	0.22179	7107
60	2.06284	6954	2.06382	7335	9.39354	20414	0.22092	8528
70	2.00147	8113	2.05361	8558	9.39347	23817	0.22030	9949
80	1.95544	9272	2.04596	9781	9.39343	27219	0.21984	11370
90	1.41964	10431	2.04001	11003	9.39339	30621	0.21948	12792
100	1.89100	11592	2.03525	12226	9.39337	34024	0.21919	14213

	Cu_{13}	N_{13}	Cu_{14}	N_{14}	Cu_{15}	N_{15}	Cu_{16}	N_{16}
10	3.55810	785	1.82077	1223	2.54857	1633	1.95062	1475
20	2.72075	1570	1.56164	2447	2.06619	3267	1.82896	2951
30	2.44163	2356	1.47526	3670	1.90530	4900	1.78840	4426
40	2.30207	3141	1.43207	4893	1.82498	6534	1.76812	5901
50	2.21834	3926	1.40616	6117	1.77673	8167	1.75595	7376
60	2.16251	4711	1.38888	7340	1.74457	9801	1.74784	8852
70	2.12264	5496	1.37654	8563	1.72160	11434	1.74205	10327
80	2.09273	6282	1.36729	9786	1.70437	13067	1.73770	11802
90	2.06947	7067	1.36009	11010	1.69097	14701	1.73432	13278
100	2.05087	7852	1.35433	12233	1.68025	16334	1.73162	14753

	Cu_{17}	N_{17}	Cu_{18}	N_{18}	Cu_{19}	N_{19}
10	2.38235	4034	1.76178	3476	1.94441	4296
20	2.24106	8068	1.71107	6951	1.89413	8592
30	2.19396	12103	1.69434	10427	1.87737	12888
40	2.17041	16137	1.68597	13903	1.86899	17184
50	2.15628	20171	1.68095	17379	1.86396	21480
60	2.14686	24205	1.67760	20854	1.86061	25775
70	2.14013	28240	1.67521	24330	1.85821	30071
80	2.13509	32274	1.67342	27806	1.85642	34367
90	2.13116	36308	1.67202	31282	1.85502	38663
100	2.12803	40342	1.67091	34757	1.85391	42959

Table (13)

Summary of relevant results of utilization (η); Unit cost (Cu); and quantity (N).

Total quantity: 40000 units

Quantity ratio: As calculated for the proposed new data.

	Cu_1	N_1	Cu_2	N_2	Cu_3	N_3	Cu_4	N_4
10	2.69875	3640	2.35575	4335	2.03346	984	3.43635	2328
20	2.11547	7280	2.21685	8670	1.87437	1968	2.54832	4656
30	1.92104	10920	2.17054	13004	1.82135	2952	2.25229	6984
40	1.82382	14560	2.14740	17339	1.79483	3936	2.10429	9312
50	1.7655	17200	2.13351	21673	1.77892	4920	2.01549	11640
60	1.72661	21840	2.12424	26008	1.76832	5904	1.95629	13968
70	1.69882	25480	2.11763	30343	1.76082	6888	1.91400	16296
80	1.67800	29120	2.11267	34677	1.7556	7872	1.88229	18624
90	1.66179	32760	2.10881	39012	1.75064	8856	1.85763	20952
100	1.64883	36400	2.10573	43347	1.74711	9840	1.83789	23280

	Cu_5	N_5	Cu_6	N_6	Cu_7	N_7	Cu_8	N_8
10	3.99762	369	1.74241	1465	5.08070	1217	1.47571	2412
20	3.73628	739	1.29374	2931	5.01664	2435	1.46618	4824
30	3.64917	1108	1.14418	4396	4.99529	3652	1.46300	7236
40	3.60563	1433	1.06941	5861	4.98462	4869	1.46141	9648
50	3.57950	1847	1.02454	7327	4.97821	6087	1.46046	12060
60	3.56208	2216	0.99462	8792	4.97394	7304	1.45982	14472
70	3.54963	2585	0.97326	10257	4.97089	8521	1.45937	16884
80	3.54030	2955	0.95724	11723	4.96860	9739	1.45902	19296
90	3.53304	3324	0.94477	13188	4.96682	10956	1.45876	21708
100	3.52724	3693	0.93278	14653	4.96540	12173	1.45876	24121

	Cu_9	N_9	Cu_{10}	N_{10}	Cu_{11}	N_{11}	Cu_{12}	N_{12}
10	3.15813	1545	1.81574	1630	7.04680	4536	0.18196	1895
20	2.19153	3091	1.65501	3260	7.04581	9072	0.17220	3789
30	1.86933	4636	1.60143	4890	7.04548	13608	0.16894	5684
40	1.70823	6181	1.57465	6520	7.04532	18144	0.16731	7579
50	1.61157	7727	1.55858	8150	7.04521	22680	0.16634	9473
60	1.54713	9272	1.54786	9781	7.04515	27216	0.16569	11368
70	1.50110	10817	1.54020	11411	7.04510	31752	0.16522	13263
80	1.46658	12363	1.53447	13041	7.04507	36288	0.16480	15157
90	1.43973	13908	1.53000	14671	7.04504	40824	0.16461	17052
100	1.41825	15453	1.52643	16301	7.04502	45365	0.16439	18947

	Cu_{13}	N_{13}	Cu_{14}	N_{14}	Cu_{15}	N_{15}	Cu_{16}	N_{16}
10	2.66857	1047	1.36554	1631	1.91142	2177	1.46296	1967
20	2.04056	2093	1.17123	3261	1.54964	4355	1.37172	3933
30	1.83122	3140	1.10644	4892	1.42897	6532	1.34130	5900
40	1.72655	4187	1.07405	6523	1.36873	8709	1.32609	7867
50	1.66375	5233	1.05462	8153	1.33254	10887	1.31696	9833
60	1.62188	6280	1.04166	9784	1.30842	13064	1.31088	11800
70	1.59198	7327	1.03240	11415	1.291200	15241	1.30653	13767
80	1.56954	8373	1.02546	13045	1.27827	14719	1.30327	15733
90	1.55210	9420	1.02006	14676	1.26822	19596	1.30074	17700
100	1.53815	10467	1.01577	16307	1.26018	21779	1.29871	19667

	Cu_{17}	N_{17}	Cu_{18}	N_{18}	Cu_{19}	N_{19}
10	1.78676	5379	1.32133	4634	1.45830	5728
20	1.68079	10757	1.28330	9269	1.42059	11456
30	1.64547	16136	1.27075	13904	1.40802	17184
40	1.62780	21515	1.26447	18539	1.40174	22912
50	1.61721	26893	1.26071	23173	1.39797	28640
60	1.61014	32272	1.25820	27808	1.39545	34368
70	1.60509	37651	1.25640	32443	1.39365	40096
80	1.60131	43029	1.25506	37077	1.39231	45824
90	1.59837	48408	1.25401	41712	1.39126	51552
100	1.59602	53787	1.25318	46347	1.39043	57278

Table(14)

Summary of relevant results of utilization (η); Unit cost (Cu); and quantity (N).

Total quantity: 60000 units

Quantity ratio: As calculated for the proposed new data.

	Cu_1	N_1	Cu_2	N_2	Cu_3	N_3	Cu_4	N_4
10	1.79918	5460	1.5705	6502	1.35564	1476	2.29090	3492
20	1.41031	10920	1.4779	13004	1.24958	2952	1.69888	6984
30	1.28069	16380	1.44703	19506	1.21423	4428	1.50153	10476
40	1.21588	21840	1.4316	26008	1.19655	5904	1.40286	13968
50	1.17700	27300	1.42234	32510	1.18595	7380	1.34366	17460
60	1.15107	32760	1.41616	39012	1.17888	8856	1.30419	20952
70	1.13255	38220	1.41175	45514	1.17388	10332	1.27600	24444
80	1.11867	43680	1.40845	52016	1.17004	11808	1.25486	27936
90	1.10786	49140	1.40587	58518	1.16709	13284	1.23842	31428
100	1.09922	54144	1.40382	65020	1.16474	14756	1.22526	34922

	Cu_5	N_5	Cu_6	N_6	Cu_7	N_7	Cu_8	N_8
10	2.66508	554	1.16161	2198	3.38713	1826	0.98381	3618
20	2.49085	1108	0.86249	4396	3.34443	3652	0.97745	7236
30	2.43278	1662	0.76279	6594	3.33019	5478	0.97533	10854
40	2.40375	2216	0.71294	8792	3.32308	7304	0.97427	14472
50	2.38633	2770	0.68303	10990	3.31881	9130	0.97364	18090
60	2.37472	3324	0.66308	13188	3.31596	10956	0.97321	21708
70	2.36642	3878	0.64884	15386	3.31393	12782	0.97291	25326
80	2.36020	4432	0.63816	17584	3.31240	14608	0.97268	28944
90	2.35536	4986	0.62985	19782	3.31121	16434	0.97251	32562
100	2.35149	5540	0.62185	21982	3.31027	18266	0.97237	36180

	Cu_9	N_9	Cu_{10}	N_{10}	Cu_{11}	N_{11}	Cu_{12}	N_{12}
10	2.10542	2318	1.21049	2445	4.69787	6804	0.12131	2842
20	1.46102	4636	1.10334	4890	4.69721	13608	0.11480	5684
30	1.24622	6954	1.06762	7335	4.69699	20412	0.11263	8526
40	1.13882	9272	1.04977	9781	4.69688	27216	0.11154	11368
50	1.07438	11590	1.03905	12226	4.69681	34020	0.11089	14210
60	1.03142	13908	1.03191	14671	4.69677	40824	0.11046	17052
70	1.00073	16226	1.02680	17116	4.69673	47628	0.11015	19894
80	0.97772	18544	1.02298	19561	4.69671	54432	0.10992	22736
90	0.95982	20862	1.02000	22006	4.69669	61336	0.10974	25578
100	0.94550	23180	1.01762	24451	4.69668	68040	0.10959	28426

	Cu_{13}	N_{13}	Cu_{14}	N_{14}	Cu_{15}	N_{15}	Cu_{16}	N_{16}
10	1.77905	1570	0.91038	2446	1.27428	3266	0.97531	2950
20	1.36037	3140	0.78082	4892	1.03309	6532	0.91448	5900
30	1.22081	4710	0.73763	7338	0.95265	9798	0.89420	8850
40	1.15103	6280	0.71853	9784	0.91249	13064	0.88406	11800
50	1.10917	7850	0.70308	12230	0.88836	16330	0.87797	14750
60	1.08125	9420	0.69444	14676	0.87228	19596	0.87392	17700
70	1.06132	10990	0.68827	17122	0.86080	22862	0.87102	20650
80	1.04636	12560	0.68364	19568	0.85218	26128	0.86885	23600
90	1.03473	14130	0.68004	22014	0.84548	29394	0.86716	26550
100	1.02543	15704	0.67716	24466	0.84012	32668	0.86581	29506

	Cu_{17}	N_{17}	Cu_{18}	N_{18}	Cu_{19}	N_{19}
10	1.19117	8068	0.88089	6952	0.97220	8592
20	1.12053	16136	0.85553	13904	0.94706	17184
30	1.09698	24204	0.84717	20856	0.93868	25776
40	1.08520	32272	0.84298	27808	0.93449	34368
50	1.07814	40340	0.84047	34760	0.93198	42960
60	1.07343	48408	0.83880	41712	0.93030	51552
70	1.07006	56476	0.83760	48664	0.92910	60144
80	1.06754	64544	0.83671	55616	0.92821	68736
90	1.06558	72612	0.83601	62568	0.92751	77328
100	1.06401	80684	0.83545	69514	0.92695	85918

Table (15)

Unit cost to utilization comparison for individual machines

First Machine				2nd Machine				3rd Machine			
Trial 1		Trial 2		Trial 1		Trial 2		Trial 1		Trial 2	
η%	Cu(P)	η%	Cu(P)	η%	Cu(P)	η%	Cu(P)	η%	Cu(P)	η%	Cu(P)
58	12	34	10	48	12	79	12	50	10	92	14
50	16	24	16	38	17	66	14	35	15	72	17
42	20	18	26	25	26	52	19	25	24	55	24
34	26	12	23	20	31	40	25	18	33	38	33
16	45	7	50	14	45	28	34	13	45	25	43
10	91	6	70	6	91	14	70	7	90	15	69

See fig (18). (P) Pence

Unit cost comparison (quantity/utilization) of the cell

(All machines involved)

Quantity				Utilization			
Trial 1		Trial 2		Trial 1		Trial 2	
Cu (P)	Q(10^3)	Cu (P)	Q(10^3)	Cu (P)	η%	Cu (P)	η%
90	10	69	10	90	10	69	12
48	20	36	20	44	13	36	23
23	40	26	30	24	28	24	35
16	60	15	50	12	42	20	48
12	80	13	60	9	60	14	60
10	100	9	75	8	69	12	68

See fig (17) (P= Pence)

Table (16)