FEASIBILITY STUDY FOR THE IMPLEMENTATION OF A G.T. SYSTEM IN A MULTI-PRODUCT COMPANY

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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

Since the late nineteen-forties, the concept of Group Technology (G.T.) has been applied in European engineering companies, first in Russia and since the middle sixties in West Europe including Great Britain.

The early applications were in plants particularly suited to this technology, but more recently general batch producing companies have looked at this manufacturing philosophy; these, according to the theory, could benefit greatly from G.T. Since approximately 80% of the engineering industry in this country is involved in batch production, it is likely that a wide-spread application of G.T. would have far reaching effects on the productivity of the engineering industry in this country.

The author has been employed by Wildt Mellor Bromley Limited, Leicester to study the feasibility of applying G.T. to the manufacture of large circular knitting machines which are complex assemblies produced in a variety of different sizes and models.

The report presented here covers the following stages of a fundamental G.T. analysis:

(i) review of the plant and its problems to test its G.T. suitability

(ii) assessment of objectives and prediction 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 report is based on a survey of the existing literature and it has been attempted to lay down certain parameters to gauge the suitability of a plant for G.T. and the savings which can be obtained. The available analysis techniques have been surveyed and by means of the test case illustrated, it has been demonstrated how techniques of analysis can be selected to suit the specific requirements of the plant in question.

The importance of supporting administrative systems, which have had limited publicity in most other applications, has been stressed.

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1. INTRODUCTION

Since the early days of automobile construction, the advantages of flow line production have been achieved. For decades it was generally thought that flow lines could only handle one or, at best, a very small number of very similar components. Whilst the advantages of such a production technology were fully appreciated, the technical difficulties of fitting batch production into flow lines were considered to be too complex to be solved. Since batch production requires a great number of different flow patterns, shop layout to optimise material flow was considered to be impractical and functional layout was generally accepted.

Group Technology (G.T.) was developed in Russia during and after the second world war to provide an acceptable compromise between high volume, high productivity flow production and lower volume, low productivity batch production.

The concept of G.T. involves the grouping of parts into families of parts requiring similar machining processes, followed by the setting up of flow lines or machine cells, where each line or cell is able to produce one or more families of parts.

G.T. attempts to group the total component spectrum using scientific methods of coding and classification. Considerable attention is placed on the design of an administrative and control system to support the new technology and this is considered to be at least as important as the engineering aspects.

A number of engineering companies producing a variety of products ranging from brake linings to valves to heavy electrical equipment have applied G.T.

A number of approaches have been developed with varying levels of success and varying amounts of resources applied to the analysis.

There is relatively little information available relating to a rational approach in batch producing companies, manufacturing complex assemblies. Whilst this is probably the most complex and difficult application, it nevertheless covers some 80% of all engineering industry in this country. It is therefore in this area where research and project work on a scientific basis can yield the greatest results in terms of potential increase of national productivity.

This report discusses the feasibility study of a G.T. installation in just such a company leading to the establishment of a pilot plant containing one major cell split into several sub-cells.

The company concerned produces a range of large circular knitting machines with a wide range of models and sizes with components produced in mainly small batches of 50 to 200. In the order of 800 manufactured parts (excluding proprietary purchased parts) are used in each assembly. The plant employs 1050 people producing approximately 600 assemblies per year. The range of parts varies considerably with a strong bias towards difficult non-rotational cams.

Towards the end of 1972, following a report by Aston University staff, it was decided to study the feasibility of converting the plant to the cell system of manufacture and two engineers were charged with the responsibility to code and classify the component range and devise a manufacturing system using G.T. principles.

By Autumn 1973 a report was to be published to the Board of Directors outlining the overall strategy of changeover, the expected benefits and detailing a suitable pilot cell for implementation.

By July 1973 it was decided that the project looked sufficiently promising to start up a pilot cell at an early date and a small plant of 10,000 sq.ft. area was made available for this purpose.

This report covers the following stages of the feasibility study and the cell analysis:

(a) The analysis of the component spectrum and development of suitable manufacturing cells for the whole plant.

(b) The detailed flow and capacity analysis of the prototype cell, its implementation and experience gained during its early months of running.

(c) A review of the administration and control systems devised for the prototype cells. These were however not developed to their fullest extent at the time of writing this report.

2. A SURVEY OF GROUP TECHNOLOGY PRINCIPLES AND APPLICATIONS

2.1. THE CONCEPT OF GROUP TECHNOLOGY

Group Technology has been defined by Thornley (1) as:

> "'Group Technology' or 'Parts Family Manufacture' is a method of achieving some degree of mass production technology in the batch production industry."

Ransom (2) and Falvey (3) quote that batch production accounts for about 80% of the engineering industry and therefore forms the largest single area of industrial activity in this country.

The benefits of mass production have become apparent since the beginning of the motor car industry shortly after the turn of the century (4), and any technology which will bring mass production principles into batch production must have a considerable influence on the profitability of a great number of engineering companies.

The concept of G.T. is basically a simple one as stated by Gombinski (5)

> "G.T. can be defined as a production method that involves the machining of parts in families."

and Ivanov (6)

> "The basic concept of component group machining is that instead of the production sequences, tooling and machine set-ups being based on single components, the planning unit becomes an entire group of similar components or operations calling for the use of similar equipment and tooling."

Whilst the early Russian work (7) tended to concentrate on single machine cells and in particular lathe work, the concept has since been developed further. Three phases of activity have been identified by Edwards and Koenigsberger (8).

"Phase I - G.T. as an improvement to individual machines" Phase I in fact refers to the early work in G.T. using often the composite component principle (7) where a number of components are selected and a real or imaginary part embodying all features of every part in the family is drawn up. The machine is set up on the basis of this 'Composite Component' and no machine resetting other than adjustment for different sizes is required between batches of parts in this family. Effectively a number of batches are combined into one large batch, saving considerable setting time. The approach to mass production could often be taken further in this technique, and Stöckmann (9) quotes a case where this system allowed the use of a multi-spindle automatic lathe for small batch production.

"Phase II - Pilot Groups or Cells of Machines"

As the natural extension of Phase I, this phase uses a cell of several machines to produce a family of components requiring several processes, such as milling, drilling, turning etcetera. Edwards and Koenigsberger (8) claim that the prototype cell concept has inherent dangers unless it is treated as the first step towards the overall change-over scheme. Often the prototype cell, whilst beneficial in its own right, does not yield sufficient savings to affect Company profitability. Furthermore, the requirement for different management systems can lead to a conflict between the prototype cell and the remainder of the plant, based on the functional layout.

Ideally Phase II should only be a short interim stage leading on to: "Phase III - The Cell System"

Thornley refers to this as the 'total approach' (10) looking at the Company as a whole rather than just a small section. The total approach, taking into consideration all Company activities is also promoted by other writers such as Edwards (11) and Ransom (2) as well as Opitz (12) who develops the overall G.T. involvement of the company from a universal coding system (i.e. the 'Opitz Code').

Thornley (10) differentiates in the total system between

(a) "The group layout system" and

(b) "The group flow line system"

The group is a collection of machines which in total contain all the processes required to make a family of components. In a group any one machine may be visited more than once, which requires some buffer storage and queueing but may be necessary to balance machine capacity. The small size of a group compared with the overall plant allows however much closer control and shortened throughput time. The group layout may be regarded as an intermediate step from the functional layout to the flow-line layout.

The flow-line is a more advanced form of group where each machine is visited no more than once during the production cycle. Machines are layed out in the sequence of operations which must be substantially common for all parts. Frequently machines are connected by roller conveyors which aid materials handling, define the flow pattern and act as buffers of strictly limited size. In a flow-line some degree of floating labour is normally required to balance the load, thus implying that a flow-line will normally have more machines than men.

The concept of G.T. has been taken beyond the machine shop and applied in the drawing office for design retrieval and variety reduction. Since some classification system is required for a G.T. analysis, it was considered by developers of coding systems to design these such that they could be used for both, production engineering analysis and drawing office work. The Opitz Code (13) is of course a typical example of such a code.

Hosang quotes three methods of dealing with variety problems which can be said to cover the total G.T. concept (14).

A. Design of cheaper machine tools by matching machine tool requirements to the component spectrum by means of statistical work-piece analysis as developed by Opitz (15). Examples of this approach have been shown by Moll (16).

B. Control of production by forming families of components and expanding this concept by forming machining cells.

C. Variety reduction in the design office to reduce the variety of components loaded on to the shop.

The above arguments underline that G.T. does not just concern itself with metal cutting but looks at the company as a whole. Ransom (2) states quite categorically:

> "Group Technology is the only management technique which embraces all other known management techniques."

The example referred to in this statement, namely the Serck Audco project, demonstrates that considerable benefits can be achieved where a company totally involves itself in G.T. and changes its complete administrative structure to coincide with this philosophy.

In fact, the key to modern thinking in G.T. as put forward by Edwards (17) and Thornley (18) is organisational rather than technological. Edwards describes how in a conventional company, control and information system design is "extremely complex", and how up to now insufficient regard has been given to adequate organisational back-up. G.T. takes a fundamental look at this situation and proposes an inherently simple solution to this apparently difficult problem. The solution proposed is:

Break down the complex system into a number of small easily controllable units, each one with its own limited range of geometrically and technologically similar components all requiring only a limited number of production processes.

The analogy is of course the specialist sub-contract shop, which by virtue of its small size and limited number of processes can be controlled much more easily and efficiently than a complex large manufacturing plant, resulting generally in lower manufacturing and overhead costs.

This point is confirmed by Petrov who quotes (19):

"... the setting up of specialised sections was found to improve the shop and works cost figures quite significantly. One of the biggest cost advantages of the closed-section system is that it increases labour productivity, since each work place can be specifically designed for a definite operation and specific component."

2.2. A HISTORICAL REVIEW OF GROUP TECHNOLOGY APPLICATIONS

2.2.1. THE RUSSIAN WORK

The concept and early developments of G.T. are generally accredited to the USSR. Whilst the real development in this technique did not take place until the 2nd World War, the early development and application of this technique, has been traced back to the 1920's (20) followed by developments by Sokolovskii in the 1930's.

Grayson (21) claims that fróm 1945 to 1953 a number of proposals of S.P. Mitrofanov were adopted in the USSR and applied in Russian factories. The first applications were at two machine tool works where "group flowlines with changeable workplaces" were organised (19). Further applications were developed between 1950 and 1957 in a number of small to medium batch production engineering plants. Machining cells for specific families of parts were set up during this time. The first major book written on the subject was "Scientific principles of Group Technology" (7) in 1958, which set down the principles of Group Technology and gave a considerable amount of information on such subjects as classification, the "complex part" and group tooling. This book which was indicative of the early experience in the USSR concentrated on the single machine concept using the complex component. Whilst some discussion takes place on group flow and group automatic lines, the bulk of the book discusses technological aspects of individual machines in a G.T. environment. Petrov confirms this and claims that from 1956 to 1960 group technology was mainly applied to simpler, two and three operation parts. There were however exceptions and the first multi-product flow line not requiring any equipment resetting was designed in 1953. By 1966 there were more than 1800 group production subsections in the USSR using more than 59,000 machine tools.

Galloway (22) provides an indication of the Russian work prior to 1960 based on personal observation. He makes mention of the Krasnii Proletarii factory which produced lathes, on a flow line basis and which was claimed to produce the cheapest lathes in the world at the time of writing (1959). A further example is the Red Proletariat Factory which increased the output of various forked components from 12,000 to 60,000 per year using group machining techniques. It was claimed that generally G.T. would increase output two to three times and subsequently cut costs. Components were said to be sorted accordingly to their size, shape, material design characteristics and range of machining processes involved.

ENIMS, a major Russian research organisation made a significant contribution towards the development of automatic transfer lines accepting a number of different but similar components. Typical examples are a completely automatic line producing 10,000 gears per month in ten sizes 3" to 12½" diameter, and another for producing 13 different size spline shafts at 26,000 output per year.

A certain amount of literature has become available from the USSR since Mitrofanov's publication, which, written by various authors, deals with such subjects as techniques of and parameters for grouping machines (6), flow-line planning, production control, and scheduling (19), flow-line and multi-component transfer line design (23).

Reference is made in the literature to applications other than the metal cutting industry such as cold forming, diecasting, casting, painting and finishing, and assembly (6).

The period since 1965 has been described as one of "consolidation" (24) and only a small number of increases in the number of applications has been reported. This reduced effort is claimed to be due to a redirection of research.

Mitrofanov (24) did however claim in 1960 that G.T. was still expanding in the USSR and that substantial savings were made.

The indication is that there is now renewed activity in the USSR to develop the use of G.T. further (25).

A conference in Leningrad in 1972 looked at the potential of G.T. and made a number of recommendations such as:-

- development of an "integrated cell" including NC and conventional machines.

- examine questions of variety control and standardisation.

- provision of funds to study the organisation of jobbing and small batch production.

- establishment of a National Scientific Centre for Data Problems integrating G.T. and comparing sciences.

- inclusion of G.T. into the syllabuses of Production Organisation at local technical institutes.

The need for classification and coding was recognised very early on, and Demyanyuk describes classification principles developed by Sokolovskii. Some references generally referred to subjective classification systems grouping components which, by their descriptive nature, fell into families requiring similar machining processes. Demyanyuk introduces numerical features by defining size ranges to supplement of purely descriptive geometric features forming the basis of this system. Petrov discusses the classification work done at "Sverdlov" works in the Leningrad Machine Tool Group where 5800 components were analysed using punched card equipment on a basis of design and production sequence. Mitrofanov also makes brief mention of decimal based coding systems.

2.2.2. THE CONTINENTAL WORK

The influence of the Russian work extended after the war into other East European Countries, and some work was done in Czechoslovakia, East Germany and Bulgaria in the late 50's (24) though French and Italian work was already in progress before that time.

Some of the pioneer work in G.T. was undertaken by Patrignani in Italy (26) who developed a complex system involving power presses with interchangeable platens for rapid press tool change-over for families of components (27). Fiat were also reported to practice G.T. by 1969 (28).

Early French work was done at the Societe Stephanoise de Constructions Mechaniques who make conveyorising equipment and who by 1956 had set up four cells (shafts, rings, housings, chassis) in conjunction with design rationalisation work based on the use of the Brisch-COPIC coding system. By 1966 a paper by Allerat, Cliquet and Guilleminot (29) referred to the extensive work done by the firm Guilleit Co, Auxerre.

There was also some evidence of the use of G.T. in Scandinavia and as early as 1947 Nathhorst was said to have laid down the principles of group production at a conference in Stockholm (30).

West European efforts were probably most strongly developed in West Germany, and considerable work was done in the early 60's in Germany mainly based on projects run in conjunction with T.H. Aachen, even though it has been claimed (31) that G.T. was applied in Germany as early as during the 1930's. In 1964 Opitz published his famous classification and coding system (18) together with a discussion on Group Technology and work piece statistics. In 1963 a G.T. Symposium in Essen, Germany had been held already, in which several contributors discussed various aspects of G.T. These were generally based towards administrative rationalisation based on the use of classification and coding systems and this aspect seemed at that time to get greater exposure than machine shop improvement and the cell layout (14, 31, 32, 33, 34). One contributor however gave a paper (35) dealing with the case study of a machine shop rationalisation and indicating the use of cells and flow lines for general engineering components. The photographs indicate that this work must have started at least two to three years prior to the 1963 conference.

Other German companies who were doing active work in G.T. by 1964 were Pittler, Gildemeister and Werner und Pfleiderer. Again reference is made to flexible flow lines in the case of the latter firm and an example of a lathe spindle line at Pittler is sketched in a paper by Stöckmann (9) at the 2nd G.T. Conference in 1965 (held in Essen, Germany).

It is important to note the extent to which the administrative requirements and advantages of G.T. were studied in Western Europe as early as 1963 and how a clear understanding of the scope of G.T. existed at that time.

Further developments in Germany were indicated by papers presented at the 3rd G.T. conference in 1967. These seemed to lead mainly towards greater sophistication in the handling of classification systems (36, 37). There is however little evidence on further applications, although it is claimed (21) that the number of applications is increasing.

There is certainly still considerable research taking place at various German Universities to lead to a clearer understanding of the issues involved in G.T. Typical areas of research are:

a) The relationships of NC in conjunction with flexible flow lines (38, 39).

b) Development of production and tooling-based coding systems (40).

c) Computerisation of process planning (41).

d) Development of a generalised classification and coding system involving all areas of company operation (42)

2.2.3. THE BRITISH WORK

The following paragraphs review some of the applications in the UK which have been published in the past. The list is by no means comprehensive and Bennett and MacConnell (43) make a mention of a survey of 150 companies studying G.T. in this country.

The examples discussed describe the Serck Audco case as the earliest major published study. This is no doubt not the start of G.T. in this country, and Sidders (31) is quoted to have mentioned one company who devised their own classification and coding system in 1948 and set up a group machining line for shafts in the early fifties. Dyson (27) quotes the use of two machining groups for producing families of similar pressed metal components in batches at Hoover Ltd., Perivale in 1950.

(I) SERCK AUDCO VALVES LTD., NEWPORT

The Serck Audco project is probably the best known G.T. scheme undertaken in this country to date. The reasons for this are as follows:

a) The Serck project which started in 1959 is the first publicised G.T. project in this country.

b) The company pioneered the total concept of G.T. at an early stage when most other companies were hardly aware of this manufacturing philosophy.

c) The savings achieved by this company were so spectacular that they caught the imagination of the Government and Industry alike and G.T. was hailed as the solution for all of the batch producing engineering companies problems.

Most of the credit must be given to Mr. G. M. Ranson who, as Managing Director, took a leading role in this project and saw it through to its conclusion.

The case study was published in 1966 by the National Economic Development Office (44) and there can be no doubt that this publication had a major influence on the development of G.T. in this country.

The Company produce a wide range of valves of three basic types, namely taper plug, butterfly and ball valves. The product range was rationalised using the Pareto approach.

G.T. was introduced with a view to rationalising the machine shop, and the product range was split into families of parts each of which was produced in a manufacturing cell consisting of machine tools linked by roller conveyors. The concept made it possible to load the shop with balanced product sets of components for assembly and eliminate Economic Batch Quantities with subsequent stock reductions. The flow line concept reduced through-put time and hence work-in progress thus reducing inventory levels and at the same time allowing better delivery control.

The principle of floating labour was used and a typical cell had more machines than men. A typical ratio was 5 men in a 12 machine cell. The use of group tooling, using common tools and fixtures for families of components was applied successfully (45) thus reducing setting time and consequently the cost penalty incurred in running small batches. A substantial investment in tooling and equipment was made to introduce these concepts. Using job evaluation a new system of payment was developed in which nine hourly rates replaced 93 previous rates.

The steps takenin the analysis were summed by Ranson as follows:-

- a team of work study engineers analysed and reviewed all operations.
- production planning was centralised using data processing equipment.
- a coding system was established.
- a "one drawing and one number per part" system was introduced.
- a high speed production facility was set up backed by diciplined stores control. This reduced inventory levels.
- through-put time was reduced by over 65%.
- overdue customer orders were reduced to less than 2% by value.
- job evaluation and labour mobility were introduced together with a productivity-related payment scheme.
- specials were greatly reduced by pricing them out.
- a total company outlook was achieved incorporating totally integration of all company activities.

It was shown that the discipline of G.T. in the machine shop calls for correspondingly well-organised back-up services in production planning and control to make this concept workable. It is important to realise that invariably those companies which have successfully implemented G.T., state the necessity to rationalise and improve all associated areas such as design, process planning, work study and production control.

It must be pointed out that the Serck component range does fall into a small number of well defined families of fairly similar components, and this must have made the project much easier than in a general engineering factory.

The benefits obtained by the company in 1966 have been published many times and have since been improved.

1966 (44)	1971 (46)
Sales up by 32%	up by 67%
Stock down 44% (£500,000	
Stock/annual sales ratio down from 52 to 25%	down to 22.5%
Average manufacturing time reduced from 12 to 4 weeks	down to 2½ weeks
Past-due orders down from 6 weeks output to one	
Wages per employee per annum up from £700 to £900	up to £1520
Increased despatches per employee £2200 to £3100	up to £5700

(II) FERODO LTD., CHAPEL EN LE FRITH

Ferodo Ltd., is one of the largest manufacturers of friction materials in the UK and their production cycle covers all aspects from raw material processing through to shipping the final product ready for assembly at customers works.

In the middle sixties this company decided to consider G.T. for its manufacturing processes and in conjunction with UMIST staff, a number of reports were compiled leading to the establishment to date of a flow line type machining and post-machine processing plant for the production of their major product, namely single component brake linings.

This project has been the catalyst for a series of papers and reports dealing with a range of G.T. related subjects such as classification and coding, cell design, management aspects of G.T., the "total concept of G.T." and production control.

Ferodo have two plants but most of the work to date has been confined to the Chapel plant.

The project was started by an analysis of all currently manufactured products with the aid of a classification and coding system to form "product groups" (2)

At this stage it was found necessary to develop a new coding system which split components three ways (47):-

i) production group (a broad geometrical split analogues to the 1st digit in the Opitz code).

ii) family group (bringing together products with similar production requirements).

iii) family item (unique identifier).

A 10% sample of three months historical manufacture was analysed to study the load pattern and component spectrum in the plant using computer aids to sort and tabulate the data.

A most complex pattern of manufacture was discovered with 20933 live specifications at the Chapel plant alone, with batch sizes from 2 to 6336 (20).

In conjunction with this analysis a study of current manufacturing methods was undertaken. Ferodo produce their own raw material by a mixing, pressing and heating process followed by cutting into suitable sections to produce blanks for machining of size and shape features (the finishing operations) including marking and packing.

Following the product review it was decided to limit the scope of the project to the finishing operations of sintered single part brake linings which account for the greater majority of the companies output.

The manufacturing stages were subdivided into cellular groups based on the work done at Serck Audco. A number of parallel machining cells were developed each one dealing with a family of parts, though some overlap between cells is possible.

The basic principle of the cell layout is shown in Fig 1 (48): blanks are received into a loading buffer and fed into cells GT1 to GT6 (depending on the component type) for cutting and grinding to size, painting, marking and inspection. After this processing sequence, parts are re-sorted in a marshalling store and either taken off as completed or transferred into the second set of cells HF1 to HF5 and LF1 to LF5 dealing with additional work such as drilling, chamfering, tapering, special features etcetera.

Within each cell, machines are linked by conveyors which predetermine the flow. All conveyor junctions occur at machining stations and the operator is responsible for passing the batch down the correct leg of the junction.

Each cell is based on the key machine principle of control, and from a loading point of view each cell is treated as one "synthetic machine" with control concentrated on the key machine. (Fig 2).

Support machines are under-utilised and the use of floating labour ensures that no bottlenecks occur.

Two rules were imperative to maintain acceptable flow conditions and these were (20):-

a) no order will be able to leapfrog another.

b) the operation layouts are of a fixed sequence.

To obtain a maximum reduction of setting times, components were reviewed in relation to their component features and parts were grouped in pyramid fashion in the order of set-up complexity, so that all parts with common features in the most complex set-up were loaded sequentially, sub-grouped together for the next most complex set up and so on. The length of conveyor was checked to ensure that it was long enough to provide sufficient buffer storage to hold all work for the planned throughput time.

Initially only one cell was developed which was followed by five further cells, all working on the flow line principle. A half week throughput time per cell is allowed with a one week intermediate buffer time, giving a total maximum manufacturing cycle of two weeks for the finishing operations.

Several observations were made by the writer on this project following discussions during a visit to Ferodo in January 1973:-

- An overall manufacturing cost reduction of 20 to 30% has been estimated after adjustment for inflation.
- Despite theoretically reduced machine utilisation (20), no additional machines were required even though output increased slightly. It was believed that reductions in setting and production times offset the theoretical decrease in utilisation.
- Floor space has been reduced from 66,000 sq.ft to 58,000 sq.ft. The additional space required by the conveyor lines was more than offset by the saving in progress area.
- No evidence of a job satisfaction increase has been found. It is believed that job satisfaction is more a feature in high-skill plants and does not apply to the same extent at Ferodo where labour is generally unskilled.
- Operators were not well enough informed of the company's intentions and this led to some resistance during the early stages of the project. These problems have now been resolved.
- The more enterprising and resourceful operators enjoyed the change-over and especially the movement to different machines much more than the older more settled operators.
- Labour turnover which was a particular problem has been reduced drastically.
- Rejection rates have been cut considerably and savings in inspection have been made.

- Delivery times have been cut and delivery promised can now be given with full confidence. Ferodo believe this to be one reason for their current growth in order intake after a period of stagnation.

Ferodo quite early on during their G.T. implementation found that with a changeover to G.T. cells, the management structure of the company would need to be examined in some detail and changes made to make the management structure compatible with the cell layout.

Typical problems which arose, were (49)

a) Delays in decision making due to the standard line management structure could stop the production line (e.g. maintenance allocation, quality, disputes etcetera).

b) The planning for manufacture was based on customer satisfaction and the shop would balance random changes by work-in-progress manipulation. This clearly is not acceptable in a flow line environment requiring a well planned sequential work input.

c) Labour flexibility required a new look at incentive payment schemes.

Ferodo overcame some of the above problems by developing a new functional management structure which was more flexible and could adjust quickly to the requirements of the cell lines.

The Ferodo project is no doubt one of the most successful G.T. installations in this country. One might argue that the product range is sufficiently homogenous to make grouping easy, but in fact the range of component features is extremely wide and only a very detailed analysis allowed the development of the relatively simple production system to cope with the wide variety of parts encountered.

The considerable amount of literature published on all aspects of G.T. have provided a very comprehensive information to users of G.T.

(III) THE ENGLISH ELECTRIC CO. LTD., BRADFORD (11)

Mitrofanov's work on Group Technology was published in this country in 1966 and was received with some interest. One of the first, if not in fact the first company to pursue his approach in practice was the English Electric Co. Ltd., at their Bradford works in conjunction with staff from UMIST. The start of this work dates back to 1965 indicating that knowledge of Mitrofanov's work existed in this country prior to 1966.

The approach used, centered around the complex part philosophy and substantial savings were made by devising group set-ups on Capstan lathes. The exercise was restricted to single machine turning applications producing components for electric motors and generating equipment.

During this early application no attempt was made to consider the total component spectrum of the company and to devise cells to improve work flow.

Whilst the savings gained are claimed to be substantial (70% average output increase) the application was insignificant in terms of total company operation and has not been developed to any greater extent since then.

There can be no doubt that a complex part set-up yields substantial benefits and will greatly improve productivity. The English Electric case-study is a good example of the benefits which can be gained in this area.

(IV) GEC ELLIOT CONTROL VALVES LTD., ROCHESTER

GEC Elliot represent a case of a successful application developed "from the shop floor up".

The company produces a range of valves for the petrochemical industry using over 650 production workers and 127 machine tools (50).

The product range is such that classification by eye and description was quite adequate and G.T. cells could be developed by the production engineering department in comparative isolation.

The work started in 1968 and there can be little doubt that it was heavily influenced by the Serck project which had been developed in a similar environment.

It is claimed that the method of classification, whilst it avoids expensive coding effort, requires skill and product knowledge and families formed may not be as comprehensive as those likely to have been formed using a formal coding system. Bearing in mind the simplicity of the component range, this seems to endorse the popular opinion that in any organisation of average product complexity a formal coding system is a mandatory analysis tool.

The shop was changed relatively slowly and it took three years to re-organise it on a cell-by-cell basis. However, it did keep disruptions to a minimum (51).

A number of additional areas had to be tackled to achieve adequate G.T. benefits. A comprehensive preventive maintenance scheme had to be introduced for all machines. Plant breakdowns were reduced by 75% and this must have contributed considerably to the smooth running of the cells. Cells and flow lines are of course much more vulnerable to breakdown than a conventional functional shop and the experience gained at GEC has been confirmed by work done at Ferodo.

The production control department had to be split into individual sections dealing with separate cells to simplify control.

The large store used previously was split into ten small stores and a common part store, each store handling a particular group of parts. The assembly shop was split into nine assembly lines, each dealing with a limited product range. The concept allowed the principle of having a section leader responsible for a product from receipt of customer order through to the final product.

As a result this concept of unit management led to the establishment of much greater control for each unit. Unit managers are now responsible for their own raw material and consumable purchasing as well as direct labour and staff.

Considerable improvements in delivery performance, work in progress indirect labour levels and lead times have been achieved.

(V) THOMAS MERCER LTD.

The company has three plants making a wide range of gauging equipment employing a total of about 400 people. G.T. was first introduced in 1966 to overcome delivery problems, reduce work-in-progress and ensure delivery of the correct part when required (52).

The initial analysis classified parts by known similar type only, without any formal classification system. Five cells were established the first of which was completed by 1969 (53).

At that stage it was found difficult to form further families without coding and classification; so with the aid of the G.T. Centre, the Optiz system was introduced leading to the selection of families of apparently dissimilar parts. Coding work also formed the basis of rationalisation and standardisation in the design office.

The use of the coding system allowed the introduction of standard planning sheets. About 1900 parts were coded. These lent themselves to the establishment of complex components leading to such rationalisation as using common cams for automatics for a number of components (54). Once the parts were classified and cells developed, a considerable amount of work was done on group set-ups and special attachments on standard machine tools indicating the strong influence of Russian work studies as explained by Mitrofanov.

Three types of set-ups have been recognised. These are:-

1. Shape :-

   Components of similar shape are made in cells producing the components complete.

2. One operation :-

Standard cam sets are used to produce parts complete or virtually complete in one operation. The grouping of parts lead to the use of automatics for components previously machined on Capstan or centre lathes.

3. Common origin :-

Components dissimilar in shape are started in a common cell up to a breakpoint where they are transferred elsewhere for completion.

By early 1973 30% of all components had been dealt with in any one of these three methods.

The following benefits have been claimed (56).

Throughput time reduced by 54 to 84%

Cycle time reduced by 15 to 25%

Availability more predictable

Productivity increased by 25%

The production control system has been changed to cyclic planning and the material non-availability has been reduced by 95%.

(VI) FERRANTI, EDINBURGH

The Edinburgh plant of Ferranti produces high-precision, electro-mechanical equipment mainly for aviation use. The quantities of assemblies produced are generally low and a small batch manufacturing environment exists, further aggravated by the need to keep batches small to minimise the effect of modifications.

Ferranti in 1966/67 aimed to reduce their throughput time and a start in G.T. was made with a single cell for small round parts.

The initial work was sufficiently promising to develop this further by combining several machine shops to set up a number of cells, apply data processing techniques to machine loading, and apply a different concept of quality control by transferring quality responsibility from the inspector to line management and the operator.

The early work developed out of a small turning bottleneck and was specifically restricted to rotational components up to 1" diameter. Using an existing Brisch system of classification, suitable parts could be easily selected. An eight-machine cell including turning, milling and drilling was set up using only four operators where one operator used five low cost, low utilisation machines.

The parts were scheduled into the cell on a sub-family basis, to provide a loading sequence which would minimise set-up changeover times.

Ferranti already used a three-month fixed cycle production control system, and based on the three-months forward load, parts were scheduled on a technological basis to minimise set-up time.

Substantial savings in set-up and through-put time were made but the system was too inflexible due to the fixed nature of the three-months forward loading cycle. As Durie quotes (31) :-

> "We could machine any part of the family in three days, but those three days were fixed at some point in time during the next three months as dictated by the sequence".

The result was a change to a composite component philosophy on the first operation lathes. This allowed flexibility of loading within any one family set-up to suit production requirements and the previous rigid loading sequence could be abandoned. The composite part analysis revealed that the total work of this first cell could be covered with four turret set-ups only.

Using PFA techniques, subsequent cells were developed (57) where the component complexity and poor production information of the classification code used, made grouping by code impossible. Furthermore the wide range of specialised machine tools used, made it difficult to relate the Brisch code to machine tools.

The analysis allowed the grouping of about 80% of the machines into cells some of which had a simple sequential flow pattern whilst others had complex flow conditions requiring the use of a good progress system. In total 13 cells had been set up by 1973.

In some instances where one expensive machine only was available or where one operator looked after several identical machines a certain amount of cross-flow between cells had to be accepted. Occasionally this was also required to balance cell loads (58).

Ferranti claim significant savings especially in throughput time, delivery maintenance and certain setting times. They have had considerable success with NC cells and have tied this in with their work on computer-aided design and computer controlled inspection.

(VII) ALFRED HERBERT LTD., COVENTRY.

The G.T. project undertaken by Alfred Herbert Ltd., is remarkable for its magnitude and the amount of resources used in the analysis.

The company produces a range of machine tools. In excess of 70,000 drawings were classified using a modified version of the Opitz code. The analysis aims to resight 1050 machine tools over 44 cells in 2 plants. By July 1973 ten cells had been set up at their Edgwick works.

The aims of the project are to reduce maximum lead time from 18 months to 6 months, to reduce stocks and work in progress, improve production methods and reduce batch sizes (59). The analysis was based on coding and classifying the whole component spectrum using data processing to form families and development of cells to produce individual families of components.

The objectives have been met by the cells set up to date. Throughput time reductions ranging from 92% to 83% and work in progress reductions of 92% to 72% have been quoted (59).

Perrins (60) gives a list of the effort involved in the analysis. The total work done in coding, analysis and detailed development, including planning and jig and tool effort, leading to the first four cells is shown to be four man years with a further nine man months to physically set up the first four cells, including the coding of 38287 components.

The input requirement is shown as 1311 man days costing £17,727 for the first four cells where the initial analysis cost is spread over 23 cells. The cost per cell can approximately be stated as £4,000 to £5,000. Against this should be weighed the potential financial benefits which are quoted as ranging from £75,788 to £168,900 per year per cell (!) for four cells developed. The cost figure does not include any capital cost.

From an analysis point of view, this project is worth investigating and the key factors can be listed as follows:-

- The company used external consultants to guide the work and supply some of the labour.
- The analysis was not based on a sample. The total component spectrum was coded, classified and analysed, but specific areas were selected for detailed study using Pareto principles.
- During the analysis production flow analysis techniques were used and the sequence of analysis was stated as follows :-

1. Usage of value analysis.
   (This is a misnomer and refers to using a Pareto analysis to identify areas of initial attack).
2. Component coding.
3. Selection of potential families.
4. Selection of actual machines.
5. Analysis of machine sequences.
6. Tool analysis.
7. Simulation of results.
8. Installation.

It must be concluded that the effort involved in such an analysis is quite complex and requires a considerable amount of initial work and available data.

Many companies may well not be prepared to put in this kind of effort on a speculative basis. There is considerable virtue in a sample analysis as proposed by Burbidge (62) and Thornley (18) to cut the initial work effort and get a good appreciation of the component spectrum as a whole at a relatively low cost.

It is claimed that for a company making a complex part with a high number of piece parts in low quantities the principle of fixed batch size ordering may be preferable to Period Batch Control which is generally associated with G.T. The possibility of a hybrid system is suggested by Craven (63).

(VIII) MATHER AND PLATT LTD., MANCHESTER

In 1968 Mather and Platt Ltd., divisionalised their company and one particular section, the Power Division, producing centrifugal pumps and rotating electrical machinery, with its main plant in Manchester, decided to pursue the concept of G.T. in conjunction with UMIST staff.

The key project stages involved were (64) :-

Setting up a component classification system.

Plans for a re-organisation of the machine shop on G.T. lines.

The development of an assembly flow line.

The introduction of a computer aided production control system.

The component spectrum analysed covered components from approximately 100 mm to 600 mm diameter and 82% of all parts were rotational. The coding system used was the Opitz system, demonstrating the considerable range of applications to which this code can be applied. The bias of the Opitz code towards rotational parts was useful in this application.

The re-organisation of the shop was planned into 10 cells to be set up over 18 months and this was completed by early 1970.

The following observations have been made by Cauldwell in relation to this project (65) :-

- the initial study into available machine tools and utilisation replaced about one third of all machines by a number of modern ones.
- the G.T. layout and machine tool rationalisation allowed a 25% floor space reduction.
- in the process of the re-organisation a number of machines had to be relocated several times to allow the plan to be met with minimum disruption.

- a computerised production control system had to be applied to relate the production commitment to available capacity. The print-out offers details on the current position of each order, the forward load on each work centre within each cell and a loading list in sequential order for each work centre. A proprietary production control package was used. This system was initially tried out on a trial basis in one cell only.

Major benefits have been achieved which can be summarised as

- 25% machine shop area reduction.
- reduction in material movement.
- reduced indirect labour.
- simplified supervision.
- increased quality responsibility by supervision.
- reduced supervisory staff.
- improved communication.
- better documentation and information levels.
- availability of forward load assessment.
- improved machine shop quality.
- determination of better time standards resulting in a better system of incentive payment and better production control.
- improved stock turn-over and reduced work in progress.
- improvement of delivery.
- increased productivity.

(IX) G. STIBBE & CO. LTD., LEICESTER.

Relatively little published work has become available on this application and its main interest to this thesis lies in the fact that it is an application in an environment very similar to that at Wildt Mellor Bromley Ltd.

The company produces a range of large circular knitting machines which are complex assemblies of possibly up to 4000 components each.

It is claimed that El-Essawy did some of his Ph.D. work on component flow analysis with this company (11).

Stibbe recently opened a new plant of 162,000 sq. ft area in Leicester (66) due to employ about 750 people. Flowline production techniques have been introduced into this plant. Material is stored at one end of the plant and components are fed from the material storage area through cells into a finished part buffer. Sub-assembly cells draw from this buffer and are geographically arranged along an assembly flow line which they feed.

Whilst this is no doubt a cell system, Stibbe have not developed the G.T. concept of manufacture as far as one might have expected. A number of restrictions became apparent during the discussion at an I.Prod.E. meeting at Stibbe during summer 1973 (67). Stibbe do not in fact intend to make full use of G.T. and have decided to ignore such factors as balanced flow lines and floating labour. Their shop consists of a number of cells aimed to reduce handling and through-put time. A small amount of material flow between cells will be permitted and a conventional inventory control system will be applied.

It is possible that these restrictions are the natural outcome of their analysis technique, namely component flow analysis which inherently does nothing more than group parts of similar flows, allowing the grouping of machines in close proximity to comply with these recognised flow patterns. The technique does not provide for geometrical grouping and consequent tooling rationalisation.

Furthermore Stibbe have not attempted to develop the "Total Concept" of G.T. and have confined it to lay-out rationalisation and supervisory management improvement.

(X) STREETLY MANUFACTURING CO. LTD.

This example is primarily quoted because it applies the techniques of G.T. outside the metal cutting industry. The project relates to a company producing thermo-plastic components employing about 450 people.

A product analysis showed that a range of shapes were produced which made the use of Opitz type codes unsuitable. Production Flow Analysis (PFA) was therefore used as the analysis tool and twelve months of despatches were analysed accordingly.

Production flow data was punched on to cards which were sorted using a standard punched card sorter producing tabulations

a) in process route order.

b) in annual-volume-despatched order.

Eight "production flow analysis" lines were developed from the PFA work.

Gallagher, Grayson, Collier and Moore (68) conclude that PFA is invaluable in an analysis of this kind where component size and shape are of secondary importance, but agree that the problem with this technique is that the basic data required is often not available, unsuitable or unreliable and always changing.

(XI) WALKER, CROSSWELLER CO. LTD.

In 1962 the Walker, Crossweller Co. Ltd., decided to rationalise its manufacturing system to reduce stocks and work in progress.

The result was a change-over to the cell system of manufacture (69). Classification was not based on parts coding but on a Pareto analysis. The annual usage valve of all parts was estimated and a typical Pareto distribution was found. A system of selective stock control was introduced and an analysis of 'A' items (highest usage value) showed a marked similarity amongst many of them which led towards family formation for G.T.

2.3 CLASSIFICATION AND CODING

2.3.1. INTRODUCTION

The starting point in any G.T. analysis is generally classification and coding.

One defination of G.T. states (70):-

"Group technology defines a production method which involves the grouping of manufactured components in accordance with those features that affect their design and manufacture".

In most companies the number and variation of parts is such that some kind of formalised coding system is necessary to form a base for data processing to assist at least in the initial rough splitting of parts into more manageable major families.

Whilst for this purpose simple systems such as those suggested by Williamson (71) or Demyanyuk (23) are probably quite adequate, classification and coding is by many G.T. workers considered to be far wider reaching. Notably the work done at TH Aachen demonstrates that classification and coding can become a key aspect of overall company operations, providing the necessary data base required to analyse the whole range of company activities is established.

There is of course nothing new about the concept of classification and coding, and such specialist consultancies as Brisch & Partners have offered such systems for design retrieval and stock control for many years now.

With the growing development in G.T. and the consequent need to classify, classification and coding has had increasing publicity over the last ten years or so.

Two reasons seem to point to this interest of G.T. workers in classification and coding as well as with design retrieval.

a) The use of classification and coding systems in G.T. analysis has led to the use of the compiled data in the design area, where it has been found exceedingly useful. Once the coding work has been undertaken and a file of coded parts has been established, it is a simple matter to run off a design retrieval catalogue.

b) In many cases the proposal to code all drawings before a G.T. analysis can be completed, has led to acceptance problems of the whole G.T. project. It is therefore often useful to "sell" design retrieval to the Board as a separate but related project which yields considerable savings in itself and provides as an additional feature the necessary data base for the G.T. analysis.

There is no doubt that companies such as Ferranti, who already used the Brisch system of coding found this very useful to short-cut their analysis. Serck Audco started their G.T. project by first applying the Brisch code to their product range before attempting the manufacturing systems design.

Hosang (14) discusses the need for classification and states:-

"The absence of a total picture and an ordered system for the whole plant has the following disadvantages, specifically for the design office and the process planning department:-

- one repeats in total or in part work which was done previously, and, worse still, one accepts unsuitable and bad records and designs from the past because no opportunity for comparison is available.

- one repeats work which could have been combined.

- in the end one increases indirect labour in the company"

He further states that no other suitable retrieval method is available for design, planning, estimating, tool manufacture etcetera.

Gombinski (72) quotes the financial potential of classification and coding:-

"In a drawing office with an output of say 5000 drawings per annum, successful retrieval of existing drawings at a rate of 7-10% of the output will produce savings in the order of £10-£15,000 per annum. Next to design and drafting come costing, ratefixing, operation planning and particularly standardisation".

Eversham (73) quotes for an average drawing a preparation cost of DM150 to 200 (approximately £30 to 40) which agrees roughly with Gombinski's figure above. During the discussion of the 3rd symposium for Component Standardisation and Component Family Production at Essen (Germany) in 1963 (84), figures were quoted of 5 to 7% of drawings saved over the previous year at Werner & Pfleiderer due to the use of a classification and coding system.

More startling still, Ransom (2) quotes that a variety reduction of 20% was achieved as a result of a variety reduction exercise made possible by the use of the classification and coding system.

2.3.2. OBJECTIVES OF CLASSIFICATION AND CODING SYSTEMS

The objective of classification techniques can be simply stated as:-

- To bring together like parts -

The term "like" is of course subject to definition and must be related to the ultimate objectives of the classification project. Clearly, different classification techniques are required for, say classification of assembly units, for parts to aid product analysis or for process analysis. For the former a functional classification system of assembly units may be required, whilst for the analysis of production flow a system based on manufacturing processes may be needed.

In G.T. work certain objectives are generally quoted which a classification and coding system should fulfil to be suitable as a production/design data base. These are generally:-

- standardisation (14) (75)
- avoidance of duplication (14)
- limiting of unnecessary component variety (14)
- reduction of disadvantages of the necessary variety (14)
- feedback production-design (14)
- setting up of work records for the standardisation of shape characteristics, shape elements as well as design shape details with consideration of D.I.N. standards (37)
- setting up of work records to expand internal standardisation and development of design guide lines.
- inventory control and reduction (75) (76)
- value analysis
- simplify process planning (32) (77)
- aid the preparation of cheaper and more accurate tenders (32)
- form a basis for investment planning (78)
- suitable to allow formation of component families for production purposes (7)

2.3.3. CLASSIFICATION AND CODING SYSTEMS

The following discussion concentrates on the classification and coding of manufactured piece-parts, an area which is of particular interest to the G.T. analysisist.

A wide variety of systems have been recommended by a number of workers ranging from the simplest functional grouping recommended by Williamson to highly developed and complex techniques some of which require a considerable amount of data collection.

A review of the areas to be considered during code design or code selection has been given by Middle, Connolly and Thornley (79) and these can be summarised as follows:-

- alphabetical systems are useful since each character gives up to 26 divisions and easily recognised symbols can be used (e.g. S for steel, B for brass). These systems are suitable for computer data processing though processing is more costly and complex. Mixed alpha-numerical systems are not recommended.
- independent digital significance is recommended for components with like attributes. This makes it possible to recognise common component features by simple code comparison. It also improves familiarisation and makes data processing simpler.
- 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 memorise to code and reduce paperwork, processing cost etcetera.
- the code terminology must be mutually exclusive, i.e. each part must only have one possible code.
- the unique identification for each part does not have to be part of the classification system.

MacConnell (80) specifies the requirements of a classification system for G.T. use as follows:-

a. Geometric definition of external and internal shape.

b. Information on sub-ordinate features such as holes, slots.

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

d. Size-major diameter and overall length, or length, width and height.

He further specifies that the system should be easy to learn, lend itself to manipulation by sorting machines to sort at varying levels of complexity and extract specific component features, not have an excessive number of digits i.e. no more than 10.

Gombinski (72), doubtlessly influenced by his work on the Brisch system, specifies the following parameters:-

"... Classification is best symbolised by codes that are:

i) purely numerical

ii) of uniform length ...

iii) made up of a 'Surname' and a 'Christian name' (e.g. 1234-567) or of a 'Surname', 'Middle name' and 'Christian name' (e.g. 1234-5-678)"

A number of systems available at present have been described by MacConnell (80) and Knight (81). Some of these have found very limited acceptance whilst others are quite widely used. Systems can generally be divided into three types:-

i) general purpose systems freely available at low cost (e.g. Opitz, VUOSO)

ii) systems based on general principles but tailored to suit specific applications, generally available from specialist consultants (e.g. Brisch).

iii) special purpose systems developed for specific applications (e.g. UMIST system developed for Ferodo).

Bearing the above points in mind, a selection of a suitable system can often be made from a number of currently available systems, some of which are reviewed below.

(i) THE RUSSIAN WORK

The works of Mitrofanov (7) and Ivanov (6) give a good indication of the early Russian approach to classification.

It should be born in mind that the Russian approach to G.T. stresses the technology improvements rather than flow improvements. Some classification systems used do not therefore provide information which can be readily used to design flow lines, but do provide all necessary data for production methods rationalisation. The aim seems to be to define types of components such that common machining techniques can be applied to each type.

Parts are classified by Mitrofanov according to the following parameters:-

Geometric form, frequency of processed surfaces, precision and finish of processed surfaces, similarity of raw material, number of parts, process economics.

Classification takes place over several consecutive stages. Ivanov's classification uses the following stages:-

i) by type of equipment (Auto, capstan, miller etcetera)

ii) by geometric shape

iii) by design and operation

iv) by similarity of equipment, tooling etcetera.

The details of family formation are not fully described, but coding is not always used and classification often seems to take place by a review of design and process planning data. The same part can be classified several times under different processes.

More recent involvement in G.T. in Russia has considered the organisational requirements of G.T. to a greater extent. Petrov (19) has reviewed early Russian G.T. and found many short-comings in the organisation of existing cells and the formation of families. Not surprisingly more formalised digital classification systems have now been developed such as the NIITMASH system (81) which applies numerical figures to descriptive titles of component types to allow machine processing of the data. Additional data such as material, machined surface relationships, weight, and secondary design features can be included in this code.

The VPTI Code (81) is another digital code developed for G.T. applications. This code defines a part by geometry and manufacturing features and marks a considerable deviation from the principles laid down by Mitrofanov.

Further developments led to the Litmo system, claimed to be similar to the VUOSO system (81) and thus more of a geometric shape coding system in the West European style.

(ii) EARLY WEST EUROPEAN DEVELOPMENTS

By the early to middle 60's G.T. was developed by a number of companies in Europe and examples were quoted in the press in February 1964 (82).

The case of two German lathe manufacturers was quoted, namely Pittler and Gildemeister. Both companies used classification systems but based on different concepts.

(iii) THE OPITZ CODE

Extensive research was undertaken at TH Aachen under Professor Opitz in the early 60's on a geometric general purpose coding system with the aim of establishing one universal system which could be applied by any machinery builder with little or no modification. The code was developed as part of a survey of machine tool requirements in relation to machinery parts used in a number of West German companies. The basic structure of the coding systems was published in 1964 (15) and the completed code was described at a German G.T. symposium in Essen, Germany during October 1965 (83). This code has been marginally changed since then and is now available in book form (16) (Fig. 3, 4 and 5).

It is claimed by Opitz (83) that his code forms a compromise solution which is suitable for design, production engineering and manufacture. He further claims that short-comings of earlier systems were that they were aimed at one of these areas only, that the choice of descriptive characteristics was not detailed enough or that they did not have a fixed code format, and were therefore not suitable for machine data processing. The system was developed from experience gained from projects into components statistics which demonstrated that there is no wide difference in component shape distribution across the general metal-working industry. A number of draft systems were tested in industry until the current system was evolved.

The inherent logic of the system is explained by Howarth (84) who points out that the code describes components to a degree of definition which is related to the frequency occurance of the component type in the total component spectrum (which is based on a review of a number of companies of course).

The Opitz system uses a five digit geometry code followed by a four digit supplementary code. Each digit has one broad area of description which tends to be common for all classes of components.

The code layout is as follows:-

Geometry

1st digit - Component class (rough breakdown in principle areas of rotational and non-rotational parts)

2nd digit - Overall or main shape

3rd digit - Rotational surface machining

4th digit - Plane surface machining

5th digit - Auxiliary holes, gear teeth, forming

Supplementary

1st digit - Dimension (diameter or longest edge length)

2nd digit - Material

3rd digit - Initial form of raw material (bar, sheet, casting etc.)

4th digit - Accuracy

There are some inconsistencies in order to obtain the maximum information for each class of component.

For example, for rotational parts (class 0, 1, 2) the external shape is described under digit 2 and the internal shape is described under digit 3. For rotational parts with deviation (class 3 & 4) digit 2 describes the overall shape whilst digit 3 describes external and internal shape. However, by adhering to the principle of allocating specific digits to specific features throughout the code, it is relatively easy to learn the main features and recognise the significance of a part code without too much difficulty.

Thus a part of code 25325/2400 can be recognised immediately as a shaft requiring external and internal turning, as well as some milling and drilling. A check on the size code will specify the machine sizes likely to be required and without checking the drawing or planning, a fair indication of the type of machinery required to make this type of part can be obtained. It is features like this which make the code suitable for G.T. analysis work. Whilst all the information required for coding can be obtained from an engineering drawing, the code is closely enough related to production requirement to enable its use for preliminary sorting into component families for G.T. investigations. A further useful feature lies in the layout of the information where as a general rule it can be stated that within any one digit increasing digit value represents increasing parts complexity.

An inconsistancy seems to be in the inclusion of the raw material shape digit since this is not generally a functional feature but a production feature. Opitz, when pressed on this point at a G.T. conference (74) admitted that this feature of the code had been included at a specific request from industry.

One important feature of the Opitz code is the independence of individual digits within each major group. Thus considering rotational parts (class 0, 1 & 2) subsequent digits have the same meaning for each of these classes, and the code is particularly convenient for use with card sorting techniques to sort on specific component features (e.g. gears). Not all codes have this characteristic and on some systems (e.g. Brisch system) subsequent digit layouts are different for each component class. It is therefore possible to specify component features in the form of a code number field (Fig 6) for computer or other machine sorting techniques.

It is claimed by Grässler (36) that the system fulfills the major codings requirements for most departments, is clearly structured, easy to use and can be applied in design, standards department, production engineering and manufacture.

Testing this system against the list of important considerations stated in the introduction, the following observations can be made:-

- the code is purely numerical and does not use the increased classification facility available within alphabetic systems.
- the code predominantly maintains digital significance within each of its major classification areas i.e. rotational, rotational with deviation and non-rotational parts.
- a constant number of digits is employed.
- with 9 digits a reasonable code length is used, and the split into main classes and use of digital significance makes it relatively easy to memorise.
- the code notation breaks parts up into clearly distinct classes and generally will probably allow parts to fall into one code only.
- a unique component identification is not part of the system.

Howarth is quoted (47) as having decided that

"the Opitz system is preferable to the Brisch system in the field of machined components, both in the design and production departments".

The argument is based mainly on the layout of the code and its digital significance feature.

Since in a total G.T. concept the code chosen would be used for design retrieval as well as cell formation, it is necessary to examine the usefulness of the Opitz code for design retrieval purposes bearing in mind that it was not initially developed for this purpose.

Opitz claims (83) that a suitable compromise can be found in designing a classification system for the use in design, planning and production and maintains that his system fulfills this function. His study on work piece statistics (83) made it possible to design a general purpose coding system which should be suitable in most machine building industries and fulfil the requirements of design, planning and production.

* Edwards and Fatheldin (84) have investigated the Brisch system and the Opitz system and have drawn the following conclusions relating to the Opitz code:-

- the Opitz system is most applicable to the machine tool industry.
- families formed are too general at times and too specific at others.
- the Opitz system is not equally applicable in all departments.
- in certain instances Opitz would separate similar parts and other times code too coarsely to allow easy selection of similar parts.

- the system was of some value for collecting items with certain features in common.

Whilst Edwards and Fatheldin are highly critical of the Opitz system, it has found good acceptance amongst G.T. workers and is recommended for design retrieval. The writer believes that the following features may have contributed to this state of affairs and make the system acceptable as a classification and coding system for company-wide use and specifically for design retrieval.

a) The coding system is readily obtainable from any bookshop and does not need consultants for implementation beyond possibly attendance at a coding course for two or three days by one or two staff members.

b) The system is simple to learn and is easily understood by personnel in all departments.

c) The code is closely production related and makes designers production-conscious. Since generally the value of the code within each digit is a reflection of the manufacturing effort, designers can be encouraged to look for ways of reducing code numbers and hence manufacturing costs.

d) The length of the code (9 digits) forms a good compromise between acceptability and usefulness.

e) The consistant code significance within the three main groups (rotational, rotational with deviation, non-rotational) makes it easy to learn the code and memorise the most used digits.

f) It is true that for complex work-pieces the code becomes decreasingly descriptive and amongst more complex parts it is possible to find widely differing parts with the same code.

This is in fact less of a problem than one might imagine, since most duplication is likely to take place amongst simpler parts and most of the complex parts are components of specific and complex requirements which are unlikely to be duplicated.
There is therefore less need for accurate design retrieval amongst complex parts than amongst simple parts.
Two further points support this argument:
Usually designers will remember the complex parts of a design well and any possible duplication will normally be detected without any difficulty. It is amongst the vast number of simpler parts that the majority of duplications and near duplications are likely to exist.
Whilst the apparent cost of manufacture is highest for the complex parts, the saving in rationalising the range of simpler parts can still be quite substantial, simple parts often require the same amount of paper work and administrative back-up as a complex part and a variety reduction amongst simpler parts may not yield high savings in direct cost but may greatly reduce overloads.

g) The cost of implementing a design retrieval code by specialist consultants can be quite high. The Opitz system can be implemented by the company's own staff using, say, apprentices for the coding work, and most of the costs would be lost within the general plant overheads. The direct cost figure would be negligable and one of the main objections likely to be raised by executions resisting changes would be removed.

(iv) THE BRISCH CODE

Since well before development of the Opitz code, classification codes for standardisation, stores control and design retrieval were already in existence. Probably the best known one of this country is the Brisch Code. This code was developed within E.G. Brisch & Partners Ltd., initially as a design retrieval code in the late 1940's. With the advent of G.T. in Western Europe the code was expanded to take account of the specific needs of the G.T. analyst and now has the following features (5):

The code is designed to suit the requirements of a particular plant and no universal system as such exists. The code is made up of two sections; firstly the primary Code (Monocode) followed by a secondary code (Polycode).

The Monocode describes the geometry and material on a broad basis over typically 6 digits. The Polycode which was specifically designed for G.T. describes certain of the geometric features (e.g. size) in greater detail and lists certain detail features which are not specified in the Monocode. It is up to the code designer to specify the required number of digits and the example in the literature (5) shows a code consisting of an 8 digit Monocode and a 17 digit Polycode (figure 7). The Monocode is split into a 'Surname' defining the family (geometric code or material code) and a 'Christian name' defining a specific part within a family.

Most users of the Brisch code have installed it for design retrieval purposes and the following observations are based on a visit by the writer to A.A. Jones & Shipman Ltd., Leicester who installed the Brisch system in the early sixties.

The system is split inherantly into three sections:-

Class 1:- raw material of un-specified length.
this class uses a nine digit code

1xxxx-xxxx

the first five digits are known as the Christian name containing the material specification and the last four digits form a unique identifier, further defining the material in question.

Class 2:- bought out commodities.
this class also uses a nine digit code

2xxxx-xxx

These two classes are built up on a simple catalogue basis not unlike the Dewey Decimal Coding used in libraries.

Class 3:- single piece parts to own design.

This class which uses an eight digit code (3xxxx-xxx) is that part of the system which is most applicable to G.T. and most comparable with the Opitz code.

The first five digits describe the component geometry. The sixth digit can either be a further classifier or together with the last two digits form a simple sequential counter acting as a unique identifier. Each code therefore identifies a part by number and the code is also used as a part number in the normal sense.

A part is coded by sequential questioning on a pyramid basis and by progressive decision making the final code is developed.

Middle (47) quotes an example demonstrating the lack of digital significance where two parts of identical shape, but different materials have got different codes. In, say, the Opitz code only the material code would be different and the remainder of the code would remain identical.

Contrasting the Opitz code with the popular Brisch code, Middle further states that the Opitz system gives far fewer separate categories and will therefore bring like parts together whilst the Brisch code will tend to disperse them. He concludes that the purpose of the Opitz code is to bring like parts together irrespective of the number of items in each category whilst the Brisch code aims to break down items into approximately similar sized groups for ease of manual sorting.

It should be remembered that the Brisch code is to some degree tailor-made for each application. It is therefore likely that if a G.T. requirement is specified initially, the Brisch code could be tailored to give more of a production bias. Also it is more flexible than the Opitz system and even though Opitz claims a close correlation of component statistics throughout the engineering industries, there must be a number of special product firms with a strong bias towards specific component features which make a standard system less suitable than a tailor-made one.

It is claimed that the Brisch code can be adapted for other purposes such as G.T. by coding a secondary "polycode" with digital significance over any number of digits. This type of code would however add considerably to the coding cost and the code itself would become long and unwieldy.

It appears that the Brisch code, which was in existence before the general popularity of G.T., was devised as a design retrieval code in its primary (mono) code and that the secondary (poly) code was added to extend the use of the code into other areas such as G.T. (5). This is confirmed by Gombinski (86) who states quite categorically that the Brisch mono code is not suitable for G.T. work. He concludes however that no existing design retrieval code is suitable for this purpose and proposes the use of two codes, namely a D.O. (design orientated) and a P.O. (production orientated) code.

As a design retrieval aid the Brisch code has found wide acceptance, and Edwards (11) quotes a number of companies as users. In particular the G.T. application at Serck Audco benefited greatly from the use of the Brisch system.

Relating to the long dispute of Brisch versus Opitz which has taken place for some years now it should be noted that both systems have been found acceptable by users and it is probably more important to analyse methods of using the available information rather than spend too much effort in deciding which system is the more suitable one for the project concerned. Either system appears to be suitable in most general engineering shops.

(v) OTHER SYSTEMS

A number of other systems have been developed to date in different countries and for different applications. Some of these are specialist codes whilst others are claimed to be general purpose codes. A detailed analysis of all these systems is a major research task and generally cannot be justified by a company wishing to embark on a G.T. project. There are summary reviews of coding systems available which briefly review alternative systems and can act as an initial selector of potentially suitable systems. The potential user is likely to make his final choice from a small number of systems which are studied in some more detail before a final selection is made. Systems descriptions are well covered in the literature and the following is a very brief list with some explanatory notes on a number of systems on which details have been published.

(a) VUOSO SYSTEM (87)

Developed in Czechoslovakia along Opitz lines, initially for use on work-piece statistics, the VUOSO system uses four digits only and is therefore more limited in definition than the Opitz system. Since the Opitz system is probably too elaborate for G.T. cell analysis (88) the VUOSO system may well be suitable for this purpose, but is unlikely to be sufficiently detailed for the wider concepts of design retrieval, standardisation etcetera (Fig 8).

(b) P.E.R.A. System (80) (89) (90)

The PERA system is a very complex system giving very detailed component data in multi-digit free-format form.

The code is applied in two parts; firstly a general statement giving a very general indication of the complexity and material of the path followed by a detailed section describing the part in terms of Cartesian co-ordinates and thus describing the component in great detail. Coding is very similar to preparing a source deck in computerised NC programming. It is hard to see the general usefulness of such a system. The complexity would require considerable skill and computing effort to analyse specific features. The coding itself would be expensive (Fig 9).

(c) P.G.M. System

Developed by industrial consultants in Sweden, the PGM system is claimed to be particularly useful for finding production families. An average of 16 digits is used (91), and similarly to the Opitz system, the code is split into rotational surfaces, flat surfaces, holes and supplementary information regarding weight, size etcetera. The number of digits involved allows a greater detail of defination, but no doubt this is accompanied by greater coding cost and more difficult retrieval.

The code is however variable and Knight quotes the code as having only ten digits and being very similar to the Opitz code with slightly more bias towards production engineering (81).

(d) Williamson System (71)

Williamson's system is hardly a system as such but is simply a functional 2 digit code which can be used to roughly split parts into families. Its use is restricted to cell design and probably only to products with clearly defined component families.

(e) Stuttgart System (81) (40)

A production based system was developed at Stuttgart University which may be suitable for detailed production analysis in G.T. work. Knight (81) suggests that the code may be used as a supplementary code to a design-based system. Components are coded, based on their tooling requirements, and it is claimed that this gives a much more meaningful classification for G.T. applications. The code is unsuitable for design retrieval purposes.

(f) D.D.R. Standard (92)

The DDR Standard consists of a complex punched-card-based system utilising 72 columns on punched cards to record detailed data such as component identification, company organisational features, demand, geometry, material, size, raw material shape etcetera. The information provided is very comprehensive and must be very useful in the G.T. analysis. It is doubtful however, if the cost of recording and processing this extent of data can be justified economically. There is possibly, similar to the PERA system, a desire to dispense with the engineering drawing for analysis purposes. It is the writer's opinion however that there is no economic substitute for an engineering drawing. Once approximate families have been devised, the total number of parts in a family is normally small enough to allow a quick visual check for any exceptions. Similarly from a retrieval point, a maximum of information appears to be desirable but in actual fact a designer still has to check similar parts by drawing comparison to ensure full compatability of features.

(g) The ZAFO System

Zimmermann developed a system based on geometric comparison and which is of considerable complexity. It relies partially on visular comparison between the part to be coded and a chart of typical component sketches.

A total of 20 digits are used to describe a component (47) and this makes the code complex and difficult to handle. It requires reference to up to thirty tables and charts to fully classify a part (81) and the coding cost would be very high.

(h) I.A.M.A. System

The I.A.M.A. system was devised by the Institute for Machine Tools and Tooling at Belgrade.

It is devised in two parts:

i) a technological classification system.

ii) a classification system of technological equipment.

System (i) is important from G.T. point of view. It has eight digits and apart from an exchange of digital significance it is almost identical to the Opitz system (93).

(j) U.M.I.S.T. System developed for Ferodo

Mention is made of this system to indicate how it is sometimes necessary to develop a specific classification and coding system for a particular company, where, because of pecularities of the product range, general purpose coding systems may not be suitable.

As indicated earlier in this report, Ferodo make friction materials and in particularly brake linings. Understandably the component shape range bears no relationship to those found in the metalworking industry and a specific system was developed.

Middle, Connolly and Thornley (79) give a good description of this system which has the following features (Fig 10):-

- a unique identifier was used in the form of a meaningless sequential counter.
- a classification code is used in three parts each of which can stand independently in its own right. These are:-

a) Product group type and characteristic code describing function and main manufacturing features.

b) Shape and size code describing the component geometry (Fig 11) and component dimensions in size range.

c) Material code giving an absolute material identity rather than a coarse grouping of similar materials commonly found in other systems.

2.3.4. DESIGN RETRIEVAL

Generally in design retrieval work it is necessary to find geometrically similar parts. A typical example occurs almost daily in most design offices, where a designer wants to use a part which may or may not already be in existence. In most companies only memory will help in this problem and this is notoriously inaccurate. Where a geometrically based classification and coding system is used, this problem becomes easy. The designer possibly sketches his part and codes it (or has it coded dependent on the prevailing system). From, say, a catalogue he then checks for parts with a similar or identical code and sees if one of these parts is suitable for his purposes.

Certain problems exist here. One particular one is the required complexity of the system. There exists here a conflict situation. From an effort and organisational point of view, a simple system of few digits is desirable, whilst for depth of retrieval a complex system with a great number of digits seems desirable. Opitz (94) demonstrates the relationship and states that with increase of coding digits, the coding costs increase and the ease of handling is lost. Only little is gained from this increase in complexity.

He states:-

> "A component classification which is really introduced to a 60% level and which indeed functions in the various areas of application, brings greater benefits than a polished classification system which remains a planning concept".

A further problem quoted by users (95) lies in the retrieval effort itself.
It is quoted that designers may have to go through a number of drawings to check for feature similarity once code similarity has been established. Hosang (14) suggests that the retrieval is handled by a central office which offers a service to the design office. This is supported by a user (95) who states that in his company the designer passes his design to the central coding office who return it with their recommendation.

Companies are aware of these problems and at times classification and coding systems are coupled with micro film systems of drawing storage and retrieval to speed up the drawing retrieval process (34). The Brisch system is generally coupled with a drawing "catalogue" where copies of all drawings are reduced to a small standard "book" size and kept in handy files for easy search and handling.

One of the pre-requisites for a successful variety-reduction programme is the availability of a suitable classification and coding system based on the coding of geometric features (96) (15).

Certain codes such as the Brisch code and the Opitz code are claimed to be suitable for these purposes. Mention is made by the workers of T.H. Aachen relating to variety reduction (14) (15) and this is generally based on the Opitz system of coding and classification.

Two ways of variety reduction are possible.

a) continuous

b) individual projects.

The continuous variety reduction effort is a result of using a design retrieval system to ensure that new parts are not drawn up as duplications of existing items. This is a continuous effort once a design retrieval catalogue has been established. Naturally, if a trained individual or a central office is charged with the responsibility for vetting all new drawings, then better results are achieved than when the individual designers' initiative is relied on.

The special project method of variety reduction results from a critical examination of the design retrieval catalogue. Certain features such as, gears, threads, grooves or specific parts such as pins, washers, shafts, castings, can be extracted by selection of suitably coded parts, and by listing the parts affected, a special feature list is set up which can be rationalised to reduce the current variety. Typical tables of this kind are shown in the references (37) (32) (77).

There can be little doubt that variety reduction can in many cases be a useful exercise which in itself often justifies the setting up and running of the retrieval system.

2.4. G.T. SYSTEMS DESIGN

2.4.1 Approaches of Analysis

It would be useful if it were possible to read up a standard approach to G.T. analysis and proceed on a standard path to a cell system. Unfortunately G.T. is not as simple as this. There is no standard method of analysis which suits all requirements and any company going into this field has to review its own situation and decide which approach will give the desired results with an acceptable load of work input. A number of factors decide the choice of analysis tools, such as:

(a) type of product
(b) product mix
(c) size of company
(d) stability of sales mix
(e) objectives of the project
(f) skills available in the plant
(g) quality of available data
   - drawings
   - process planning data
   - operation times
   - production plan
(h) manufacturing processes used
(j) available machine tools
(k) available space
(l) engineering resources which can be made available to the project
(m) capital available
(n) class of labour available
(o) extent of G.T. involvement planned
(p) labour relations

The list shows that a number of factors have to be weighed up and a rational approach of analysis can be used by applying a number of analysis tools, some of which are closely linked with G.T. (e.g. classification and coding) whilst others may be just general techniques such as flow process charts or activity sampling.

Certain fundamentals of analysis can however be specified to which the detailed techniques can be attached to provide a rational approach.

The basic objective of a G.T. project must by definition be the splitting of components into families of similar parts and forming manufacturing cells to produce these families of parts, where the cells may be single machines, groups of machines or flow lines.

Edwards (74) lays down the fundamental steps involved in this analysis as follows:

"Stage 1: The analysis of components

Stage 2: The rough determination of machine groups

Stage 4: The assessment of component demand

Stage 5: The labour requirement balanced with machine utilisation

Stage 6: Planning the work programme within the group, plus incentives, plus foremanship"

As a framework of G.T. analysis it is hardly possible to fault this list and if the above stages are clearly kept in mind, each stage can be planned independently to suit the requirements of the company concerned. Thornley (18) fully endorses the above approach (Fig 12) but adds some useful refinements such as the use of sampling techniques to cut the work involved. He also stresses the need to look at "the overall group technology concept" i.e. bear in mind the overall system at all times. It is easy to get side tracked into developing one cell to the exclusion of the overall concept, leading to very limited achievements in terms of the overall company.

It is useful at this stage to review the six steps of analysis. The first stage must be some kind of classification whatever form this may take. Different methods of classification have been reviewed previously and there is no dispute amongst workers that classification is necessary to separate parts into families of similar components. It must be stressed however that the classification system must allow the splitting of parts according to their manufacturing requirements. Fortunately in most engineering plants there is a good correlation between component geometry (including size) and manufacturing methods, so that in most cases a geometrical coding system will provide an acceptable basis for G.T. classification.

The next stage involving the initial rough determination of machine tools requires that process planning data is analysed to see which machine tools are required to produce each family. This is basically a problem of resource allocation. The available machine tools have to be split over the families of parts. A useful tool is here Production Flow Analysis (P.F.A.) described later in this chapter.

Whilst P.F.A. has been offered by Burbidge (97) as an alternative to component coding it has been found in practice by many workers that both techniques are required.

PFA can have certain weaknesses when used on its own, but as a secondary analysis tool of families formed by classification and coding it can no doubt be exceedingly useful. Thornley maintains that both classification of parts and PFA need to be carried out to introduce G.T. successfully. At the same time, it must be noted that there are rare cases, e.g. reference (68), in which classification and coding is of limited use and PFA does in fact form a more acceptable analysis tool. Only a review of the product range and a sample coding exercise will prove this situation in any one application. At the PFA stage it is necessary to review current methods and often the need to rationalise and modify production sequences becomes apparent at this stage.

4 Having split out rough groups, the component demand must be determined. This may sound easy but in practice this can cause considerable problems. A company with a well-established product of approximately constant mix would find this simple. In many companies the forward load is totally dependant on customer whims and only with great difficulty can a proper plan be established. A number of workers (20, 98) found it necessary to base their work on historical data by analysing the total output over a fixed period in the recent past. If this is done, it is important to ensure that no bias due to an unusual order pattern or seasonal fluctuations is introduced. In general this approach is probably quite safe. Studies into component statistics have demonstrated that the similarity of parts throughout the engineering industry is surprisingly similar from firm to firm (15, 90, 99). Within any one firm, especially if the product range consists of basically similar equipment, this must be even more pronounced, so that reasonable variations in mix can probably be accommodated. More important is the level of activity (i.e. output). If a false level of output is used as a planning basis, then gross over or under-utilisation of machines can result.

Stage 5 is initially a simple arithmetical step which will occur in every G.T. analysis. Having determined the family, the machines to produce the family and the expected output level, computation of capacity required to meet the output will demonstrate the level of machine utilisation likely to be achieved in each cell.

Labour utilisation may be no problem where floating labour is involved, but machine utilisation is more difficult to balance. Considerable ingenuity may be required to master this stage. This is no doubt the most difficult part of the analysis and, requires sound production engineering knowledge to fully explore all of the above alternatives.

Stage 6 can be treated as the "tidying up" operation. Once a cell has been designed, the management and control systems to support it must be designed to ensure that the cell will function satisfactorily.

Supervision and machine loading are the two key areas which must be fully thought out before the first cell can be established.

PERA (100) define the stages of a G.T. study as

"Identifying and defining product groups"

A classification system is strongly recommended and the choice is offered from the following techniques.

- visual grouping.
- component classification and coding system.
- process flow analysis.
- Pareto distribution analysis.

The previous chapter describing G.T. applications has shown that all of these techniques have been used successfully and a brief description of each technique is given later in this chapter with indications of use, to aid the selection of the correct technique for any application under consideration.

"Establishing component families"

Three basic shape families are quoted:-

a) identical shape and function.
b) identical in shape but differing in function.
c) similar in shape.

In most applications families of type (c) will need to be formed to obtain groups of components providing an adequate cell load.

"Establishing Production Data and Machine Groups"

It is recommended to analyse the tooling at this stage after a rough machine load has been established. Charts of tooling requirements can be drawn up and certain unacceptable components may have to be removed from the family.

"Establishing the Machine Group"

Based on the rough load and the tooling requirements, machines can be allocated to the family and tooling layouts must be finalised.

"Balanced Loading of Machine Groups"

The machine balancing must be based on historical data and PERA suggest that 10 to 15% of the existing times are deducted to allow for time improvements in the new system.

It should be noted however that the PERA sequence of analysis is not necessarily the only sequence. Often it may be preferable to balance cells based on existing times before a detailed tooling analysis is undertaken. Also, it offers the option to install cells based on existing methods and tooling and introduce manufacturing improvements after cells have been fully installed. This is the approach generally put forward by exponents of PFA and reduces the implementation lead time.

The argument is fully endorsed by PE consultants (61) who state:

> "Once families of components and groups of machines have been identified, and possibly installed, a further opportunity is presented to the production engineer to provide savings.
> He can consider ways in which both major and minor set ups can be speeded up....."

The G.T. centre recommend the following sequence of analysis (101)

- classification and coding
- family formation
- form machine groups by simply calculating manufacturing times in relation to quantities required for each family.
- examines the manufacturing processes of the components.
- define tooling requirements
- form manufacturing cells

They confirm the standard line of approach laid down by various other workers.

A crucial factor in cell design which has hardly been mentioned in the literature is the design of the inter-cell flow-pattern which determines if a cell can be developed as a flow line or if it will have to remain as a loose machine group. Also, this analysis will determine the best lay-out for machines in the cell.

There are complex approaches available to determine the optimum sighting of machines in a machine shop using computer models. In a cell, especially if it is of a small size, this kind of sophistication is not warranted since distances moved between machines are quite short and handling cost is low. Useful indications of suitable planning aids can be gained from standard text books of lay-out design.

Summarising the work published, the following independent analysis stages can be defined in a G.T. project.

1. Classification.
2. Family formation.
3. Cell formation based on current times and component demand.
4. Inter-cell flow analysis.
5. Tooling analysis to rationalise manufacturing methods and reduce setting time.
6. Plan the management services required to support the cells.

2.4.2. THE TOTAL SYSTEM

During a G.T. analysis it is most important to always remember that one is dealing with a complex manufacturing system. There is little point in attacking only one small area of, say, obviously similar parts or a particularly troublesome area. Whilst this may yield a quick analysis and a quite satisfactory one within its limitations, its impact on the company as a whole may well be negligable.

Thornley (18) stresses the need for the whole systems approach and indicates that the analyser will have to study all areas of company activity to appreciate the changes which will have to be implemented. He points out at the same time that

> "it is... therefore necessary to introduce any system a little at a time, but it is equally necessary to have an overall plan for the company".

Hence it is quite acceptable to use a prototype cell as long as it has been developed as an outcome of an overall product analysis and as long as it is clearly understood that this forms only the first step towards total conversion.

Most companies have certain "obvious" families which can be selected by eye, and there is a considerable temptation to start a G.T. project by forming cells around these "obvious" families. This invariably leads to problems at a later stage when components which do not readily fall into such "obvious" families are to be formed into groups. It is likely that the spread and quantity of these parts is such that they cannot be formed into viable families, whilst a thorough analysis during the initial stages might well have grouped many of these parts together with the "obvious" families. Similarly classification by a coded classification system might well have shown that the "obvious" families do not in fact form the best basis for family grouping in any case.

At this stage it is useful to apply the OSA (Overall Systems Approach) which has been proposed by Malik, Connolly and Sabberwal (102). The OAS principles have been stated as follows:

1. The reduction of the work input (i.e. supply) to each production section to a minimum, ideally one supplier.
2. The splitting of production into either material groups (for processing industry) or product groups (assembly industry).

3. The creation of as much product (material) group autonomy as possible.

4. The completion of the highest amount of finished work for the least number of sectional (or departmental) visits.

5. The siting of each section to be geographically compact and compatible with other physical constraints.

6. The splitting of work in each section into simple/complex types to overcome the problem of extra machinery investment and to allow for manufacturing flexibility.

The above rules imply that in a G.T. type project a grouping by product is to precede a grouping by component feature and that ideally each product would have its own group of cells or cell sequences. This does of course represent the ultimate simplification of management control. Certain problems will arise in practice such as changes in product mix and the difficulty of forming viable cells for each separate product group. No doubt in larger companies the approach can be applied and will result in tremendous improvements of control. At the same time a more involved analysis may be required to overcome the two potential problems mentioned.

2.4.3. PRODUCTION FLOW ANALYSIS

PFA was developed by Burbidge in the early 60's (97) as an alternative to classification and coding for cell design.

It is argued by Burbidge and more recently by Edwards (11) that geometric coding is not necessarily the best approach to G.T. They claim that:-

a) there may not be a clear enough link between geometry and manufacturing process and

b) there is already a considerable amount of data available in the form of planning sheets, route cards etcetera, which reflects the production flow requirements of the components within the manufacturing programme of the company concerned.

The approach of PFA and El-Essawy's Component Flow Analysis (CFA) (103) uses the existing operation sequences, and manual or computerised data processing sorts components into families of parts having similar flow characteristics and also determines the machines required to produce each family and the machine capacity involved.

The aim of PFA is "to find the simplest possible material flow system" (26) and "seeks to eliminate all unnecessary routes, or material flow paths, in order to find the simplest material flow system".

The analysis progresses over three stages:

1. Factory Flow Analysis.
2. Group Analysis.
3. Line Analysis.

The factory flow analysis looks at the plant flow pattern in overall departmental flow only by dividing the plant into major departments, using the argument that components are made by fundamentally different processes requiring different types of plant.

A "basic flow chart" (Fig 13) is drawn up identifying the flow of material between major departments. These are numbered and for all parts the sequence of departments visited is recorded by noting sequentially the numbers of departments visited. The "Process Route Number" thus formed is the basis of analysis to find the parts following the same route. By concentrating into fitting all parts into the high frequency flow patterns, the basic flow chart can be simplified (Fig 14) to minimise the number of flows and arrange siting of departments in a more rational manner.

The group analysis looks at each department in turn to discover common flow-patterns and arrange parts into families and the shop into corresponding cells. An eight-stage analysis takes place.

i) renumber operations by numbering from 1 upwards for every department visited in turn ignoring certain manual operations.

ii) sort routes into packs by applying machine numbers to all plant and sorting by plant number sequences relating to part operation sequences to split all parts into families of common operation sequences.

iii) draw up a pack/machine chart (Fig 15) which graphically represents the spread of flow-patterns for each department and provides a basis for examining exceptions and splitting parts into groups.

iv) find families and groups. The items on Fig 15 (a) must be arranged logically as shown on Fig 15 (b) to allow the splitting into groups. A set of rules is suggested, but there is no doubt that this is the most difficult part of the analysis where the number of flow patterns is considerable as in general engineering plants.

v) check load and allocate plant involving the calculating of annual machine hours for each machine in each group.

vi) investigate exceptions.

vii) draw final flow system network and check.

viii) specify groups and families.

Line analysis is the final stage of PFA and involves the review of each group to analyse the flow patterns to develop rational production lines for each group and define the optimum machine grouping.

A network analysis approach is suggested in the form of flow process charts which are rationalised to find the best flow condition (Fig 16).

The techniques suggested are basically drawn from factory layout theory and a number of the charting techniques used in PFA can be found in similar form in layout planning books. As a systematic analysis approach to PFA can be very useful however.

Certain limitations must be recognised:

i) where there is a lack in standardisation of process planning techniques for similar components, PFA may have difficulty to bring together similar parts and may well perpetuate the lack of standardisation of methods.

ii) in a reasonably sized machine shop with a wide range of components there may well exist a vast number of different flow sequences, making it very difficult to rationalise these into a limited number of groups.

iii) in many companies having only a machine shop and assembly shop, the factory flow analysis can be dispensed with.

iv) bearing in mind the comments (i) and (ii) above the grouping stages of the group analysis may be dispensed with in favour of classification and coding. In that case the stages of load balancing, exception analysis and flow system charting will still be useful for subsequent group analysis.

v) Line analysis is well worth considering during detail cell design and provides to the best knowledge of the writer the only systematic method of cell analysis put forward in the G.T. literature.

* [Burbidge suggests that computer techniques may be used for the group analysis and this suggestion has been taken up by El-Essawy who developed the concept of component flow analysis (CFA).] The work has not been made available and there is thus little detailed literature available to date on this technique.

* [It would seem that CFA uses PFA techniques applying computer techniques to develop groups of machines to produce selected families of components.]

Basic data is supplied in the form of component numbers, process planning data, plant data and component demand and their inter-relationship is analysed over three stages.

Groups of components with related machine requirements are formed during the first two stages and groups are structured in detail in the third stage. The two basic analyses seem to be roughly equivalent to Burbidge's Group Analysis and Line Analysis.

The factory flow analysis as such is not separated out as an individual stage and Factory Flow Analysis and Group Analysis are combined. Malik, Connolly and Sabberwal (102) see this as a fundamental difference which makes CFA superior to PFA in its basic philosophy providing a simplified and more rational flow system (Fig 17). There must however be limitation here in CFA in as far as it deals predominantly with a multi-product machining and assembly plant in which Factory Flow Analysis can be largely ignored. PFA takes a much broader view and splits up the plant initially into broad areas which may not be compatible. No one would consider mixing, say a foundry with a precision machine shop, and even a forge and a precision machine shop may only be compatible in limited circumstances. The difference in approach between PFA and CFA is probably not very great if a broad view is taken in a PFA analysis and only sections totally alien to the machine shop are split off as separate departments. At the same time, bearing in mind the above comments, CFA must use an informal Factory Flow Analysis in as far as it must set certain constraints in its analysis such as "casting and forging processes will not be considered as part of the flow analysis".

2.4.4. THE USE OF SAMPLING IN G.T.

The analysis of the total component spectrum of a company can be a formidable undertaking. 10,000 parts are no high number for many plant and examples of 40,000 and more parts have been mentioned. To analyse this number of parts manually is virtually impossible and computerised data processing techniques are required. Furthermore the time and effort involved in coding, collecting drawings and obtaining operation data can lead to excessive project lead times before the usefulness and potential benefits of G.T. installation can be assessed. Many companies may not be prepared to put this kind of effort into a feasibility study if they cannot be sure of getting any return on this investment.

One method to overcome this dilemma is by using sampling techniques. A suitable sample is chosen and the analysis is developed on the sample, assuming that, if a realistic, unbiased sample is chosen the results of the sample analysis will relate directly to the total component range.

Other companies find it difficult to assess their forward production programme. The customer may have a choice of a number of models or sales may be geared to specific designs for particular companies where the forward load forecast cannot be established with certainty. In this case sample analysis is the only practical method of analysis available.

Under these conditions it might be argued that the sampling technique is invalid since no sample can be chosen to represent a component spectrum which is not yet known. Fortunately an answer to this can be found by reviewing the work done by various workers who have investigated work-piece statistics across various industries. Notably the work by Opitz (15) has shown that there exists close correlation in the product spectrum between a wide range of engineering companies irrespective of company size and end product. This means that the distribution of geometric component features across most engineering companies tends to be fairly similar.

Extending this argument to any one company, the spread of component features and, by implication, the range and unit volume of production processes involved will remain fairly constant over long periods of time, especially if the same kind of product in similar size is produced. Furthermore, if an unbiased sample is chosen from amongst the total number of parts, the production requirements for this sample, scaled up to the equivalent actual output of the plant, must form a sound basis for the design of a manufacturing system which, with negligable adjustments, will cope with the total component range.

Thornley (18) recommends a sample size of 10 to 15% of live specifications as adequate on which to base a classification system and production flow analysis.

A difficulty lies in the selection of a suitable sample. Various methods are possible, such as:

i) specific past period order input.

ii) specific past period finished part store receipts.

iii) random sample of live specifications or drawings.

iv) selection of a "typical" assembly and use of all parts making up this assembly.

v) random choice of stores locations.

Each method has advantages and disadvantages. The two key factors which must be balanced are:

- avoidance of bias
- ease of retrieval

Often these factors are contradictory and in that case the first factor must of course take preference.

Specific past period order input or order receipt (e.g. 3 months order input into the machine shop) is often easy to measure but can produce bias conditions which may be hard to detect. Seasonal sales variations may exist, which owing to the manufacturing lead time are hard to relate to order input. An inventory control based system may miss vital components because batch sizes and timing are such that certain parts were not loaded during the period under consideration. Where fixed order cycle production control is used one cycle may well be the ideal sample.

A random sample of drawings gives probably the most unbiased sample, but it may contain a number of non-current parts on which no reliable production data may be available.

Where a record of current parts only is kept a random sample of these should form a very good sample.

The selection of a typical assembly provides an easily available list of sample parts (i.e. the parts list) and the correct choice of assembly ensures that all parts are current, and good data is available. There is however a problem in choosing a "representative" assembly. It is very easy to introduce bias by selecting an assembly which by virtue of its size or its number of constituent parts may not give the proper indication of capacity required. If the previous method of sample selection are not convenient and the selection of a typical assembly is considered, certain precautions can be taken to ensure a suitable selection, such as:

- it must be ensured that a size in the mid range of all assemblies is chosen. For safety sake it may be considered to lean towards the larger size to ensure that adequate capacity is chosen.
- unit costs can be reviewed so that an average assembly is chosen since unit cost will often be approximately proportional to the manufacturing time.
- a choice of a high volume unit will provide for a high percentage sample in terms of total plant output.
- the choice of more than one unit increases the sample but allows inclusion of boundary size parts by using, say, one small and one large assembly.
- if there is a wide range in unit sizes with a correspondingly wide range of component sizes, more than one unit must be chosen to be able to cover the total spread of components.

The use of sampling is a very useful tool in a G.T. analysis and reduces the work content significantly; moreover sample usage usually allows economic manual data processing and is therefore cheaper and more flexible.

2.4.5. CLASSIFICATION INTO PRODUCTION FAMILIES

Classification to form production families is totally distinct from classification for design retrieval purposes. For production purposes it is necessary to split the whole component spectrum or as much as can possibly be accommodated into a limited number of families of parts which can share common production facilities.

To illustrate the point, a nine digit classification system provides 1,000,000,000 different classes of components. Whilst probably many permutations will not be covered by any parts, it is likely that hundreds and even thousands of differently coded part families will occur in most companies. Even if one is to consider an average cell size of only five machines in a machine shop of say 200 machines, then a classification system with ideally only 40 permutations of code digits is called for. Thus most classification and coding systems are far too "good" for the initial grouping of parts. This argument no doubt explains why many authorities accept that G.T. can be implemented using visual selection, functional grouping or simple 2 digit codes. Purely for the selection of rough families for cell formation these and especially the latter may be perfectly adequate even though it ignores the broader concepts of classification and coding discussed previously. *

Five methods of classification have been proposed, the first four are taken from Burbidge (26) and the fifth is added from a PERA training manual (100)

1. Division of eye.
2. Division based on design classification.
3. Division based on production classification.
4. Division based on production flow analysis.
5. Division based on Pareto analysis.

Division by eye has been used successfully in certain applications where circumstances were particularly favourable for this method. Where a large number of parts is involved, it is unlikely that this method will be practicable.

Selection from design classification has been used most frequently. A problem exists where the classification system does not have digital significance for all its individual digits. G.T. requires selection of parts based on certain pre-determined features such as overall shape, size and possibly material.

The latter two may well be of a lower priority in a design based system and if no digital significance exists in the system, complex and long-winded search procedures may be required to retrieve families.

It would appear that for initial grouping only up to four component features are of interest.

These are:

- basic overall shape (e.g. Opitz first digit) differentiating between rotational and non-rotational parts, and splitting these up into broad groups based on dimensional proportions.
- size
- material
- raw material shape

The first two features in general define the type of machine tool used in the manufacturing process. Rotational parts are generally turned for their major features, whilst non-rotational parts are generally milled. The component size will roughly define the machine size and hence the detailed machine type.

The set-up requirements are often well defined by the raw material shape which groups all castings, all sheet metal parts, and all bar parts. Very often castings and sawn-off billets require totally different machining and the split appears to be reasonable. The information in the raw material code gives further information to group in more detail and provides for families of identical materials which would want to be loaded in groups to reduce the swarf mixing and rake angle change problems.

It must be understood that this split is only a quick guide and certain of the groups thus established will need to be combined. Four digits still lead to a maximum of 10,000 families, so the need for further grouping becomes apparent. However, once the minority groups of only a few parts each have been eliminated for the initial grouping it is likely that a manageable number of families for further grouping will be obtained.

These can be grouped on the basis of intuition, product and machine knowledge and a practical production engineering approach.

To site an example based on the Opitz code, it is likely that all castings below 6.1/2" diameter will be grouped for turning on the smallest machine. Bar work may have to be split into up to .8", 0.8" to 2", and 2" to 4" size ranges for initial grouping to suit progressive sizes of capstan lathes, but once an adequate load for these machines is established, they can be grouped together into one cell in which all work up to 4" diameter can be handled on the same type of support machines (e.g. mills and drills). Should adequate cell loads be available for any one size then a separate cell can be established to cater for this one size range only. Non-rotational parts can be conveniently split into casting/forgings and bar stock components. To suit the general range of drilling and milling machines in most plants, sizes can probably be grouped into ranges of up to 4 inch, over 4 inch and up to 10 inch, over 10 inch and up to 25 inch, over 25 inch.

It is better to establish too many families at this stage and build up a capacity breakdown for each family during the next stage. If the capacity analysis shows poor loading or insufficient machines to form an efficient cell, it is an easy matter to combine compatible families using identical machines to build up a suitable load. One could envisage that a four-digit analysis would produce, 1,000 to 5,000 different codes depending on the sample size, of which possibly half could be removed as minority codes and the remainder combined into, say 50 to 200 different families. To rationalise 200 families into a requirement of, say 40 cells is an easy matter, even manually.

Dill (88) quotes an example of a computer programme used at TH Aachen for G.T. analysis using the Opitz code. This programme sorts on the basis of:

- main shape (digit 1)
- diameter or largest edge length
- material
- if required further geometric shape

This supports the argument put forward above regarding the importance of certain information for G.T. classification. The information priority is totally different to that in the full code giving the data in a form most suitable for design retrieval. Furthermore a considerable amount of the information in the code is not required at this stage.

Brankamp (104) offers a similar approach for the selection of machine tools to match the existing component range. This is the same requirement as that necessary for cell formation. He suggests that the following code extract should be used.

- component class (on the digit 1)
- external shape element

- dimension
- material

Perrins (60) offers three methods to select potential families using the Opitz code, all of which will have to be used in any one study.

- specific component groupings; mainly major obvious components
- specific manufacturing features; typical examples being gears
- size and component feature selection matrixes (these are identical to code number fields used by Brankamp (104) relative to key machine capacities (Fig 18)

On the other hand, classification by production code would appear to be ideal for G.T. purposes, but to date there seems to be little evidence of its use in actual applications, some work has been done at Stuttgart University in this direction but this work does not appear to have found ready acceptance in industry to date.

The following reasons can be suggested for this:

1. The use of a specific production code as distinct from a design retrieval code would involve duplication of costly coding effort.
2. Manufacturing methods are not static in the same way as geometric component features, and any production coding system would either have to be set up either specifically for the initial G.T. analysis only or would require continuous updating.
3. The long term usefulness of a production code is very limited and whilst a design retrieval code can be gainfully incorporated into the company information system, a production code will only make a minor contribution when the G.T. analysis is completed. Furthermore a design retrieval code is an adequate analysis tool for a G.T. analysis in any case.

As a practical technique, production based classification systems can probably be discounted at the present time.

There is little more to be said about selection by PFA beyond the discussion earlier on in this chapter.

Division by Pareto analysis is an interesting alternative. It revolves around the concept that if 80% of the product cost lie in 20% of all parts, then the 20% only should be attacked leaving the 80% as they are at present. This approach can have considerable merit, but certain points must be considered:

- the approach does provide for a greatly simplified approach offering high reward for effort.
- the technique largely ignores the G.T. benefits of assurance of parts delivery and greater flexibility to order changes.

- to run the Pareto approach successfully, certain additional parameters would probably have to be laid down, such as

  i) an efficient inventory control system for low value parts

  ii) a high-stock system for low value parts such as a sealed bin system

  iii) the great majority of low value parts can be bought out at no appreciable cost penalty to obtain the flow simplification and managerial benefits of G.T.

There is the danger with this system that it ignores high value, low usage parts which would usefully combine with high-value, high usage parts falling into the 20% high revenue group. Tooling duplication and unnecessary overhead would be incurred.

A more plausible approach would seem to be to form families based on the total component spectrum and introduce cells on a decreasing value basis, so that high revenue output cells are introduced first.

2.4.6. CELL FORMATION

The formation of machining cells after classification can be split into three stages.

1. Capacity calculation for each family.
2. Capacity balancing by combining families.
3. The integration or elimination of minority groups and machine loads.

The first stage involves simple arithmetic and requires as input:

- operation and set-up times for each operation.
- machine description for each operation.
- component demand per unit time (say yearly for convenience)

The above items allow calculation of operation times per year per machine type for all different machine types used for each family in turn.

To form viable cells, an indication of desirable cell size must be established. Williamson (71) claims that 6 to 10 people make a good cell. This figure agrees with that quoted by Brown (105) for primary groups in industry claimed to be typically 8 to 10.

It would seem therefore that one appropriate parameter for cell size is 6 to 10 operators per cell. Two approaches to reach this aim can be suggested:

Firstly, it is possible to just add total yearly machining hours for each family and combine families using similar machines until enough yearly hours to utilise 6 to 10 operators have been accumulated. Often it is better to aim at the higher figure to improve the utilisation of support machines. The process cannot take place in isolation for each cell and the grouping of families must be balanced (i.e. it is better to have two cell utilising 6 operators each than one with 10 operators and another with 2 operators).

The second approach occurs where a family has more annual hours per year than can be handled by ten operators. In that case it must be considered to either break up the family or to form sub-cells within the main cell.

There may be a tendency to look at individual machine utilisation too closely at this stage and this cannot be recommended. Detail cell development should be left for the third stage.

The final stage of analysis to form viable cells consists essentially of capacity smoothing.

The previous stages of analysis will no doubt lead to a number of very poorly utilised support machines and those must be dealt with.

A number of methods are possible such as:

a) replanning of the work on to different machines.

b) using group tooling to reduce operation and setting times on overloaded machines.

c) the use of special attachments or unit heads for a limited amount of special work on certain components in the group.

d) accepting poor utilisation on low cost machines.

e) (in extreme cases only !) considering the sharing of one machine by more than one cell.

f) producing parts to a semi-finished state in one cell and transferring them to another cell for finishing.

It should be noted, that the cell size of 6 to 10 is an idealised figure and cannot always be maintained. Single-machine cells (e.g. auto-lathes) may exist naturally and in certain cases two or three operators may form technically the ideal unit. If a cell exceeds 10 numbers however, it is likely that the benefits of small, closely knit sections will be lost.

INTER-CELL FLOW ANALYSIS:-

Once cells have been formed it is necessary to analyse the flow pattern within the cell to determine if the cell can be developed as a flow line or if a group layout is more suitable. Furthermore it is necessary to develop the best layout pattern for the cell. When only dealing with at the most 10 to 15 machines this problem is not too difficult and where a sample analysis is chosen, it can be done manually without undue problems.

Burbidge recommends line analysis for this process which has been mentioned earlier in this chapter. No doubt the technique shown is suitable especially where the greater majority of parts have a similar flow pattern. Where the analysis is part of a PFA, this condition is likely to occur since PFA groups parts by their material flow requirements. It is likely that where classification by other means has taken place, a wide variety of flow patterns could exist and network charting may prove to be difficult since networks may become too elaborate and confusing for easy analysis.

It may be beneficial to look at conventional layout-planning techniques such as laid down by Muther (106) especially in relation to the detailed layout plan for a department.
A useful aid to determine the primary flow patterns in a cell is via the "FROM-TO" chart which forms an excellent basis for flow charting but gives possibly a simpler method of analysis than Burbidge's operation route number analysis.

Either technique will show if the cell is potentially suitable for flow line design. If a high proportion of the sample have the same flow direction, then those parts not conforming can possibly be re-planned, or, by duplication of similar machines at different places in the line, two (or more) patterns of flow may be combined in one line. It should be noted, that any one part must not necessarily use every machine in the line, as long as all parts flow in one direction only along the line.

Where cells are a more suitable arrangement, flow and handling can be developed by locating machines in the correct flow sequence for the majority of parts. It is doubtful, bearing in mind the likely small size of a cell, that sophisticated decision criteria need be introduced and a grouping based on a total number of parts per unit period is quite adequate.

The use of a circular, square or rectangular cell reduces the distances of travel in cross-flow and provides face-to-face contact of group members which is beneficial for primary group formation. This type of layout is therefore preferred to a line layout.

In the case of a flow line, the line layout is in most cases mandatory. From the above reasoning it would seem preferable that machines are arranged on both sides of a conveyor to shorten the line. By the same token it should be avoided to feed each side of the conveyor with separate work since this could split the group in half.

2.4.7. OVERALL PLANT LAYOUT

The literature has concentrated in the past on the details of each cell. It must not be forgotten, however that the location of cells in the plant is of considerable importance.

In order to maintain an efficient flow-pattern throughout the plant, cells must be arranged in such a way that their relationship to services, stores and assembly provides for efficient material flow.

This work falls into the realm of good plant layout technique and Muther (106) is one of the better guides to develop an efficient layout within the existing building constraints. Because of the self-sufficient nature of G.T. cells there is not likely to be any cross-flow between cells and net-work charting is particularly suitable for this work.

2.4.8. TOOLING ANALYSIS

One of the major savings achieved from G.T. is often quoted in terms of setting time reduction. As Craven points out quite rightly (63) this saving is only achieved by adequate production engineering effort.

The advantages of G.T. in general hinge around the concept that families of components are produced on like set-ups using as far as possible common tooling. Therefore, once families and cells have been formed, it is necessary to analyse the tooling requirements for each family and rationalise tools and fixtures into common set-ups.

It is possible that more than one group set-up exist within each cell and each sub-family may well be analysed individually.

One powerful technique of set-up rationalisation is the "Complex part" technique developed by Mitrofanov (7) and used in applications in this country such as English Electric, Bradford and Ferranti.

The philosophy of the complex part is quite a simple one. A number of similar parts are grouped and by comparison one part is chosen, or specifically drawn up, which contains all of the features of all other parts in the family such that the tooling and the set-up to make the complex part will be capable of producing any part in the same family without machine re-setting. No account is normally taken of actual dimensions and size adjustment of tools between batches is accepted.

Compromises may sometimes be made for, say, special form tools or specific size drills and reamers which may change between batches. The use of the complex part technology does however lead to considerable setting advantages.

Certainly with such aids as digital read-out to assist in the rapid and accurate change of sizes between batches and the use of pre-set tooling for special tools requiring frequent changing, a very efficient group set-up can be achieved.

There are however difficulties with the complex part technique. This philosophy is in most cases restricted to one machine type only and in a general engineering plant with a wide range of different component shapes it is very unlikely that one complex part covering all machined features of the family for all machines in the cell can be determined, such that a meaningful group set-up can be developed.

This problem can only be overcome in one of two ways:

i) draw up separate complex parts for each machine and regroup parts after each operation. This would require a considerable stock build-up between machines and would make control very difficult. One could however, envisage situations where a wide range of parts are to be made over several extensive set-ups in very small batch sizes, where this philosophy could be justified.

ii) select the machine which in general has the longest set-up time and developed a complex part for this machine only, accepting that on all other machines of the group no further group set-ups can be formed. This philosophy can be extended as described by Connolly (20) by breaking each family on the highest set-up machine up into sub-families for the next highest set-up family and feeding within each family the highest set-up machine in sub-families to enable group set-ups to be used on the next highest set-up machine. This approach can be continued down the line, but of course, the families become continuously smaller and the benefits reduce as the set-up time for the machine reduces.
On certain machines, such as drilling and tapping or surface grinding machines, standard setting times may well be so low in any case, that they can be ignored.

Not surprisingly, the complex part technique has been used widest for turned parts and specifically on capstan lathes which tend to have long set-up times and accept a considerable number of tools, allowing greater scope for complex part development. On a capstan lathe one restriction of the technique is the limitation on the number of available tool stations, so that parts must be classified initially into families of fairly similar components to be able to draw up a manageable complex part.

Various charting techniques have been used to record the variety of component features and tooling requirements in a family of parts. A comprehensive sheet format is shown by Bennett (101) (Fig 19) for turned parts analysis giving a good indication of the tooling requirements and size distribution of features. Similar format sheets have also been devised for other machining operations.

A tool analysis sheet covering turning as well as other operations is shown by Eldred (107) (Fig 20). It is likely that a different format sheet would be drawn up for each cell specifying features and current tooling. Where a family is large, it may be useful to split it into sub-families first and make the analysis simpler and more meaningful.

Perrins (60) shows a similar method of tooling analysis specifically related to turret lathes (Fig 21) in which all tooling set-up requirements are listed for complex part set-ups.

As indicated, some kind of component/feature matrix is generally required for this analysis and this is of course a standard methods engineering approach, not confined to G.T. in particular.

The complex part philosophy can also be applied to fixture design and Mitrofanov (7) gives a considerable amount of detailed information of the design of group fixtures. Since parts in a family are generally similar in size and shape, the use of standard features in conjunction with specific component adjustors or setting blocks make it possible to cheapen fixture cost considerably and at the same reduce the setting of fixtures between batches to negligible proportions. Whilst a tooling analysis is very suitable for turning, a fixture analysis is more important for such operations as milling and drilling.

No detailed information is available for group fixture analysis, but a feature matrix of such items as location faces, clamping faces as well as machined features will be useful. Useful information on standardisation of clamping and location features can be obtained from both Mitrofanov (7) and Demyanyuk (23).

2.4.9. COMPUTERISED DATA PROCESSING IN GROUP TECHNOLOGY

G.T. is inherently concerned with the collection on sòrting of data, i.e. work piece statistics, component codes, production data etcetera. The amount of data to be processed can be quite substantial and it comes as no surprise that computer techniques for data processing have been considered by a number of workers.

There may in many cases be no need to use any computer aid as such at all. Punched card equipment is ideal in many instances and quite adequate for many studies. Where a sample of parts have been coded, a simple card sorter can be used to rapidly sort all coded parts in any digital order required. Once cards have been sorted a tabulator can be used to print out a list of all parts in code sequential order. Tabulators are becoming rarer these days but printing of lists from pre-sorted cards can normally be done on computers using a standard programme and no programming effort is involved. Also, sorting of random input cards is expensive and requires considerable core storage, so sorting in an electro-mechanical card sorter followed by computer printing is a cheap and efficient way of obtaining a print-out. The G.T. worker further retains the flexibility of sorting in any digital order without having to write a specific programme for each listing.

A particular chore in G.T. work is the capacity calculation for each cell, which involves the apportioning of setting times to operation times and the multiplication of these summary times by quantity requirements for each operation on each part in the list of parts under analysis. Total hours per period then have to be added up for each machine in each particular family of parts. A computer is ideal for this work as demonstrated by Hunt (98) who incidentally goes further to introduce family division by computer.

Hunt introduces a set of pre-sorted Opitz coded cards into the computer, and his programme "Opus" prints cumulative machining times for each machine for every Opitz code, with grand-totals for each main class (First digit change). His programme "Opal" is similar, but sums up for each different code in the first five digits only. Naturally the same approach can be used after families have been formed to sum each family's machining capacity.

A more complex approach is used by P.E. Consultants (61) who propose the use of a computer for a greater amount of work. After sorting by Opitz code, selection matrixes (described earlier in this chapter) are introduced to use the computer to select families of parts from the total component spectrum according to pre-determined decision parameters. After introducing requirements figures and component values, this data is used to select promising families for cell formation. After operation details have been fed in, a P.F.A. is undertaken by computer leading to a capacity analysis, P.F.A. charts for exception analysis, machine tool list and layout sequence.

It should be noted, that decision parameters are introduced in the form of the selection matrixes. It is doubtful that it is possible to write a programme without manual intervention which would suit all requirements. The P.E. programme suite appears to be a very useful aid for G.T. analysis. It is however quite extensive and it is not possible to draw up such a programme for each application. For industrial consultants, however, this should be a useful approach.

A different approach relying extensively on computer aided data processing is of course Component Flow Analysis which was briefly reviewed early in this chapter.

Other techniques, such as "Work Flow Structure" (108) have been developed to analyse the work flow pattern in a plant, and whilst no particular reference to G.T. is made in this work, it is likely to lead to a cell system of layout in a similar manner to PFA.

A number of more advanced techniques could be developed and reference has been made in the literature to simulation models to design manufacturing systems. One must wonder however, to what extent this type of work is really justified bearing in mind that G.T. in its initial break-down into cells reduces the problem into manageable proportions which can be analysed without complex techniques.

2.5. MANAGEMENT ASPECTS OF GROUP TECHNOLOGY

2.5.1. PREREQUISITES OF G.T. SUITABILITY

Before a G.T. project can be undertaken it is necessary to check if G.T. is suitable for the company under investigation. Whilst the great majority of batch manufacturing plants are suitable, there can be exceptions.

Furthermore some companies are more suitable for G.T. installation than others and will therefore reap greater benefits.

Leonard and Koenigsberger (109) have laid down a set of optimal conditions which are listed as follows:-

i) a large number of small batches.
ii) accurate production information.
iii) customer delivery requirements.
iv) company control of raw material.
v) light components.
vi) minimum inspection.
vii) simple jobs and flexible labour.
viii) inexpensive plant.
ix) similarity of components and production operations.
x) a balanced machine utilisation.
xi) maximum advantage of classification system.

These items merit further discussion to indicate certain areas which require specific study to test G.T. suitability.

Item (i) is generally accepted as a key factor towards G.T. suitability. Where a large number of small batches are involved, the production system is likely to be very complex and G.T. will help to simplify the system and make it more controllable. Surprisingly no reference was made by Leonard and Koenigsberger at this point to discuss the product itself. Small batches are a result of production planning and not always the basic manufacturing requirements. By the use of such production policies as Economic Batch Quantities or conversely smallest batches to minimise stock holdings, batches can be generated which do not reflect the real requirements of the company and which, if used as a basis to test G.T. suitability, may well give a totally false picture.

The first look should therefore be at the product. The wide range of G.T. applications to date shows that it is difficult to specify the type of product which is most suitable for G.T., but one general rule appears to apply throughout, namely that the product sales pattern is such that a wide range of components are required in medium to small quantities, preferably, periodically recurring. Within specific products, there are different requirements for different product types.

Where single piece parts are made such as brake linings, it is preferable that a number of different specifications are called for, to be produced in small batches. For simple assemblies such as, say valves, it is useful if a considerable number of assemblies are to be made in small quantities, but all assemblies consisting of a similar component range, so that, say all housings or shaft etcetera can be grouped together.

In a multi-part assemble plant the requirements get more complex. The requirements are:

a) as great a number of component types as possible.

b) a great number of different assemblies to be built in small quantities each.

c) assemblies to be preferably compatible in terms of size, material and average component spectrum, thus requiring similar manufacturing plant.

Conversely there are conditions which may make the use of G.T. in such a plant unsuitable:-

a) a small number of components only exist, with quantities too small for individual flow lines, but the range of parts so widely spread that insufficient parts of any one type can be grouped together to form a family. In general the more parts are available for classification, the greater is the probability of forming viable families and cells.

b) a wide variety of parts are to be made in a small plant with only one of most types of machines. There is in this case a great likelihood that cells cannot be formed without duplicating a considerable amount of plant to allow the split of identical manufacturing processes over more than one cell. This problem is aggravated in a plant making complex multi-operation parts such as used frequently in, say, aircraft equipment. If such a situation is likely, it is necessary to take a sample check of machine loads to test the extent to which key machines need to be split over more than one cell.

In many cases an experienced G.T. worker will be able to decide almost immediately that, based on product requirements, the plant under survey is suitable for G.T. application.

In other instances, a sample based study may be required until an answer can be given in confidence.

It has been pointed out quite rightly by Leonard and Koenigsberger that accurate production information is a ncessary prerequisite to G.T. installation. There is however a distinction between the levels of accuracy required for different types of information.

It is imperative that accurate information on product demand is at hand. Where no reasonable production forecast exists, a lot of time may be lost in establishing the picture of manufacturing requirements by a review of historical data, modified by forward orders, trends etcetera. The G.T. worker would in fact be forced to establish a production forecast as a working basis.

Operation data must be available together with existing tooling information. A certain degree of inaccuracy or shortage of information for certain components could be accepted, since for the components affected the information could be quickly updated by comparison with other parts in the family.

Operation times and setting times are vital for capacity planning. Again the degree of accuracy is not too important since, firstly, times which are widely out would be highlighted early on by comparison with other parts in the family and, secondly, the times applicable to the G.T. cell would differ to some degree from current times in any case and times existing at present could only be used as an approximate guide in any case.

Having made the above argument, it should however be remembered that during a G.T. project it is inherently easy to update and improve current information levels and a lack of information should be taken as an encouragement to introduce G.T., not as a hindrance. Whilst the lack of data would draw out the G.T. implementation over a longer period of time, it would provide a reasonable data basis as part of the analysis. This on its own is a good objective for a G.T. project.

Company control over raw material is useful from an organisational point of view, but in many engineering plants, raw material must be purchased in the form of bar, plate, castings etcetera. As a G.T. consideration this item can be ignored in most instances. A high raw material stock holding may be called for in many cases to ensure supply to the cells, but in many instances in general engineering plants raw material is not the major cost item and inventory cost for a high material stock-holding does not incur too high a cost penalty.

Component weight as indicated by Leonard and Koenigsberger is important where roller conveyors are to be used in a flow line. It cannot, however, be considered to be a major limitation to G.T. suitability of a plant.

Flexible labour is certainly useful and in many G.T. installations a necessity. Where floating labour is already used, a major potential obstacle to cell formation is removed.

The current use of inexpensive plant is useful since it allows underutilisation of plant without excessive cost penalty. If this situation does not apply, the cell system can be supplemented by cheap, even second-hand machinery to be employed in certain low utilisation areas.

Leonard and Koenigsberger point out that a long-life product is preferred to obtain maximum advantage of a classification system, but in fact, this advantage goes further. Where a short life product and frequent introduction of new designs is involved, the G.T. cells will have to be very flexible and it is doubtful that the full benefits of flow line production and group tooling can be exploited. Frequent revision of the layout may be called for. At the same time the G.T. system and existing group tooling is however likely to reduce new product lead times and tooling costs, so that advantages can be gained irrespective of short cycle or long cycle products.

The following questions can be laid down which need to be answered to assess the suitability of a plant for G.T. introduction.

1. What is the product?
2. What is the production forecast?
3. Is an assembly product involved?
4. What is the manufacturing mix of assemblies?
5. What is the assembly complexity (average number of parts per assembly)?
6. What is consequently the total number of parts to be made per year and the average usage per part per year?
7. Do components fall into families of similar parts, recurring in each assembly?
8. What is the spread of components and component features?
9. What machine tools are used at present and what is their cost and complexity?
10. How many of them are special purpose machines?
11. Are there generally more than one of each machine?
12. If not, do one-only machines handle a wide range of different parts?

13. What is the average number of operations per part?

14. What proportion and what component type is sub-contracted?

15. What is the level and accuracy of production data?

- parts lists
- production forecast
- process planning sheets
- tool and gauge information
- operation and setting times

16. What is the raw material and how is it obtained and controlled?

17. What system of production control is used?

18. Is floating labour used at present? Is there likely to be strong resistance to floating labour?

19. What are labour relations like at present?

On the basis of such questions and a review of assemblies and parts in store, an assessment of the vital questions can be made:-

1. Can the component range be split into separate families of similar part?

2. Can the machines be split into groups to make these families?

3. Is the necessary data available for a meaningful analysis?

If these three questions can be answered in the affirmative, it is almost certain that G.T. is the correct production system for the plant in question. It is a matter of more detailed analysis of the product and the existing systems to decide the extent of benefits which can be achieved.

2.5.2. OBJECTIVES OF G.T.

Having decided that G.T. is indeed a suitable manufacturing philosophy for a particular plant under consideration, it is necessary to set down the objectives of the project. There are two reasons for doing this:

Firstly the company, that is, the board of directors, need a reasonable assurance that the cost of the G.T. project will be recovered, and the only way this can be done at the early stage, is to review the company's problems in relation to other companies' experience to assess what savings and improvements can be expected. Often there is one specific overriding reason which makes the introduction of G.T. imperative, such as the necessity to improve delivery performance or to reduce stocks.

Secondly a set of objectives provides the project team with both, the project target and the authority to requisition information and assistance. For this reason it is important that the objectives are approved by a senior executive, preferably the technical or managing director, to ensure that the project team has the proper backing for its analysis and implementation.

Setting objectives involves two activities, namely the review of the kind and magnitude of advantages to be gained from G.T. by looking at published experience of users of G.T., and secondly an analysis of the company's problems to see how the advantages of G.T. will assist to solve these problems.

The following areas merit particular attention when reviewing the problems of the company.

- current work-in-progress stocks
- finished part stocks
- average batch size and usage period of each batch
- shop loading policy
- throughput time of batches
- delivery performance
- production control staff and in particular progress chasers
- losses due to material shortages
- space occupied by work-in-progress

On the basis of the information obtained, objectives can be set and an assessment of the savings to be expected can be made. A work-in-progress reduction can be calculated by

a) reducing the current figure in the ratio of current to proposed batch throughput time (the latter can be roughly estimated as between one and four weeks, depending on the size, complexity and flow rationalisation of the cells).

b) reducing the figure further by a ratio of current batch usage periods to expected usage periods based on reduced batch sizes. If an E.B.Q. loading system is used, average batch usage may well be 6 months or more whilst in the G.T. cell a one-month fixed cycle loading may be acceptable, reducing work-in-progress by a ratio of 3 to 1.

Finished part stocks will be reduced similarly though not necessarily in proportion to the average batch size reduction.

There is little point in trying to be too accurate at this stage, since too little detailed information of the ultimate G.T. system exists. In most cases it will be found, that even a very conservative assessment of stock reductions will provide startling savings which will pay for the whole project.

It is always difficult to predict improvements in productivity, but it may be taken for granted that productivity will improve. Whilst figures of 20%, 30% and more have been quoted, it is often not wise to use these in the objectives. It can be taken as certain that at least a 10% productivity improvement will be achieved if the project is extended across the plant as a whole and this figure is usually adequate as an initial objective to show a most substantial saving. If it is anticipated, that only part of the plant will be turned over to G.T., the figure of productivity improvement must be scaled down accordingly.

2.5.3. HUMAN ASPECTS OF G.T.

It is claimed by industrial psychologists that all organisations are built up from a number of smaller groups of average size 8 to 10 people. These are the so-called primary groups where the upper size is limited by problems of communication and adequate face-to-face contact. Where groups exceed this size they will tend to break up into smaller groups and the process has been likened to the cell-division in animals or plants. It is mentioned (105) that throughout history groups of that size have been found whenever high morale was important, i.e. cricket eleven, army section etcetera. Primary groups are characterised by an interrelationship of personal relationships and clearly defined attitudes of members towards one another.

The primary groups form irrespective of the formal organisation of the plant but naturally considerable benefit could be gained if, not unlike the army platoon, the primary group could be incorporated into the company organisation and the moral strength of the primary group be directed towards the aims of the company.

In a functional shop primary groups are likely to form in individual sections and there is a tendency for the shop to "break-up" into separate units, which, by virtue of the work flow, have to be integrated into one unit. Rivalry between groups is likely to cause disruption and a lack of co-operation between groups can result in ill-feeling. Certainly no close working harmony across the shop is achieved. One might further argue that the foreman will have divided loyalties, firstly to his primary group, and secondly to secondary groups such as the foremen's association and the management team of which he is a member.

In a cell layout the primary group principle is utilised to provide conditions which are suitable for the formation of primary groups, to give each group a definite goal (i.e. to produce a certain range of components) and minimise conflict by making groups self-supporting.

If primary groups form in cell layout, then considerable benefits in terms of morale and output can be achieved. Schein states this as follows (110):

> "For example, a formal work crew such as is found in industry or in the Army (say, a platoon) often becomes a phychological group that meets a variety of phychological needs mentioned. If this process occurs, it often becomes the source of much higher levels of loyalty commitment, and energy in the service

of organisational goals than would be possible if the phychological needs were met in informal groups that did not coincide with the formal one".

Brown points out, that closely-integrated groups are most likely to be found amongst skilled or semi-skilled workers, married men and elderly women. It is therefore likely that a batch-producing general engineering plant using mainly skilled labour would benefit greatly from the sociological circumstances of G.T.

Naturally G.T. is no substitute for good motivational management, but the Hawthorne Experiment has demonstrated how groups can be motivated to increase productivity considerably without undue pressure and better morale than before.

Fazakerley (111) claims that in a number of G.T. installations a marked lack of group feeling is apparent and gives three reasons:

- alternative reference groups
- physical placement of machines
- the low degree of commitment to work as an activity

To form new groups, the old groups have to be broken up and a considerable period of time and some degree of labour turn-over may be required before new primary groups based on G.T. cells will develop. Also as mentioned previously, adequate face-to-face contact is ncessary to maintain a primary group. It is easy to violate this principle during actual layout design by bad placing of machines, shelving, gangways etcetera.

The low degree of commitment is a factor which is difficult to counteract, but it is likely that the development of an ordered, cell-based shop will assist in this area and that over a period of time an improvement in morale and job satisfaction will lead to a greater commitment to work.

Fazakerley discusses the human problems involved when G.T. is introduced as:

i) uncertainty and insecurity felt by employees affected by the innovation

ii) the lack of understanding at management level of the principles behind G.T.

iii) the lack of group feeling within the cell.

iv) the collapse of indulgency which accompanies many innovations.

v) the difficulties surrounding the evolution of a satisfactory wages system.

A radical change such as G.T. is bound to cause a lot of anxiety, more so amongst management than amongst operators. As Ranson puts it, "departments are run as little empires" and a whole list of potential problems become immediately apparent to departmental heads as G.T. is put forward, such as a possible reduction of the "empire", a fear of not being able to cope with the new technology, a possibility of loss of status, a potential clearing out of "skeletons", and even the loss of job due to redundancy in the general re-organisation. Foremen are particularly affected since they have to change from single-process technologists to multi-process managers. Often foremen have been appointed on the basis of their technical excellence in the particular section which they control, They feel that they would be unable to cope with the problems of other processes. The only answer is frequent consultation with managers and unions alike well ahead of time, the drawing up of a suitable training scheme, and a general "amnesty" for all members of personnel as their departments' malpractices and shortcomings become apparent during the analysis stage.

"The collapse of indulgency" is a closely related aspect which is likely to cause problems. Fazakerley refers to such things as "legal fiddles" and "gravy jobs" which will be discovered and discontinued during the implementation. This is likely to cause considerable resentment.

There will also be a fear of loss of earnings and a suspicion that the project is a plan to reduce real earnings. This can only be overcome by letting operators "share the cake", i.e. any improvements must be shared by management and operators.

Williamson (4) discusses the growth of engineering plants from the small workshop of the 19th century to the engineering factory in the 20th century and concludes:

> "If such an effective organisation (the small workshop) were to be increased in size, a parallel would have been drawn with biology, where the cells of a living organism do not themselves grow in size, to form one big cell, but duplicate themselves as the organism grows. When abnormally large cells do occasionally form, it presages cancerous growth, and usually results in the eventual death of the organism".

This somewhat emotional anology and conclusion appears to represent to a great extent what has happened to present day batch producing plants.

Williamson presents his case for a cell layout in terms of communication problems in a big plant making it impossible to control efficiently. He quotes the example where drawings do not contain all information and a considerable amount of know-how is held by individuals. As the organisation grows it becomes increasingly difficult to harness this "know-how" and ensure the efficient transfer of correct data, through the hierarchy.

If management were concentrated in specialised manufacturing cells, it could be ensured that the know-how would be shared by one closely knit group of people and would become less vulnerable to personnel changes. Williamson further confirms that the optimum size of a cell is 6 to 10 people.

Revans (112) confirms this argument and derives the conclusion that with the growth of an organisation serious communication problems exist. He sees the problem as one where too many people handle different facts about the same working situation resulting in disorganisation. The term "a tendency to vertical disruption" is coined by him describing this phenomenom, where size explains the degree of dilution of the manager's ability to take decisions. The cell system of manufacturing must counteract this tendency and help to solve one of the engineering industry's problems.

Closely allied to this is Revans hypothesis that "human relations in the factory depend upon the extent to which we perceive the work to be economically and effectively arranged. Where this is not so, discontent will arise and it may eventually break out in a dispute". Again G.T. provides the answer since it will, if organised properly, provide this ordered and effective work arrangement in which work can be done with a minimum of disruption and frustration.

Other, closely related reasons for improvements in labour relations are listed by Burbidge (113). A small group of men work closely together with simple, clearly defined goals. Inspection can be delegated to the cell, which would be difficult in a functional layout shop and hence each group can take full responsibility for product output and quality, leading to job enlargment due to wider responsibilities and the possibility of group decision making. The independence of each cell results in less need for co-operation with other sections and hence reduced stress across the company as a whole.

2.5.4. PRODUCTION PLANNING AND CONTROL

In a G.T. environment production control becomes one of the most critical areas of management control. In order to operate cells efficiently, it is imperative to schedule the work carefully in the right sequence.

The reasons for this more rigid control are as follows:-

- one of the objectives of G.T. is invariably the reduction of setting time. In order to achieve this, parts must be scheduled in the correct sequence to minimise change-over time. Often some degree of "technological scheduling" is required.
- a small cell is much more vulnerable to random fluctuations in work-load than a large machine shop and advance loading of the cell and capacity balancing is required so that a reasonable capacity balance is obtained. It should be remembered at this stage that G.T. will inherently simplify the production planning and control requirements, by treating a cell as one machine from a loading point of view, thus reducing most parts to single operation components.

(a) Inventory Control Systems and G.T.

Many batch producing plants control their ordering system by a simple inventory control system, where, once parts are loaded into stock, a record of outgoing stock is maintained, and when stocks drop below a certain "re-order level", a new batch is ordered on a lead-time such that when existing stocks have fallen to a minimum safety stock, the new batch will be received in store (114).

Inventory or stock control systems of this type, are generally based on a batch size known as Economic Batch Quantity (E.B.Q.) which is that quantity which balances setting and ordering cost with stock holding cost to minimise overall batch cost.

In view of the common use of this system it is necessary to briefly note why this technique of ordering is not acceptable in a G.T. shop.

Burbidge and Duckworth (115) both condemn the E.B.Q. as a means of batch production control and state quite categorically that it is not acceptable for production control in a batch production plant. From a G.T. point of view it is particularly unsuitable, since it inherently calls up a random pattern of batch loading. Batches are only very indirectly governed by the demand pattern and batches are called up, not to suit assembly requirements but in response to specific stock levels. G.T. necessitates that requirements are calculated in detail and batches arranged to suit these requirements to a specific loading sequence to minimise change-over times.

With a random call-up of components it is not possible to plan loading sequences in this manner.

Secondly the E.B.Q. by its random nature produces capacity fluctuations. In a large machine shop, these can be absorbed by balancing the random pattern over a considerable number of machines. The use of buffer stores (progress stores) helps to overcome the problem of capacity balancing by providing a pool of work for each type of machine. Since two of the objectives of G.T. are rapid throughput time and low work-in-progress, the use of buffers to balance random fluctuations caused by the stock control system can clearly not be accepted.

(b) <u>Period Batch Control System</u>

Another popular production control system is the period batch control i.e. single phase-single cycle ordering system.

The concept is exceedingly simple: for each production period (week, month, quarter or other suitable time period), the exact requirements for each component are worked out to fulfil assembly or sales requirements, and batches are loaded covering this requirement only (with possibly adjustment for expected scrap and spares). For each period a production requirement list is drawn up and batches generated accordingly.

Clearly if the same mix of products is manufactured during every period, the period requirements list will not change from one period to the next. Even where a changing product mix is involved, whole sections of the period requirements schedule may remain unchanged in sequence and only change in quantity; clearly it is a relatively easy matter to compile a prepared component loading list and only adjust quantities for each period. Also, if it is assumed that the shop is only called upon to produce assemblies or goods within its normal capacity limits over every period, the period batch control can easily ensure that capacity balance is obtained during each loading period.

The period batch control system therefore seems to satisfy the major requirements of a G.T. system.

Burbidge goes even further than this and states the definite requirements for production control in a G.T. system as follows (26):-

i) a single-cycle ordering system must be used for cell-made parts.

ii) a high order frequency (short cycle) must be used.

iii) with standard products, a standard machine loading sequence is preferable, the different parts being loaded on the machines in the same sequence in each successive cycle.

The high order frequency is important to reduce work-in-progress and finished parts stock, especially since single-cycle ordering generates fundamentally higher finished part stock than a stock control system. This aspect of single cycle loading is explained further below:

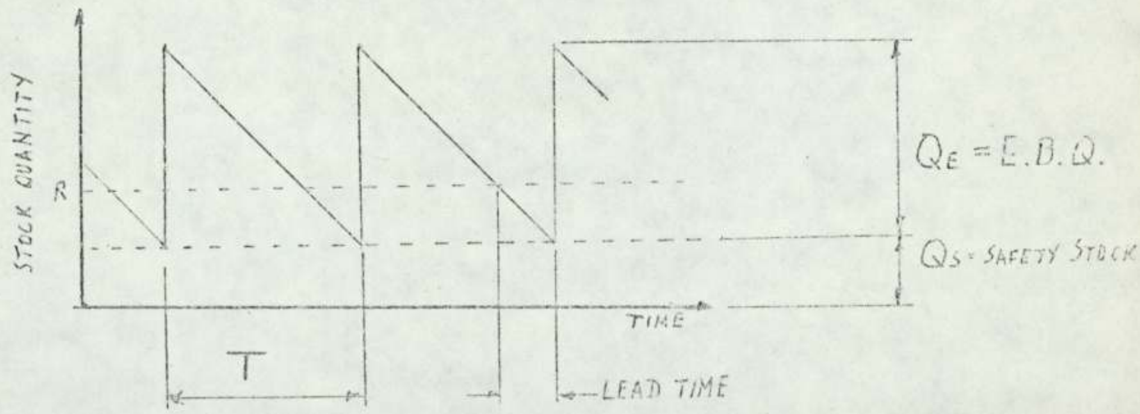
Burbidge accepts that single cycle scheduling using short cycle times is often only feasible in a G.T. environment where the production system is organised in such a manner that small batches can be accepted. He further claims however (113) that "it is accepted today that period batch control is an essential ingredient for successful group technology applications" (where period batch control is synonymous with single-cycle ordering).

(c) <u>Stock levels in Stock Control and Single-phase, Single Cycle Control</u>

As mentioned previously, it can be shown that Stock levels in single cycle control are fundamentally higher than in stock control systems.

The comparison is easiest explained by means of simple stock movement charts.

In a stock control system ideal stock movement of finished parts takes place as follows:



T is the usage time for one batch.

At re-order level R a new batch is ordered which ideally arrives in store when stocks have fallen to the safety stock Qs where T is the manufacturing lead time of the next batch.

Quite clearly

Average stock $S_{AE} = Q_S + \frac{1}{2} Q_E$

The total average stock for the plant will of course be

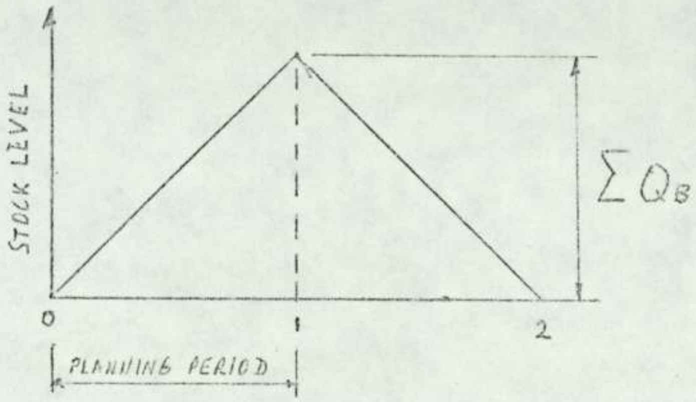
$$S_{TAE} = \sum Q_S + \frac{1}{2}\sum Q_E$$

(d) Stock level in a period batch control system

In a period batch based system, assuming one assembly product only, all parts are made over a period prior to the start of the assembly period. When all parts required for this period are in stock, assembly can commence and stock is progressively drawn out of stock in kit form over the assemble period. For capacity balance, say, one month assembly period must tie up one month of shop capacity and the total lead time must be one month plus throughput time plus kit marshalling time.

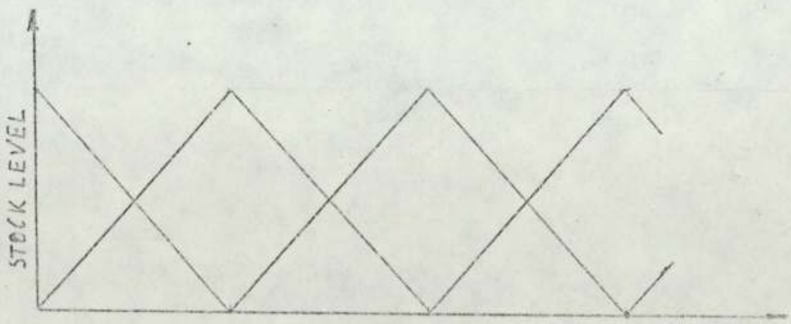
The stock situation for random loading, and ignoring kit marshalling time, can be shown diagramatically

One cycle:-



$\sum Q_B$ is the total parts requirement for one planning period.

For several cycles:-



Clearly the average stock holding at any one time is $\sum Q_B$

For a comparison of period batch control and stock control, equal batch sizes should be assumed to give an equal manufacturing cost basis.

In that case

$$Q_E = Q_B = Q$$

Thus in inventory control

$$\text{STOCK} \quad ST_{AE} = \Sigma Q_S + \tfrac{1}{2}\Sigma Q$$

and in period batch control

$$\text{STOCK} \quad ST_{AP} = \Sigma Q$$

$$\text{IF} \quad \Sigma Q_S < \tfrac{1}{2}\Sigma Q$$

$$\text{THEN} \quad ST_{AE} < ST_{AP}$$

Generally the safety stock would be less than half the batch quantity and hence, where the above simple relationships apply, a stock control system will provide a lower stock holding than a period batch control system.

In practice this is not necessarily so, since the inventory control system does not allow as accurate control as the period batch control system.

There will always be a great number of parts which fluctuate wildly between their control limits. The risk of Obsolescence on declining products is high and since E.B.Q.'s are not generally re-calculated on a continuous basis, there may be a considerable number of parts which are stocked, much larger than planned in the E.B.Q. calculation.

There are three methods in which stocks in a period batch control system can be reduced, all of which apply to single cycle control only and cannot generally be used for stock control systems:

(i) schedule work over the planning period on a Pareto basis to load high value parts later in the planning period.

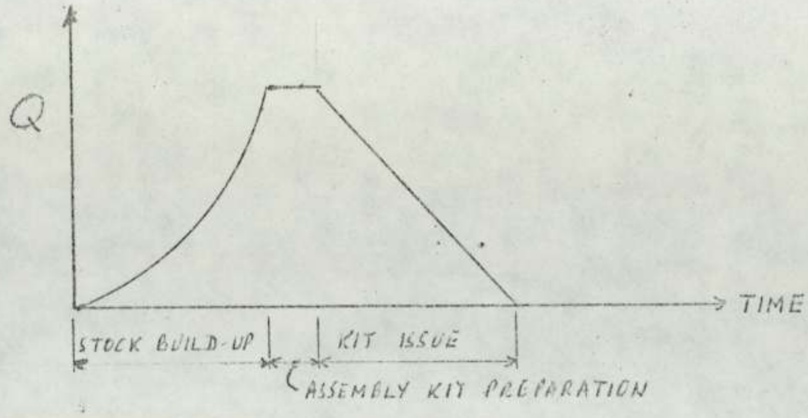
(ii) in a multi-assembly plant, identical assemblies can be batched together and parts produced for specific batches of assemblies. This has the effect of apparently reducing the planning period and hence reducing the average stock holding.

(iii) period batch control allows the use of "technological scheduling" where similar parts are grouped together using common set-ups. This reduces the set-up time per batch drastically and allows the processing of small batches and hence short planning periods.

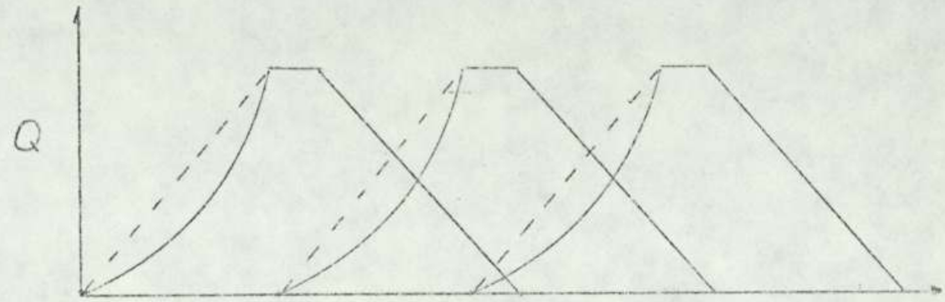
(i) Schedule in Value Order

By scheduling in value order and producing the most expensive parts last, a stock pattern as shown below is achieved:-

For one cycle:-



For several cycles:-

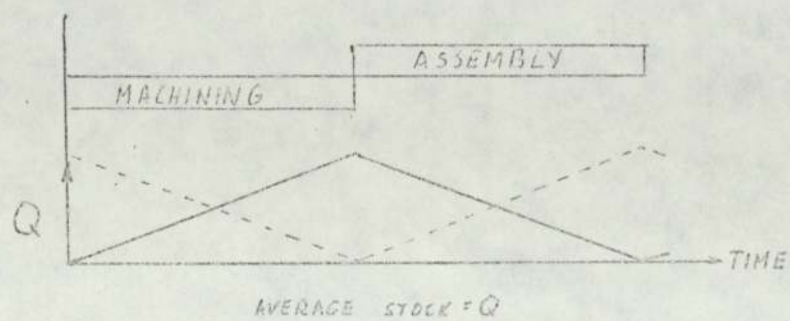


The dotted line shows the equivalent stocking pattern not using a Pareto based scheduling system. Clearly a considerable reduction in stock value takes place by suitable scheduling.

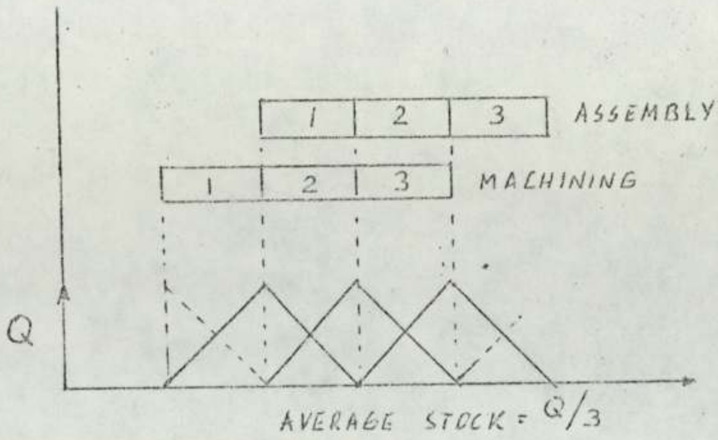
(ii) Scheduling for Assembly

This is easiest understood using the concept of capacity balance, ignoring the assembly kit preparation time.

Stock pattern without assembly scheduling time



Stock pattern with assembly scheduling into three batches



It should be noted that this does not affect batch sizes since the same quantities of parts are produced at the rate of only one batch per period.

(iii) Group set-ups

In a company producing a wide range of parts for a great number of different assemblies in small quantities economic batch size may dictate batches which cover long assembly periods such as 6 to 12 months ahead.

Two problems arise if it is attempted to maintain economic batches by using long assembly cycles:-

- the fixed cycle ordering system depends on a firm order book and assuming a 6 months planning cycle with assembly batching resulting in a three months lead time, a nine month firm order book must be available at any one time. This is in most cases not acceptable, and even if it were possible to maintain a 9 months firm order book, it could well be subject to changes, modifications and cancellations as the customers' situation changes over the months.
- assembly batching means that similar machines must be grouped together in any one planning cycle. That would mean that delivery times would be fixed up to 12 months ahead by production constraints. This would certainly not be acceptable to the customer. From a marketing point of view, an order cycle as short as possible must be aimed at.

The practical solutions to cut the planning period are:

- to accept the penalty of increased setting cost and offset this against the saving yielded from improved control, reduced absolescence and increased labour efficiency.

- to introduce group set-ups where families of parts are produced on one set-up, spreading the set-up cost over several batches of components. This is only really feasible in a Group Technology environment since in a functional layout shop the flow constraints between operations are such that the control of group set-ups over several operations is not feasible.

In summary it can be stated that to get a reasonable stock holding with acceptable manufacturing cost in a single cycle control system, the following parameters must be maintained:-

- the planning period is the same for machining and assembly.
- the order cycle (i.e. batch size) is equal to one planning period.
- parts are scheduled in cost order starting with low cost items.
- within a planning period like assemblies are grouped together.
- high cost parts are produced on group set-ups.

(e) Technological Scheduling

As stated earlier, it is necessary to schedule parts in such an order that change-over times are minimised. There are several ways of achieving this aim.

If a complex part set-up is used, the problem is easy. It is only necessary to group all parts together which are covered by each set-up in turn and load components within any one set-up in any convenient sequence. The only loading criterion is to ensure that all parts within a family set-up are completed before the next complex part is set-up. This approach is used successfully at Ferranti (31).

The complex part approach is only suitable for one machine as a rule, and if this technique is applied to a cell it can be used where one machine has very much greater basic set-up times than any other machine in the cell. Often this situation exists in a turning cell where a high set-up turret lathe is supported by low set-up machines.

It is possible to draw up a change-over matrix of change-over times between any two parts and calculate an optimum loading sequence, minimising change-over cost using mathematical techniques such as linear programming.

This approach has in the past been suggested by PERA, but is only acceptable for a small number of parts and constant loading pattern to justify the effort involved.

(f) Overall Machine Shop Scheduling

In a batch production shop it is a considerable problem to schedule and progress work from operation to operation through the shop. Considerable progress effort is required and a number of techniques of lead-time predictions are applied, one of the commonest probably being the "one operation-one week" rule where one week is allowed for the completion of each operation.

More sophisticated systems use a Gannt-chart-type scheduling board or computer assisted scheduling. Both these techniques require operation-by-operation progress feed-back to update the data used to schedule the shop.

In G.T. the problem of scheduling is greatly simplified:

- each cell can be treated as one synthetic machine and thus all parts produced in cells can be treated as single-operation parts reducing machine progressing to negligable proportions. It is only necessary for production control to issue batches at the right time and monitor the output of each cell to record completion.
- the lead time of a cell and in particular a flow-line is very short and hence much more predictable. Lead time can therefore be closely specified.
- if single cycle ordering is used, it is only necessary to issue a loading list for each period in advance of the standard lead time and "tick off" receipts against each period list. A complete list of "ticks" against a list indicates that all parts required for the period concerned are completed and such practices as "shortage-chasing" are virtually eliminated.

Within each cell the work can be subsequently scheduled on a small scale. Varying degrees of work are involved depending on the nature of the product cell and the work-flow.

In a flow line it would be normal for production control to issue batches in the correct sequence for machining and no further scheduling is required since the sequence of operations is self-determining. In a cell, some degree of inter-cell scheduling is required, especially where a more complex pattern of cell work flow exists. In most cases the size of the cell, coupled with the limited variety of work make it possible for the cell leader to schedule the work.

In a complex cell, a cell scheduling clerk may be used for detailed inter-cell scheduling.

One clerk may well cover more than one cell and the total work-effort would still be much less than in a conventional machine shop.

Some companies (e.g. Ferranti) have found it beneficial to use computer assistance for internal cell scheduling, but in most cell systems this degree of involvement ought not to be necessary. A problem with computerised cell scheduling is the long delay period for data processing in relation to the short throughput time of the cell. It is likely that, unless on-line control is used, computerised scheduling may well increase throughput times rather than reduce them.

(g) Capacity balancing of cells

The balancing of capacity is more critical in a cell than in a functional machine shop. The latter uses buffer stocks to balance capacity and the greater number of machines allows more flexibility.

Two types of capacity balance must be distinguished:

i) Static Capacity Balance

The term "static capacity balance" is used here to refer to the overall balance of capacity for all machines over an overall production period (e.g. one month). It is necessary that work for cells is selected such that a reasonable overall average machine utilisation is obtained and that the total capacity requirements of the family of parts is met by the machines in the cell. Static capacity balance is generally established during initial cell design when families of parts are allocated to individual cells. Where the product mix or volume change from period to period, repeated capacity checks will be required to ensure that an adequate static capacity balance is maintained. It is generally not necessary to periodically check capacity on all machines in each cell. A cell is likely to have one or two key machines (or machine types) which are most highly utilised, and if the overall component mix remains approximately constant, a periodic check on the key machine load alone will test the cell capacity position.

ii) Dynamic Capacity Balance

Even if the static capacity balance of the cell is adequate, severe capacity problems can result from the method of loading parts into the cell. If the production content mix for the range of components varies across the items scheduled for each cell, it is possible that during sections of the production cycle certain machines become severely overloaded and other sections greatly underloaded.

Where floating labour is used, this problem can be greatly reduced by channelling labour into specific overload area. Where a cell is expected to cope with several families of parts, this approach may not be acceptable. One can visualise, for example, a case where gear blanks and other disc type components are produced in one cell, where gear blanks are sufficiently similar to be loaded together for part of the production cycle followed by other parts for the remainder of the cycle.

Depending on the length of the production cycle, either a poor gear cutting machine utilisation or substantial buffer stocks would have to be provided.

A number of solutions to this problem are possible:-

i) split a cell into a number of rough sub-groups and feed several families of parts in parallel.

ii) attempt to form tooling families which accept a good spread of cell component types in each set-up. This may not be easy, but where possible, provides a useful solution.

iii) accept buffer storage at certain points of the cell or flow line.

iv) use floating labour in conjunction with the above solutions.

A capacity check can be undertaken by listing all batches for a production cycle and listing cumulative machining hours for cell components. A survey of comparative cumulative load on each machine would indicate particular capacity bottlenecks. This technique would lend itself well to data processing by computer. There is a considerable work content in this analysis and it lends further strength to the argument that in a reasonably constant production mix situation standard loading charts should be used which are marginally modified from period to period. This would stabilise the dynamic capacity position, and only with major production mix changes would further checks need to be undertaken.

2.5.5. WORK STUDY AND INCENTIVES

When introducing G.T., payment schemes must be considered from three points of view:

i) which incentive scheme is suitable for a cell system of manufacture?

ii) how can the anticipated increase in productivity be fairly shared between labour and management?

iii) how will varying rates affect labour flexibility?

Turning to the first point, little has been written to date regarding incentive schemes and G.T. Individual incentive schemes are generally used in the engineering industry and there is often a wish to continue these to avoid labour problems in the introduction of G.T.

Individual incentives can however cause problems in terms of an excessive number of bookings and also with different rates for different jobs where floating labour is used. Group incentives come to mind and are no doubt worth considering, especially with regard to the ease of bonus calculation. In a group incentive scheme it is merely required to log the output per week of each cell and pay according to actual output compared with a standard.

Fazakerley (111) has considered the problem of group incentives and observed that there are considerable problems where these were used. It is claimed that in two schemes good results were achieved, where:

"a) there was homogeneity of task and skill in the group.

b) the men had had some say in the membership of the group, and had agreed to the system prior to its implementation.

c) the men were compatible on grounds of personality".

It would seem that a system of fixed or semi-fixed pay-rates such as measured day work may well supply the answer by maintaining individual incentives but allowing greater flexibility.

Turning to the second point it must be recognised from the onset that, if productivity improvements are to be gained, operators must be given the opportunity to share the savings with management. A suitable productivity agreement should be agreed. Management can simplify the procedure of such a scheme by accepting existing allowed times to be permanent, so that labour are rewarded in any productivity improvement by proportionately increasing wages.

Whilst this appears to be a high level of incentive, it must be remembered that overheads may be two to four times direct labour cost, and where increased output can be sold, virtually all overheads may be considered variable so that the gain of management would be very much greater than the gain to operators.

To guard against abnormally high earnings in certain areas it can be proposed to peg an individual ceiling bonus and to pass any excess into a common pool to be shared out on a group or overall shop basis.

Thirdly, a problem exists where different basic wage rates are used. G.T. demands a degree of floating labour and where operators on different machines have different wage rates, floating labour is unlikely to be acceptable. Furthermore there may be claims that operators who can operate more than one machine type should be paid on a higher basic rate than operators who only operate one machine. These problems can become quite complex and job evaluation may provide the only plausible answer.

Arn (116) has devised a job evaluation based measured day-work type of system which effectively develops a variable day-rate incorporating such factors as job evaluation, personality evaluation, seniority and experience rating, quantity performance rating and quality rating. Whilst the system is fairly complex it provides a sound basis for a payment scheme (Fig 22). By an ingenious method of using two graphs for performance evaluation, it is possible to balance the quantity rating with the quality rating to get an optimum assessment for different situations (Fig 23).

3.0. A FEASIBILITY STUDY FOR A G.T. PROJECT

3.1. INTRODUCTION TO THE PROJECT

During summer 1971 the Bentley Engineering Group Ltd., Leicester were introduced to Group Technology when the Group Managing Director advised the Group Production Engineer of a B.I.M. symposium on G.T. and requested that an engineer should attend. Following the appointment of the Joint Managing Director (Engineering) in the Bentley Group subsidiary Wildt Mellor Bromley Ltd., the Group Production Engineering Department took up discussions regarding G.T. application in this Company.

The Joint Managing Director decided to pursue this possibility and invited Professor Thornley of Aston University to make an initial assessment of the potential usefulness of G.T. in two of the three plants of Wildt Mellor Bromley Ltd.

Professor Thornley's major conclusion was:-

"From the experience gained during the visit and from past experience in other similar companies there is no doubt that Group Technology can be applied in the Leicester Factory to the advantage of the company. Some problems may be encountered with regard to the methods of planning the work through the cells and the methods of payment systems to be employed. These however are not insurmountable and with a little thought will be overcome".

On the strength of this report the authority was given to proceed with a feasibility study in December 1972 and the author was seconded to Wildt Mellor Bromley Ltd., on a full-time basis and some months later transferred to the staff of this Company.

The plant concerned was the Aylestone Road plant of Wildt Mellor Bromley in Leicester which was considered to be much more suitable for G.T. by virtue of its wide product mix of inherently similar assemblies and its particular manufacturing and organisational problems.

3.2. WILDT MELLOR BROMLEY LIMITED, AYLESTONE ROAD PLANT

3.2.1. THE COMPANY

Wildt Mellor Bromley Limited (W.M.B.) are makers of circular knitting machines for industrial purposes. There are three plants, each with its own product range.

The Aylestone Road plant produces basically two types of "body length" machines, namely:-

Rib-type machines

Purl-type machines

in a variety of complexity and size, but with a high degree of commonality in terms of overall product features and component geometry. The machines are complex assembly units of capital value ranging approximately from £5,000 to £15,000 each. These machines produce patterned material for pullovers, dresses etcetera to suit different sizes and varying patterns. The material is knitted in the form of a continuous tube divided into suitable lengths for garments for cutting and sewing.

The plant capacity is in the order of 600 machines per year with a labour force of approximately 500 direct, 330 indirect and 240 staff employees.

3.2.2. THE PRODUCT

As mentioned previously, there are two basic types of machine produced at Aylestone Road:

(i) Rib Type (Fig 24)

These break down into several sub-groups of different models and sizes, namely:-

(a) RTR4, RTR2-4, RTR2-6

Sizes: 13" 14" 15" 16" 17" 18" 20" 22"

(b) RTR8, RTR8/E, RTR12

Sizes: 18" 20" 22" (RTR8 & 8E) 33" (RTR12)

The RTR8/E machine is distinguished from the RTR8 machine by its use of an electronic type pattern control, which is supplied by a specialist contractor.

(c) RTC, RTW

Sizes: 12" 13" 14" 15" 16" 17" 18" 20" 22"

(ii) Purl Type

(a) SPJ

Sizes: 16" 18" 20" 22" 30"

(b) SPJ/DE

Sizes: 22" 30"

The SPJ/DE machine again uses an electronic pattern control purchased by Wildt Mellor Bromley.

Within each major sub-group there is a high degree of commonality of structural parts, but most functional parts related to the knitting action are different for each size machine, even though they are geometrically similar across several sizes.

The total range of current parts is estimated to be in the order of 10,000 to 15,000, but the Aylestone Road "current" drawing files contain 26,000 part numbers, many of which are now obsolete or only required for spares requirements.

The Company is at present attempting to rationalise its product range by limiting the variety of machine sizes offered to the customer, and at the same time provide for a high degree of parts commonality across rib and purl machines.

From a G.T. point of view, it should be noted that the component spectrum of the new machine models is likely to be similar to that on current machines, and G.T. cells will not require any major changes during the change-over period.

A typical machine contains around 1,500 different parts, plus 2,000 to 3,000 specialist pressings and needles purchased from a sister Company in the Bentley Group. Of these machined parts, typically 500 are made in-house, 300 are sub-contracted and the remainder are proprietary purchased parts. An impression of the complexity of these assemblies can be gained from Fig 25 which shows specific areas of one machine, the RTR8 22", (though by no means the total assembly). There are certain "natural families" such as cams and large turned castings, but in terms of the total component spectrum these are in the minority.

A review of the component range in a spares catalogue does however give the impression that the majority of parts are likely to fall into well defined families of parts.

The overall sales pattern of the plant is well known, certainly up to twelve months ahead and is quite firm for 6 to 9 months ahead.

The sales forecast works on a basis of firm orders and Agents' allocations and the order book is such that the greater proportion of machines are covered by orders for up to 18 months ahead.

Whilst the product mix varies quite substantially over a period of years, the fundamental similarity of machines is such that this affects the component mix only insignificantly from a processing and capacity point of view.

3.2.3. THE PLANT

The Aylestone Road plant consists of several interconnected buildings, generally low-roofed with close stanchion layout, limiting layout possibilities. A number of additional buildings have been erected over the years to house various activities of the plant.

The plant is laid out in a functional layout with a small amount of grouping of a number of processes on a specialty component, the "cylinder".

The major machine shop sections are:-

Turning	3900 sq. ft.
Milling	5900 sq. ft.
Drilling	2800 sq. ft.
Grinding	3000 sq. ft.
Cylinder Production	7850 sq. ft.

Each section has its own progress area for work marshalling. One important feature is the low degree of small turning, caused by a sub-contract policy which provides for virtually all small turned components to be purchased from outside sub-contractors. A high degree of skill is generally applied in the shop and most simpler parts are also sub-contracted, amounting to about 35% of all part-numbers of machined components.

The plant covers a total area of 133,000 sq. ft. manufacturing area split approximately into:-

28000	sq. ft.	machining
42000	sq. ft.	assembly/test
64000	sq. ft.	services, stores etcetera. including offices, garage etcetera.

There are approximately 170 machine tools used in direct production.

Some salient production control factors are:-

Average batch size	3½ months usage
Average throughput time	13 weeks
Production Control staff	11% of direct labour

All direct personnel in the plant are skilled and paid on the same base rate plus incentive bonus. There is only one negotiating body consisting of the section shop stewards and the shop convenor.

Each section is supervised by a Foreman who is responsible for his section only.

3.2.4. THE PROBLEMS OF THE PLANT

Like in most Companies, there exist at present a considerable number of problems at W.M.B. accentuated by several circumstances which result in a particularly difficult Management environment. There existed during the period of the G.T. investigation a poor morale, soaring stock levels and decreasing profitability. No criticism could be made at the existing Management team who had been introduced fairly recently and had inherited a particularly difficult situation, which they improved as fast as was possible.

The key problem areas are those specified below:-

(i) Wide variety of parts required in small numbers

The component range for the type of knitting machine involved is very wide indeed, requiring small batches and an extensive production control effort.

Considering a typical content of 1300 machined parts per machine, a build of 600 machines per year and 4,000 machined part numbers, an average annual usage of 195 parts per part number is required. For an average batch, throughput time of three months and average batch usage time of 3½ months, 13,700 batches would be on the shop floor at any one time, with a batch issue of 58 batches per working day, of an average of 6 operations per part. The number of completed operations logged per working day would therefore be 350.

(ii) The complexity of the component range has led to considerable problems in production control. A rudimentary E.B.Q. approach is used in which batch sizes are determined by practice and experience to allow a reasonable spread of setting times.

(iii) Lack of Data

The Aylestone Road plant suffers from a poor level of information, which makes it exceedingly difficult for Management to make proper decisions.

(iv) Poor Morale and Labour Relations

The Aylestone Road plant had a particularly low level of operator and management morale at the time when the G.T. project was introduced. There was some degree of conflict between the older, established managers and the newly appointed ones. Managers in general suffered from a poor level of data and control and felt frustrated in their effort.

(v) Competitive Pressure.

Whilst there used to be a sellers market for the Aylestone Road product in the past, there was, by the time the G.T. project was started, a reasonable degree of competitive pressure, and profit margins tended to reduce as there was less opportunity to pass increased cost on to the customer.

(vi) High Inventory

As mentioned earlier, component requirements tend to be low at W.M.B. leading to batches covering long usage periods. An excessive finished part stock had been built up. Work-in-progress was high and this was caused by two factors:-

- The functional layout together with a high average number of operations per part led to long average throughput times, caused by the high cumulative progress waiting time.
- Production control problems accentuated the problem resulting in part-completed batches not on a shortage list having prolonged throughput times.

The inventory figures shown later in this report show the seriousness of this situation and the reduction of inventory was on its own a great enough incentive to pursue G.T. as a suitable manufacturing philosophy for this plant. Figs 26 & 27 demonstrate the work-in-progress problems in the machine shop quite clearly.

(vii) Poor Delivery Record

The Company found it increasingly difficult to maintain an acceptable delivery record, mainly caused by its inability to maintain its production programme. The programme specifies an output of 'x' machines per month and little regard is given to the increasing size and complexity of modern machines, requiring more capacity.

(viii) Production Bottlenecks and Lack of Capacity knowledge

Over late 1972 and 1973 there was a trend towards larger diameter machines, which changed the production mix to create bottlenecks in certain areas such as milling and drilling. Because of the lack of capacity planning, this had not been detected earlier and caused supply problems for the assembly shop.

(ix) Poor Incentive

A piece-work bonus system exists in the plant, in which allowed times are derived by observation and negotiation. Bearing in mind the strength of labour, the absence of rating during time studies and the age of many times, the level of allowed times made it easy for operators to earn their bonus.

A further problem associated with this situation is the tendency of operators to hold back job cards and component batches until they wish to book in the operation in question. This leads to increased throughput times and unpredictable completion dates.

(x) The Functional Layout

The shop is currently laid out on a conventional functional layout basis, resulting in the usual control problems, i.e. the whole factory is one complex interlinked manufacturing system, too big to control efficiently as one unit. The work-flow between sections causes considerable progressing and paperwork effort to keep track of individual batches. There is some difficulty in locating individual batches and of course batch completion dates are hard to predict. A number of progress chasers and scheduling clerks are required to keep track of work movement, and ensure a steady work-flow and machine loading. All of these problems coupled with high throughput and high cost penalty for producing small batches are of course typical for any functional layout shop trying to cope with a complex multi-product environment.

3.3. THE DECISION TO STUDY G.T. AT AYLESTONE ROAD

A number of factors appear to make the Aylestone Road plant particularly suitable for G.T. As indicated earlier the key factors of the existing manufacturing system are as follows:-

- Complex product with many piece-parts and low average usage.
- High batch sizes in relation to their usage but in keeping with E.B.Q. theory to balance set up times.
- A functional layout.
- Long through-put times.
- Increasing W.I.P. and finished part inventory.
- Poor morale [illegible].
- Inadequate control systems.
- Components appear to group into well-defined families.

There can be little doubt from a review of these factors in relation to the earlier discussion that this plant is ideal for G.T. introduction.

The key factor is the relationship of component to batch sizes. Unless batch sizes are reduced there can be little opportunity to make any real impact on finished part stocks. But, of course, to cut batch sizes without excessive cost penalty, a way must be found to cut setting up times. Without a cell system of manufacture coupled with technological scheduling it is impossible to make a real impression on set-up times and only expensive tooling and high-cost machine tools such as N.C. machinery are likely to yield any benefit. A G.T. approach is likely to yield greater benefits at lower capital cost and more simplified administration.

There appears to be a "classic" case for a need of the main features of Group Technology, embodying the cell system of manufacture, a single-phase, single cycle production ordering system and technological scheduling to solve the problems of this plant. Considering the particular relationships of part-usage, component range and component complexity it is difficult to visualise any other manufacturing system capable of coping with this situation with any degree of efficiency.

On the basis of these thoughts, terms of reference were set out by the G.T. team and presented to management in a preliminary report during May 1973 as follows:-

(i) To study the feasibility of using G.T. at Aylestone Road factory.

(ii) To make an analysis of the current manufacturing system and design a manufacturing facility based on G.T. principles.

(iii) To undertake such data collation and analysis work necessary to design the system (i.e. coding and classification, operation sequence, times, plant data, audit data etcetera).

(iv) To present to Management a full report of a cell layout together with a provisional loading pattern.

(v) The report to contain the information required to implement a pilot cell subject to Management approval.

(vi) To offer recommendations for support systems such as production control, process planning, work study, training and to discuss these proposals with heads of department concerned during the analysis stage.

(vii) Subject to Management approval to implement the G.T. system, to provide overall project control and guidance to all departments affected.

(viii) To subsequently study G.T. at the Bookham and St. Saviour's Road Plants.

(ix) The G.T. team will report to the Joint Managing Director or a person delegated by him, such as the Works Manager of the plant under investigation and will work under the supervision and guidance of Professor Thornley.

3.4. OBJECTIVES OF THE G.T. PROJECT

Following an initial review of the product range, a survey of the Company's problems and a sample coding exercise, a number of objectives were set, namely:-

(i) Simplify Management control.

(ii) Reduce progress inventory.
Reduce inventory in assembly kits awaiting shortages.
Improve delivery performance to the assembly shop.

A 50% reduction in work-in-progress and finished part stocks was set as an initial objective.

(iii) Reduce progress effort.

A saving of 4 to 9 clerks and progress chasers out of a total of 14 clerks current employed was set as a target.

(iv) Rationalise sub-contract policy.

(v) Revise methods as a basis for improved productivity.

The introduction of group tooling, power clamping and pre-set tooling was one of the initial aims of the study.

(vi) Improved working morale.

(vii) Reduce floor-to-floor time.

(viii) Form a design retrieval catalogue as a basis for standardisation and rationalisation work in the design department.

(ix) Ultimately study the total manufacturing/assembly system by

(a) Scheduling for assembly dates, i.e. eliminating finished part stores and using transit points between machining and assembly only.

(b) Scheduling sub-assembly to assembly to minimise sub-assembly stocks.

(c) Setting up group sub-assembly techniques and using sub-assembly cells to feed main assembly lines.

(d) Designing assembly flow lines fed with parts and sub-assemblies as already practised by machine tool builders. Such a system is currently being introduced by a competitor of W.M.B.

(x) Develop proper Management control.

The need for proper data preparation and maintenance and much tighter controls was recognised early on. There was naturally a need to change administration systems to suit G.T. requirements, and it was hoped at the time that the G.T. project would lead the way towards more adequate Management controls, and in particular, Production control.

3.5. PROJECT INTRODUCTION

3.5.1. PHILOSOPHY OF ANALYSIS.

There existed about 26,000 drawings in file and around 10,000 current parts were used at the time. It was felt that a total component range analysis would firstly be too expensive and secondly too time-consuming.

There was a danger that a prolonged analysis would result in a loss of management interest. It was therefore attempted to develop a reasonably accurate and quick method of analysis.

There were two fundamental approaches: namely production flow analysis or classifications and coding. It was decided to pursue the family formation using classification and coding techniques. The following reasons seemed to favour this approach:-

The poor level of data availability made it difficult to apply P.F.A. or C.F.A. without a considerable amount of initial work. For example, process planning sheets only indicated the production process (i.e. turn, mill, grind,) and not the machine tool involved. It would have been necessary to specify all machine tools for all operations on all current planning sheets.

One of the objectives of the project was to compile a design retrieval catalogue for design purposes. It was beneficial to use the data thus generated for both design rationalisation and cell design respectively.

The literature seemed to indicate that classification and coding is the favoured approach to G.T. in a general engineering, small batch manufacturing environment. There was insufficient evidence of successful applications using P.F.A. or C.F.A. and there was the case of the W.M.B. competitor Stibbe Ltd., who, following a C.F.A. based project, had not progressed as far in G.T. as one might have expected (66).

Having decided on the classification and coding approach, preference was given to a sample based analysis. A number of advantages were expected from this approach:-

· The analysis work would be greatly reduced and computerised data processing and other sophisticated techniques could probably be largely ignored. This would lead to a reasonably quick analysis at an acceptable cost.

The work done by various workers in work-piece statistics seemed to indicate that this was a valid and accurate approach.

Within the range of knitting machines built, all models tend to have a fairly similar product mix; there was therefore a fairly well defined component range without undue bias towards any one machine type.

The production planning process was particularly poor when the analysis was started and there was little information on future demand patterns for individual components. Only by taking a suitable sample and extending its quantities to cover an average yearly machine build programme could a reasonable assessment of annual capacity demands be made.

Once these key factors had been decided, the subsequent project stages were almost self-determining.

The main project stages could be laid down as follows:-

- Select a sample of components and calculate its equivalent annual usage.
- Select (or design) a suitable classification and coding system and test its usefulness.
- Code all parts in the sample.
- Split the sample into families.
- Break the machine shop into cells to suit these families.
- Calculate cell capacities and design the manufacturing system.
- Code all current parts.
- Based on code features for each cell derived from the sample analysis, split the total component range into families to suit each provisional cell.
- On a cell-by-cell basis:-

  Obtain component demand pattern.

  Obtain operation times.

  Obtain machining sequences.

  Verify the capacity balance.

  Make necessary changes and modification to "clean up" the flow pattern in each cell.

  Specify machines, labour and tooling requirements to establish the cell.

3.5.2. THE INITIAL PROJECT PLAN.

To provide an overall plan for the execution of the project and to demonstrate to management the extent of the work involved, a critical path chart for the feasibility study was drawn up. This was converted into a Gannt-type chart for issue to management (Fig 28).

In the event, the project plan was not adhered to as planned originally. Towards July 1973 a small plant became available and it was decided to set this up as a test plant. Consequently priority was given to the initial cell design and establishment which, in view of the requirement to lay-out and service a complete plant of 50 direct operators, took much more effort than had been planned for the first cell in the initial project plan.

3.6. SAMPLE SELECTION AND CODING.

As mentioned earlier, a sample analysis was chosen for the G.T. project for a number of reasons.

The selection of a suitable sample was given some consideration and two "typical" assemblies were chosen as a representative sample of the whole product range.

Other techniques of sample selection were not appropriate for a number of reasons:-

- specific period order input or stores receipt was difficult owing to the use of an E.B.Q.-based loading system where batches tended to cover long usage periods. There was thus a danger that any reasonably sized selection period could miss out vital components.

- random sampling of live specifications was difficult in the absence of a convenient list of current parts.

Furthermore, the existing production data availability was such, that popular components had to be chosen by selecting high-usage assemblies to obtain at least a reasonable degree of available data.

It will be recalled that W.M.B. Aylestone Road make two types of knitting machines, namely:-

Rib Type Machines	(RTR, RTW, RSC)
Purl Type Machines	(SPJ)

Machines within each of these two types tend to be fairly similar.

A typical knitting machine contains in the order of 1,500 drawings excluding proprietary purchased parts. It is thus feasible to construct a manageable sample representative of the total product range to a high degree of accuracy by taking a full set of drawings of one machine model, out of each of the two main types, rib and purl respectively.

The choice of selection is affected by the following factors:-

(i) The machines chosen should be produced in sufficient quantity and should be of sufficiently long standing for established cost records to exist.

(ii) Since the product range is rationalised at present, the sample machines should reflect the future requirement, and specifically the requirement towards the end of 1974 when the first cells could be implemented.

(iii) The complexity of the machines should adequately represent the average level of complexity, of the rib and purl range respectively.

A sample was therefore chosen as follows:-

(i) Rib type machine:-
Chosen sample machine:- RTR 8-22"

(ii) Purl type machine:-
Chosen sample machine:- SPJ 18"

The above sample represents the manufacturing requirements as follows:-

Current Model	Quantity per year (1973 forecast)	Proposed model (following product rationalisation).
RTR4 Plain	7	RTR4 Mechatape
RTR4 Mechatape	95	RTR4 Mechatape
RTR2-4 Plain	1	RTR8 Mechatape
RTR2-4 Mechatape	69	RTR8 Mechatape
RTW8	40	RTW8
RTC	27	RTC
RTR12	40	RTR12
RTR8	34	RTR8 Mechatape
RTR8E	30	RTR8 Mechatape
SPJ	159	SPJ Mechatape
SPJ (DE)	43	SPJ (DE)

Rationalised programme:

Model	Quantities	Represented by
RTR4 M	102	
RTR8 M	134	
RTW8	40	343 RTR8-22" Machines
RTR12	40	
RTC	27	
SPJ M	159	202 SPJ-18" Machines
SPJ DE	43	

It can be seen that it was possible to rationalise the total product range into two models only, with corresponding annual build quantities to be equivalent to the proposed annual build load based on the total product mix.

The analysis was therefore based on the assumption that W.M.B. build only the RTR8-22" and the SPJ18" machines respectively at annual build quantities of

RTR8-22"	:-	343 machines per year.
SPJ18"	:-	202 machines per year.

3.7. THE CODING SYSTEM FOR THE G.T. PROJECT

3.7.1. INTRODUCTION

Following a review of the literature on component coding and classification, the following coding philosophy was adopted:-

(a) Use a geometric code for family formation.

(b) Use a production data code for flow analysis and production systems design.

(c) Place all information on 80 column punched cards for data processing.

The literature seems to indicate that neither the geometric nor the production code would fully satisfy all requirements of the analysis and the dual approach was more likely to yield the most economical overall results. Within this general philosophy the code was developed in detail as follows:-

3.7.2. GEOMETRIC CODE

Again, following the review of the literature it was decided to use the Opitz code for this study. The reasons were as follows:-

(a) Previous exercises by other workers seem to indicate that, whilst criticisms have been levelled against certain aspects of this code, those who have used it for G.T. projects have generally found it satisfactory.

(b) This code is rapidly establishing itself as a European Standard.

(c) The code is readily available in book form from any book shop, and it is not necessary to engage consultants for its implementation. Also, sufficiently accessible advice is available from Universities or the Group Technology Centre if any difficulties are experienced with the interpretation of certain features of the code.

By management constraint the possibility of a specialist code installed by consultants was not acceptable in any case. Furthermore, an initial visual review of typical assemblies seemed to indicate a spread of component features which was likely to be consistent with the requirements of the Opitz code.

The literature seemed to indicate that it might be useful to include a second size digit (i.e. a diameter as well as a length code for rotational parts and a longest edge length and shortest edge for non-rotational parts) and this feature was included in the code.

Certain other minor changes to the supplementary code were also included to suit the specific requirements of the project (Fig 29).

3.7.3. PRODUCTION FLOW CODE

Once families had been selected by sorting on the Opitz code, it would be necessary to test the flow suitability of these families. For this it was necessary to list for a family in question the constituent parts together with the machining processes used and the operation and setting times; also important was the sequence of operations.. To define the recording of such production data, a number of conflicting requirements had to be weighed and a suitable compromise solution found. Current operation sheets (Fig 30) gave a broad description of the process, specifying generally a process, e.g. mill, drill, but occasionally a machine, e.g. 'W & B','Vero Drill'. It was initially considered to use an up-to-date plant list, code the machines and apply the correct machine code to each operation. This would have been a very time-consuming process and would have tied up much planning and supervision time. It is likely that the project as a whole would have lost considerable goodwill in the process.

The need for such detail was therefore reconsidered and after some thought a new point of view was developed, in which the production flow data is split into six broad areas, namely turning, milling, drilling, grinding (straight), grinding (circular), others.

This decision was justified as follows:-

(a) There is generally sufficient data in the Opitz code to define specific machines within each of the broad groups.

(b) The more complex the machine data, the more complex the flow patterns generated by the analysis. It is a problem of production flow analysis that it is difficult to establish the correct flow pattern for a family of parts if the flow is spread over a great number of machines falling into basically a small number of fundamental processes. The purpose of the G.T. analysis is, to recognise these simpler flow patterns and to use production engineering techniques to fit as many parts as possible into this pattern.

To obtain an indication of sequencing of operations, two methods are possible:-

(i) Free format, sequential recording of operations using a process code for different processes.

(ii) Fixed format recording of processes in which each process has a fixed field on a punched card. This is acceptable if a sequence code is applied indicating the position of each process within the flow pattern.

The second approach was chosen. This offered two advantages, namely economic data processing and better visual presentation of the data by listing processes in distinct columns. A sequence code was applied to each operation starting from 1 up to 9 denoting successive operations. Where one process was used more than once for a component, it was dealt with in one of two ways:-

If operations using the same process more than once were consecutive without intermediate processes, they were treated as one operation for sequencing purposes. Where they were not consecutive, the sequence code 0 was applied indicating that, based on current methods, the process was used more than once at different stages of the flow. The latter information level was not very high but it was felt that to use a more complex data processing technique to give a greater detail of sequence definition could not be justified.

From a flow line point of view, it was important to know if a process would be used more than once, even if the operations would be consecutive. If the process was used, say, twice in this manner and only one machine is provided, a bottleneck could occur since the total batch would have to be machined before the machine concerned could be reset for the next operation. To highlight such cases, a single-digit frequency-code was used to specify the number of times a process was used on each component.

A further important piece of information required was the operation time. Normally the setting time and operation time should be listed separately. However at W.M.B. no setting time records were kept, and recorded times were calculated by dividing the total batch time including setting time by the batch size. The recorded allowed times therefore included an allowance for setting. This was not an accurate measure since it implied that setting times varied with batch size. Furthermore, this could cause problems when the expected reductions in setting time would be accounted for in the cell design.

3.7.4. FURTHER CODED INFORMATION

Certain additional features necessary or useful for the analysis were included in the code. These are described below:-

(i) Number per machine

The quantity of each part required per machine was listed as a straight "no. off" using an up to 3 digit number. This quantity was required to calculate annual cell loads by multiplying the operation times by the number of parts per machine and multiplying the product by the number of machines built per year.

Since the annual build programme had been rationalised for this analysis to be represented by two sample models only, a close approximation of actual cell loads could be obtained by this method, using simple arithmetic.

(ii) Source Code

One particular area which had to be considered closely in the analysis was the current level of purchasing and specifically subcontracting. Parts affected had to be analysed to determine if current subcontract policies were compatible with the proposed cell structure and what changes, if any, would be necessary to establish this compatibility. A single-digit code was therefore applied specifying the source of supply, i.e. made in-house, subcontracted (group factory), subcontracted (outside supplier), purchased proprietary part.

The source code took account of sub-contract parts and high-lighted them for special analysis by including subcontract codes split into the categories, "fully subcontracted", "first op subcontracted", "last op subcontracted" and "intermediate op subcontracted".

(iii) Special Parts

Certain special parts peculiar to the knitting machinery industry or certain parts known to occur in clearly defined families were coded for convenience and easy segregation. This was thought to be useful in the analysis stage.

A simple one-digit code was used to pick out certain ones of these parts.

3.7.5. CODE SPECIFICATIONS (Fig 31, TABLE II).

(i) Geometry

Nine digit Opitz Code.

(ii) Production Flow Code.

This section was split into six sets of data, each one relating to one of the following machining processes:-

Turning

Milling

Drilling

Grinding, straight

Grinding, circular

Others

These sections formed data-sheet headings of a fixed format and information was entered for each part under each of these processes. Under each heading, the following three codes were listed as applicable:-

(a) One digit sequence code.

1 to 9 for op numbers (i.e. 1 = op 1, 2 = op 2, etcetera).

0 to indicate a process occuring more than once non-sequentially.

(b) One digit operation frequency code.

Under this heading, the number of times the process in question is used was listed for each part in turn.

(c) 4 digit operation time.

The actual operation time for each process was listed in 1/100 hours. Where the same process was used more than once on one part, the sum of all times for this process was listed.

(iii) Additional information.

(a) Quantity per machine

Three spaces were allocated allowing up to 999 parts per machine.

(b) Source Code.

A single digit code was used with the following numerical significance:-

0 = made in complete

1 = 1st operation subcontracted

2 = last operation subcontracted

3 = intermediate operation subcontracted

4 = fully subcontracted group plant

5 = fully subcontracted outside supplier

6 = purchased proprietary plant

7 = others

(c) Special parts Code

A single digit code was used with the following numerical significance:-

0 parts not special

1 cams, general

2 cams with circular stems (integral)

3 cambox and camplate sections

4 cylinders and dials

5 - 9 spare

(d) Additional Operations

A single-digit code was applied to highlight additional un-timed operations such as heat-treatment and fitting. The code significance was:
0 = no additional operations, 1 = fitting, 2 = heat treat, 3 = 1 + 2.

(e) Parts Identification (Drawing number)

Ten spaces were reserved for existing drawing numbers for parts identification.

(f) Machine Number

To separate the two sample machines, a one digit code was used to show the usage of parts on the sample machines. The code significance is as follows:-

0 = both models

1 = RTR 8-22"

2 = SPJ 18"

3.7.6. THE G.T. DATA SHEET

A standard 80 - column computer coding sheet was used as the basis for data collection.

The columns were marked out and labelled to make the entering of data easier (Fig 31).

A typical punched card is shown in Fig (32).

3.7.7. THE SAMPLE CODING

The process of sample coding started with the requisition of a full set of RTR8-22" machine drawings.

A very small sample about 100 components were chosen (every 10th drawing) and coded using the unmodified Opitz code with the inclusion of a second size digit (7th digit) and elimination of the accuracy digit. This very small sample indicated that the Opitz code could adequately cope with all machined parts and would give a feature distribution not unlike that found common throughout industry as demonstrated by Opitz (Table I).

At this stage it was decided not to consider certain parts such as sheet metal parts and springs which were not at present produced in the machine shop.

There were relatively few problems in interpretation at this stage and it was decided to code the total project sample without further code changes.

The retrieval of operation times caused some problems. There were basically two time records.

(i) Allowed times.

(ii) Actual times.

Allowed times were those times allowed for the operator for each operation and formed the basis of the incentive system.

The allowed times were made up as follows:-

$$\text{Allowed time} = \text{actual time} \times \left(1 + \frac{\text{bonus factor}}{100}\right)$$

where a bonus factor of about 570% was average. These times initially seemed fairly promising but two problems made their use unsuitable.

(i) There were glaring gaps in the records. To complete these would have required the analysis of individual rate-fixer's personal records on a job-by-job basis.

(ii) The allowed times were periodically updated to allow for wage increases by increase of allowed times. These updates had not been recorded conscientiously and a number of cards held values which were outdated. Again the help of rate-fixers to fix the current values would have been required with consequent time delays.

The second record was a batch-by-batch return of actual hours used on previous batches. Tests showed that in general the times returned for consecutive batches tended to be very consistent and there was a close correlation between allowed times and actual times. Both times included a variable setting time and in terms of accuracy there was no reason to suspect that the actual times returned were any better or worse than the allowed time. Generally there were several records of different batches. Thus an average could be taken and any inconsistancies could be queried with the rate-fixers. Furthermore there were less operations missing in these records and little estimating needed to be done. It was therefore decided to use averages of actual times returned as a working basis, which would reflect the current level of activity and would certainly provide adequate capacity in the cell layout.

For a number of operations it was not possible to find time records and on these the G.T. engineers estimated the times.

For this purpose all planning sheets and drawings were sorted in Opitz code sequence and estimates were made by straight comparison with similar parts. For a few components, the work study department were requested to return their estimates and for most items there was a close correlation between the two estimates. There were also cases where the work study personnel agreed that their estimate was poor and that of the G.T. engineers was more realistic. This interchange of ideas lead to considerable interest in the coding and the design retrieval project by the work-study department.

3.8. PREPARING THE DESIGN RETRIEVAL CATALOGUE

3.8.1. INTRODUCTION

From the time the G.T. project was first conceived, the need for a Design Retrieval Catalogue was recognised, and the establishment of a design retrieval catalogue was one of the objectives of the project.

Initially, it was only planned to provide a double print-out:-

(a) In Opitz code order, with the corresponding drawing number against the code.

(b) In drawing number order, with the corresponding Opitz code against each drawing number.

Work on the sample parts indicated that the Opitz code was suitable for the components in question for retrieval and classification. The concept of design retrieval was discussed with senior design staff and after some scepticism was accepted as potentially useful.

Aylestone Road have some 85,000 drawings, most of which are obsolete, but all of which could be called up for spares requirement. Approximately 15,000 current parts drawings are held in a file of about 26,000 drawings in numbered sets with alpha prefixes as follows:-

RTR	-	prefixed
SP	-	prefixed
W	-	prefixed
RS	-	prefixed
S	-	prefixed
Z	-	prefixed

Coded drawings (1 to 4 digit number prefixed by drawing size letter code A, B, C, D, E, F or G)

Whilst only about 60% of these drawings were likely to be current, any other selection of current parts would have been most time-consuming. It was therefore felt that it would be easier to code the 26,000 parts and eliminate obsolete parts at some future date when a computer print-out would be available listing all current parts. The additional work was considered to be reasonably worthwhile in any case since a number of non-current parts could be called up for manufacture to supply spares.

3.8.2. ORGANISATION OF THE CODING PROCESS

The project plan indicated that three months would be available to code these 26,000 drawings and staff planning was developed accordingly, assuming the following parameters:-

Average coding speed, 150 parts per man per day

Non-productive training period, 2½ days per man

Total time in the coding department for each man, 1½ months

Two apprentices were to be used at any one time, who would attend day release one day per week. Thus labour requirements were calculated as follows:-

Allowing for day release and monthly training, each apprentice would contribute approximately 24 coding days or 3,600 coded drawings over his 1½ months stay in the department. Over three months two apprentices at a time would code 14,400 drawings. A third coder such as, say, a draughtsman could contribute approximately 30 days per 1½ months since he would not go on day release. This third coder could therefore code 9,000 drawings over 3 months. Allowing for some safety margin, the following staff schedule was set up:-

Two apprentices changing over on a 1½ month basis

One further coder (i.e. draughtsman, planner, estimator) changing over on a 1½ month basis

One clerk to transfer codes and drawing numbers on to G.T. data sheets for data processing

One G.T. Engineer as supervisor on a part-time basis

The following procedure was adopted:-

- During the first two days, the coders were trained using actual component drawings as examples.
- After that period each coder was assigned to one set of drawings, i.e. RTR, SPJ and coded drawings for three coders respectively. Starting with the smallest size drawings, each coder would remove one drawer section full of drawings (approximately 100 drawings per section) from file, starting with the lowest numbers in the drawing size in question and working his way up through increasing numbers. Having completed all drawings of the smallest size, he would then move on to the next larger size. Since average drawing complexity was roughly proportional to drawing size, a gradual training and improvement cycle would be set up.
- The coders were equipped with rubber stamps with which an Opitz code box was stamped into the top right hand corner of each drawing, and the code was entered into this box.

- When a coder had completed a set of drawings, he would pass them to the supervising G.T. engineer who would check for accuracy and after checking pass the set to the clerk.
- The clerk entered the code and the corresponding drawing number on to the G.T. data sheets.
- A daily record of completed sheets was kept and recorded on a chart to check on progress and compare planned performance with actual.
- If the actual fell below an average of 150 drawings per man per day, the supervising G.T. engineer would code some drawings to maintain the average. The G.T. engineers would each choose one size of drawing with a specific alphabetic suffix to avoid confusion with the sets coded by the coders.
- The G.T. engineers specifically chose large drawings to:-

  (a) Code those parts where their greater experience would make them much faster than the coders, and

  (b) Leave sufficient small drawings for future coders to train on.

3.8.3. TRAINING FOR OPITZ CODING

Training for a coding system such as the Opitz system was a fairly easy process. The code is not very complex and most people can quickly understand it. Two things, however, are required:-

(a) The ability to read an engineering drawing

(b) A rudimentary knowledge of the common machining processes.

For all coders who were trained as part of the W.M.B. design retrieval project, the same training technique was adopted. This consisted of the following stages:-

First Day

(1) Introductory talk on Group Technology and classification and coding (approximately 2 hours).

(2) General description of the Opitz code; its format; the significance of each digit etcetera (approximately 1 hour).

(3) Teaching of the code for rotational parts (0, 1 and 2 parts only) (approximately 2 hours).

(4) Coding practice for the rest of the day on rotational parts only, using small size (relatively simple as a rule) drawings. The first 5 to 10 parts were coded in conjunction with the trainer. After that the trainee was left to code on his own, but encouraged to ask if he had any difficulties or doubts. A 100% check was made on roughly an hourly basis.

Second Day

(5) Teaching of rotational with deviation and non-rotational parts. Introduction to the sheet metal and plastics code. Interrupted by frequent reference to drawings and coding of example drawings in conjunction with the trainer (approximately 3 hours).

(6) Coding practice for the rest of the day on 3 to 9 class parts.

No doubt the most difficult aspect of coding over the early stages was the decision of the correct component class, based on length/diameter or cartesian co-ordinate length ratios. To ease this problem, special instructions were drawn up to simplify the decision making, in the form of a simple decision tree where the coder by simple step decisions worked his way down the decision tree until he came to the correct code. (Fig 33).

Once a coder was trained over two days, he was given sets of drawings and was left to code independently. Lengthy discussions amongst coders had to be discouraged, especially during the early days, since this tended to lose a considerable amount of time.

Bearing in mind that the timely completion of the coding was considered to be more important than the training of high quality coders, the personnel were instructed to ask if they had problems and not to spend too much time thinking about a component code. For reasons discussed in a later paragraph a 100% checking system was used, which picked up any mistakes made by the coders.

3.8.4. OBSERVATION ON THE QUALITY OF STAFF USED FOR THE CODING, AND MOTIVATIONAL PROBLEMS ENCOUNTERED

The initial estimate showed that approximately 26,000 drawings were to be coded, and as shown previously, it was estimated that using three full-time coders, including two apprentices and allowing for training and day release for the apprentices, the total task could be covered adequately within the planned three month period, if after training, a coding rate of 150 drawings per man per day could be maintained.

In practice, various useful observations were made which were taken into account during the second six week period.

For each coded drawing, the code and drawing number were recorded on to the data sheets, initially by coders and later by a clerk. A chart was drawn up to record the actual coding progress against the planned output of 150 per man per day ($7\frac{1}{2}$ coding sheets rounded up to 8 coding sheets per man per day with 20 code entries per sheet).

A separate row was kept for each coder to check individual progress. A cumulative total and a variance row was kept as well as a "G.T. make-up" row recording the coding efforts of the G.T. engineers towards reducing a negative variance. Since the programme time scale was considered to be most important, any adverse variance would, if at all possible, have to be made up by the G.T. engineers.

The chart was started after two days of training, and, not surprisingly, developed an increasing adverse variance. All three coders achieved a coding figure of approximately 50 per day from the third day, with only a small rate of increase for 1½ weeks. At this stage the coding rate was remarkably similar for the apprentices and the third coder, a 45 years old draughtsman with several years service in the Drawing Office.

Around this time the variance became alarmingly high and the G.T. engineers supervising the coding office were unable to spend sufficient time on coding to balance the variance. Some thought was given to motivation and the chart was put up on the office wall showing cumulative daily targets and achievements for each coder. These targets were approximately 10% in excess of the planned output. There was some loss in morale, especially for the apprentices who appeared eager and willing to do the required work quota but did not think that it was possible to do so. To provide a stimulus to them and to demonstrate what could be achieved with practice and determination, one of the G.T. engineers spent one day coding continuously at a good pace and without interruption coded 620 drawings within an 8 hour working period. (Discussions below will try to explain why this cannot be achieved on a continuous basis).

Towards the end of the second week, the coding rate was as follows:-

Coder A (apprentice)	150 per day
Coder B (apprentice)	100 per day
Coder C (draughtsman)	100 per day

Coder A tried to give an expression of eagerness and willingness. He tended to apply himself more diligently and since he also had at that time a slightly better grasp of the coding principles, he tended to patronise Coder B slightly. It was interesting to observe, though, that Coder A was the least accurate one and that the inconsistency of his errors seemed to indicate that mistakes were caused by excessive speed and not lack of knowledge.

At the beginning of the third week, a clerk was delegated to transfer the codes and drawing numbers on to G.T. data sheets, thus relieving the coders of this chore. An assessment of the coding accuracy at this stage was:-

Coder A	80 - 90%
Coder B	90 - 95%
Coder C	Better than 95%

This compared with a corresponding query rate, where coder C asked for the highest number of his codes to be confirmed by the supervising G.T. engineer, whilst coder A rarely had any queries at all and preferred to rely on his own judgement.

Around the middle of the third week, Coder B had a particularly simple set of drawings and at around 3.30 p.m. he proclaimed that he had completed 200 drawings that day and ceased work for the rest of the day. Coder A, who had completed close to 150 drawings by that stage, worked non-stop until just before shift finishing time (4.30 p.m.) and claimed completion of 200 drawings.

From that day onwards, Coder A and Coder B set their own daily target at 200 and achieved this target irrespective of the complexity of the work. The speed of work and length of breaks was matched by them to the degree of difficulty of coding of the particular set of drawings involved.

Since coding started on small size drawings, the increasing complexity of parts coupled with an approximately constant coding rate resulted effectively in a continuous increase in coding efficiency.

There was also an expected conflict between speed and accuracy. According to the Coders, the reason for their improved speed was the fact that they could:-

(a) Remember most codes without referring back to the code book

(b) Judge the proportions and hence the component class from the picture on the drawing, without having to calculate length ratios.

It was found however that the high speed caused an increasing number of errors, due mainly to two points:-

(a) Not remembering the codes correctly

(b) Overlooking certain component features

Generally the number of parts with a totally correct code in every digit was on average no more than 50 - 60% by this time.

Naturally this called for a 100% check by a coding engineer, which was however a preferable compromise and was accepted for the following reasons:-

(a) It ensured a high level of accuracy owing to 100% checking.

(b) It ensured the maintenance of a consistent standard within the conventions set by the G.T. engineers.

(c) It was overall the most efficient way of achieving the target, i.e.

It was estimated that to obtain an acceptable standard of accuracy, a coding speed of 100 to 120 per day could not have been exceeded. Thus to obtain a good standard of accuracy, the section output could have been only in the order of 300 to 350 as against the 500 achieved with poor accuracy (Coder C never exceeded about 100 per day and some thoughts on the reasons for this are given later). To code 150 parts to make up the target would have taken a G.T. engineer approximately half a day. Checking parts could be done in short bursts at a rate of about 10 seconds per drawing or in the order of one hour per day. Thus the overall gain of high speed with sacrifice in accuracy was considered sufficiently worthwhile. For the same reason no great pressure was applied to improve accuracy, though periodic "teach-in" sessions were given, where the more common mistakes and particularly misinterpretations of the code were explained to the coders.

The difficulty of constructive motivation can be considerable in coding and a good example can be given by contrasting the performance of the three coders.

There is no doubt that to most people coding as an unrelated activity is particularly unpleasant. After training and comprehension, it quickly develops into a largely clerical and mechanistic activity, which is boring and offers little job satisfaction. Furthermore it is unfortunate, that to learn and comprehend the code and to read engineering drawings with the speed required, it is essential to have a person who understands engineering drawings and has a certain level of knowledge above that of the average clerical worker. A further problem is, that coding in most instances is a purely temporary exercise done by people who are delegated from their usually much more interesting and rewarding occupations.

Where the work is directed by staff outside their own department, and where there is no long-term accountability to the coding supervisor, motivation becomes a problem. It is then up to the coding supervisor to devise motivational aids as best he can and to aim at maintaining as good and pleasant an office atmosphere as possible. The following list consists of some of the motivational aids which were considered by the G.T. engineers at W.M.B., some of which yielded some success.

(a) Set a target which is realistic and plot day-to-day progress for each coder. It is important that it is made clear that this is not a measure of ability or personal assessment, but that this is required by the supervisor to check on overall progress to ensure that he, the supervisor, is maintaining adequate project control. By giving each coder a distinctive set of drawings and counting the coded drawings within each set, a personal record is shown for each coder, but the supervisor can claim to be more interested in a particular set of drawings than in a particular person. The personal incentive will set itself up automatically between the coders, especially where coders from different areas and possible age groups are used, who will set up rivalries and tests of ability.

(b) Especially during the, say, first two weeks, it is necessary that the supervisor shows that he himself can achieve the target without difficulty. The technique adopted by the author was that he coded in short but highly concentrated bursts of effort, which allowed him to code, say, 200 parts per day whilst apparently not spending much time doing it. The danger is that the supervisor may be regarded as such an outstanding expert that coders believe it to be impossible to catch up with him. Here the answer is to point out (if applicable) the relatively short and limited experience of the supervisor and how the increase in speed is a natural result of practice and effort over a short period of time. Because of the temporary nature of the job, there is generally no way in which the supervisor can exert direct pressure to improve performance. If a spirit of competitiveness springs up in the department, this is generally the happiest solution and yields best results.

(c) It was found useful to keep the amount of control and supervision proportional to the target achievement. During the first two weeks, reasonably close control of discipline and working hours was kept to enforce a disciplinary level without which a good output during the early stages of practice is impossible. The discipline was relaxed once the coders achieved 200 components per day. An understanding was reached, that, as long as the target was achieved, limited regard would be paid to discipline.

The coding office was next to a fairly noisy machine shop, and whilst it was not very pleasant to work in, it drowned all talking noise so that coders could talk without disturbing anybody else in the office. A working routine soon established itself whereby 1 to 2 hour coding sessions when followed by discussions and talks amongst the coders, or coders going for walks through the plant or into the yard. It is interesting to note that the apprentices tended to work this way and had no trouble in achieving 200 parts per day, whilst maintaining a good working spirit. The draughtsman worked steadily without interruption, other than short tea-breaks, and only achieved 100 to 150 parts per day with increasing boredom. Especially during the afternoon, he was prone to day-dreaming with very little output.

(d) The limited experience resulting from this exercise seems to indicate that there are distinct phases of morale which must be recognised and treated in the correct manner.

3.8.5. FURTHER DEVELOPMENT OF THE OPITZ CODE FOR W.M.B.

As described earlier, the Opitz code was used for the sample codings with an unchanged geometric code and some minor changes to the supplementary code. The Opitz recommendations were accepted with interpretation of certain difficult components based on the judgement of the G.T. engineers. This was quite satisfactory for the sample analysis where the G.T. engineers were the only ones dealing with the information who were aware of the conventions adopted. As always, when such ad hoc conventions are developed, they are quite meaningful to the persons using the information, but when they have to be explained to others, some cases of illogic and difficulties with interpretation will arise.

A further difficulty arose in as far as the Opitz code explanation book did not give very detailed information on certain code interpretations and the examples shown do not necessarily cover the components encountered in the Company in which the code is applied. Typically these apply to the higher codes of the non-rotational parts such as 76, 77, 78, 64, 65, 66, where the examples and explanations are somewhat scarce.

Certain explanations do appear to be either illogical or not completely meaningful to the specific company in which the code is applied. A typical example is the convention used for minor deviations which are ignored on codes 60 xxx and 70 xxx. A number of these conventions were developed and noted during the sample coding stage.

During and after training of the coding staff, a list of all disputes and queries on which the G.T. engineers gave a ruling were kept, and some were entered in pencil into the Opitz book of explanations. After about four weeks, a number of problems became apparent and threatened to diminish the usefulness of the code:-

- The G.T. engineers disagreed on the interpretation of the code in certain areas
- There was a problem in handling sheet metal parts, some of which were coded as flat parts and others of a more complex nature were ignored completely
- There was some difficulty in deciding between rectangular bar, sheet and plate.

To resolve these problems, the G.T. engineers visited Mr. McConnell at the G.T. Centre, who, as the editor of the translation of the Opitz code and extensive user of the same over several years, was probably the best authority on the interpretation of the code in this country at that time.

The visit resolved some of the problems:-

- A mutual agreement was found on most aspects of code interpretation. Whilst on certain items the G.T. engineers did not accept Mr. McConnell's guidance because of their better knowledge of the overall spread of components and their wish to segregate these in a certain manner, they accepted most of the suggestions made, and on others benefited greatly from the discussion, which helped to put the difficult areas into a better perspective.
- The G.T. engineers were introduced to the G.T. Centre's sheet metal code. This code was far too complex for the limited amount of sheet metal work involved at W.M.B., but it prompted the G.T. engineers to draw up a greatly simplified sheet metal and plastics code.
- No useful guidance was obtained on the decision of sheet, plate or bar application, and this problem was re-considered by the G.T. engineers to find a simple workable solution. Initial investigations lead to the following observations:-

- At W.M.B. sheet material from about $\frac{1}{8}$" thickness upwards was generally called "plate".
- There is a tendency to use bright bar rectangular section where possible. Only a search through a wide range of planning sheets and purchasing records would have established the limits of this. As a short-cut to get a simple rule of thumb with a high degree of accuracy, a survey of the bar store was made and discussions with planning engineers were held. On this basis, it was established that for sheet and plate with a width of up to about 32 times the thickness, rectangular bar would normally be used.
- A survey of drawings showed that for decimal size thickness of up to 1/16" thickness, where the surfaces were not machined, these were in the great majority of cases sheet metal parts.

Based on these findings, raw material shape codes were developed as follows:-

2: Rectangular Bar

Any bar material with a width B less than or equal to 32 x thickness C. Up to and including 1/16" thickness, the thickness must be fractional (i.e. 1/32", 1/16") or the surfaces must be machined.

5: Sheet

Any material up to but not including $\frac{1}{8}$" thickness, where the width exceeds 32 x the thickness. Any decimal thickness material up to and including 1/16" where the surfaces are not machined. Any material where the thickness is given by a gauge dimension (e.g. 16 S.W.G.).

6: Plate

Any material of thickness $\frac{1}{8}$" or greater where the width exceeds 32 x the thickness.

All sheet metal parts were coded under the sheet metal code.

On the basis of the experience gained and the discussions, all conventions were entered into the Opitz reference book together with a set of coded drawing copies representing the more difficult components. This reference book represents now the Company standard and is held in the G.T. office for inspection by Company staff. Excerpts of this book are shown in Appendix I to demonstrate the kind of information included. The information added to the original text is underlined and the sketches added are shaded in grey.

Experience has shown that this book is extremely valuable to arbitrate in borderline cases and give a clear indication of the conventions applied within W.M.B.

Fig. 34, 35 and 36 show certain additions to the Opitz code to cover sheet metal parts and springs and plastic components.

3.8.6. THE DESIGN RETRIEVAL CATALOGUE

The coded data was transferred onto punched cards and Company data processing staff prepared the design retrieval catalogue which was in two parts:-

(a) A list of all parts with their code in numerical code sequence (Fig 37).

(b) A list of all parts with their code in numerical drawing sequence (Fig 38).

3.9. THE TOTAL PROJECT

3.9.1. TRIAL FAMILY FORMATION

The brief of this project was to develop an overall system of manufacture for the Aylestone Road plant, based on G.T. principles.

At this stage it is useful to recall the fundamental steps of the analysis determined from the literature in the previous chapter, namely:-

1. Classification
2. Family formation
3. Cell formation based on current times and component demand
4. Inter-cell flow analysis
5. Tooling analysis
6. Plan the management services

The classification and coding work had been done by this time and the next major step was the family formation.

Relatively little has been written about the methodology of forming families following coding work. Some degree of fundamental thinking was required to come up with a meaningful method of grouping parts. The thoughts were very much based on the work in the previous chapter, in which it had been concluded that for an initial grouping, only certain coded characteristics should be considered.

As indicated earlier, sample data had been collected including the Opitz code and production data for all sample parts on G.T. data sheets. The information on these sheets was punched onto 80 column punched cards and these cards were sorted on the Opitz code using a standard I.C.L. electro-mechanical card sorter:

(i) In strict numerical order based on the Opitz code

(ii) In numerical sequence on the Opitz, but using a different sequence of digital significance, in the order:-

1st digit	(Class)
6th digit	(Diameter or longest edge length)
8th digit	(Raw material)
9th digit	(Raw material shape)
2nd digit	
3rd digit	
4th digit	

5th digit

7th digit

The latter sorting sequence was chosen following a review of the literature and a basic consideration of the requirements of cell formation (See previous chapter). It would appear that a sort on this basis is likely to provide a more meaningful base for cell selection.

A simple tabulation of each print-out was obtained. Whilst the cards were sorted, the number of cards for each digit was recorded using the counting facility of the card sorter. (Table II). The data thus obtained was used as a basis to review the feature distribution of the sample, to form some thoughts of the potential usefulness of certain families.

In order to split all parts into a limited number of families for production purposes, it is necessary to review the frequency distribution of all component features and, with due regard to machine tool capacity, pull out the high-frequency features. The technique is similar to the philosophy of the Pareto analysis, i.e. a high percentage of all parts are likely to fall into a small number of families. Once these families have been drawn out, the remainder can be dealt with by either trying to integrate them with the chosen families or by excluding them from the G.T. principles.

Considering rotational parts only, these generally consist of lathe work. Lathes are split up initially by size and subsequently by length/diameter ratio.

As an initial starting point, it was decided to split parts by size as follows:-

0 to 2"	Small capstan, auto etcetera.
2" to 4"	Medium sized capstan.
4" to 16"	Large turret lathe, centre lathe.
16" +	Vertical boring mill.

A check on Table III (a) indicates that the great majority of all parts are made from ferrous material and all materials had been grouped together at this stage. There was little concern regarding materials at this stage, since by intelligent scheduling parts of similar material can be loaded together to minimise the swarf separation problem.

By accepting the size split indicated and reviewing Table III a, a percentage distribution or rotational parts within these size ranges was established as indicated in Table IV which formed the basis for initial cell splitting.

By considering the length to diameter ratio, the following additional rules were established:

Up to 2" diameter rotational parts are in the main made from bar (this was confirmed on the computer print-out). Bar components are generally made on the same type of machine (capstan, auto) with only minor regard to length. This certainly applies at W.M.B. where very long small-diameter parts are relatively rare, and those which occur are not machined along their whole length. The same argument does not however apply to all companies, and any hypothesis of this kind must be checked by reviewing the components in detail.

Accepting this argument as valid at W.M.B., it was possible to combine all 0, 1 and 2 parts up to 2" diameter in one family.

Similarly, all 0 and 1 parts from 2" to 4" and from 4" to 16" were combined. It was argued that these parts would be chucked and not machined betweencentres. All 2 parts from 2" to 4" were grouped as parts to be turned between centres.

These considerations resulted in the specification of the following rotational trial families:

1.	0, 1 and 2 parts	0 < diameter ≤ 2"
2.	0, 1 parts	2" < diameter ≤ 4"
3.	0, 1 parts	4" < diameter ≤ 16"
4.	2 parts	2" < diameter ≤ 4"
5.	2 parts	4" < diameter ≤ 16"
6.	0 parts	16" < diameter

A similar analysis was undertaken for rotational parts with deviation (Table IV). The coding exercise had indicated that many of these items could be included with rotational parts. So a similar split was applied:-

7.	All 3 and 4 parts	0 < diameter ≤ 2"
8.	All 3 parts	2" < diameter ≤ 4"
9.	All 3 parts	4" < diameter ≤ 16"

10.	All 3 parts	16" < diameter
11.	All 4 parts	2" < diameter ≤ 4"

For non-rotational parts, the same kind of size based analysis was used (Table IV).

Small non-rotational parts fall in the main into a 4" cube and can be split into

(a) Cams.

(b) Other parts.

"Other parts" are basically small milled, drilled, surface ground parts, whilst cams form an "obvious" family of functionally as well as geometrically related parts. These latter parts are small plate cams which actuate the knitting needle movements.

For larger items, most of these fell into the 4" to 16" size range, and here it was necessary to distinguish between different classes.

Flat (6) and long (7) parts can be handled by fairly light and small machines. Furthermore these parts tend to be the more simple shapes made from bar or plate.

Cubic (8) parts in this size tend to be the complex castings and require larger capacity machines.

Larger parts of all classes are in the great minority and can be split off for separate analysis.

The following trial families suggested themselves therefore.

12.	Cams				
13.	6, 7, 8 parts	0 < largest dimension ≤ 4"			
14.	6, 7 parts	4" <	"	"	≤ 16"
15.	8 parts	4" <	"	"	≤ 16"
16.	6 parts	16" <	"	"	
17.	7 parts	16" <	"	"	
18.	8 parts	16" <	"	"	

3.9.2. CAPACITY ANALYSIS

As indicated earlier, a punched card had been prepared for each part number, specifying the major production date such as operation numbers and times, as well as usage data, i.e. number of parts used per machine and machine type. Clearly, to calculate the capacity requirements for each family, the following stages were required.

(a) Split punched cards into packs, each pack corresponding to one trial family.

(b) For each card and each process:-
Multiply the number used per machine by the number of machines built per year and multiply the product by the operation time per part.

(c) Accumulate the annual operation times for each process.

This is of course a major chore and, as indicated by Hunt (98), is particularly suitable for computerised data processing. Whilst Hunt used certain decision criteria to automatically break the cards into provisional families, it was decided in this study to select families manually and use an electro-mechanical card sorter to split all cards into packs of suitable trial families. It was felt at the time, that for the effort involved and, bearing in mind that different companies are likely to need different selection of trial families, the writing of a computer programme to split cards into families as well as calculating the family capacity was not warranted.

A simple programme was therefore written to just calculate the capacity requirements of each family in turn. Fig 39 shows the programme flow chart and Fig 40 the final programme. Since in the sample coding exercise the class codes 5 and 9 were not used, these codes were used as decision makers in the programme. Code 5 was used to terminate any one family i.e. when a card with a first Opitz digit 5 was read, the computer printed out the cumulative hours per year. Similarly the first Opitz digit '9' was used to terminate the programme. After the programme had been tested with sample data cards and found to operate correctly, all cards were split into 17 trial families (families 12 and 13 were combined) and divider cards (Opitz '5') were inserted. The programme was run with all data cards and a listing was obtained showing for each family.

- a print of all cards making up the family.
- a print-out of the annual capacity requirements of the family. (Extract fig 41).

The initial print-out provided a set of machine loads which gave a good indication of the load requirements of the cell (Table V). Following a review of the table V it was possible to refine the choice of families somewhat and a further computer run was obtained with the following family break down.

1.	Rotational 0, 1, 2	(0-2" dia.)	
2.	Rotational 0, 1	(2-4" dia.)	
3.	Rotational 0, 1	(4-16" dia.)	
4.	Rotational 2	(2-4" dia.)	
5.	Rotational 2	(4-10 dia.)	
6.	Rotational 0	(16" dia.+)	
	Rota. with deviation 3	(16" dia.+)	
7.	Rotational 2	(16" dia. +)	
8.	Rot. with deviation 3, 4	(0-2" dia.)	
9.	Bolt cams (special family split off rotational with deviation)		
10.	Rot. with deviation 3,4	(2-4" dia.)	
11.	Rot. with deviation 3	(4-10" dia.)	
12.	Non-rotational 6, 7, 8 steel	(0-4")	
13.	Non-rotational 6, 7, 8 cast iron	(0-4")	
14.	Non-rotational 6, 7	(4-16")	
15.	Non-rotational 8	(4-16")	
16.	Non-rotational 6	(16" +)	
17.	Non-rotational 7	(16" +)	
18.	Non-rotational 8	(16"+1)	
19.	Non-rotational	(0-2")	Requiring turning operations
20.	Non-rotational	(2-4")	
21.	Non-rotational	(4-16")	
22.	Non-rotational	(16" +)	

Table VI shows the capacity breakdown of this print-out which formed an acceptable basis to combine families into suitable groups for cell formation. Small rotational parts (family 1, Table VI) could be combined with small rotational parts with deviation and small non-rotational parts requiring turning. These parts require the same kind of machinery and appear to be suitable for production in one cell.

Similarly other families were grouped to eliminate families which were too small to justify their own cell. Table VII shows the rationalisation into nine groups which form the basis of nine main cells. Some of these groups are too large for one cell and some sub-groups are required in the detailed cell analysis.

It is therefore likely that ultimately more than ten cells can be set up. A typical example is group 6 which includes cams. A parallel analysis had indicated that the 4" cube cell could usefully split into

(a) a cam cell consisting of four sub-cells and

(b) 4" cube steel cell excluding cams and cam-like parts.

It would be basically wrong to attempt to split the groups up at this stage and the detailed design should be left for the next stage of analysis. The lack of detailed information does not cause any problems. The main objective of the project, i.e. the splitting of the plant into manufacturing cells can be done with the information available so far. Similarly area allocations can be made at this stage even though the allocated areas may be split down further during the detailed cell analysis.

Table VII was used as a basis to allocate machines to each group. Since it is the objective to change the existing machine shop, the allocation of machines to groups must by necessity be based on the existing plant list. It would be surprising if the machine tool requirements of the groups matched exactly the existing plant list. Part of the G.T. analysis is to demonstrate any capacity miss-match in the plant. Any major deviations could then be investigated individually.

To be able to allocate existing machines, a certain amount of information was required, namely:-

(i) a list of existing plant.

(ii) a knowledge of the capacity and specification of the individual plant items.

(iii) drawings of sample components to visually check on the suitability of plant for particular groups.

(iv) a knowledge of existing manufacturing methods and conventions.

(v) the ability to relate Opitz code data to specific machines.

Whilst factories invariably have a plant list this is not necessarily complete and often does not include machine data, such as capacity. This situation existed at W.M.B. and the first task was to update the plant list. Capacity data had been gathered by apprentices over the preceeding weeks. The author's general know-ledge of the plant and their general capacity was useful here in as far as it allowed the allocation of most machines without detailed reference to individual records. In certain areas (e.g. the use of the copy lathes) a talk to the section foreman concerned provided a useful check on the proposed allocation.

Since all of the data required for allocation of machine tools is not usually available in a written form and since usually the G.T. worker does not have all the knowledge, it is important at this stage to discuss the allocation with staff members such as production engineers, planning engineers and foremen. This speeds up the analysis considerably and ensures a greater degree of accuracy. There is also a better assurance that certain factors not apparent from the available data are accounted for (e.g. the "Elliot" copy lathe is now only used for one type of component and stands idle most of the time).

Only one major discrepancy was found between the theoretical and actual capacity:

There are 16 vertical borers available, but the capacity analysis indicated a need for eight machines only. A discussion with the foreman revealed two facts:-

(i) The section was certainly underloaded by perhaps two to three machines.

(ii) The section capacity was understated by at least 50% in the sample analysis.

The section turns large complex castings where a very high reject and rectification rate occurs owing to casting faults. According to the foreman, four machines are used at any one time on rectification work.

Tables VII (a) to (j) show the allocation of machines to specific groups together with a labour allocation and area requirements calculation. The areas required were taken from the plant data sheets prepared earlier.

The areas quoted on the plant list referred to plan areas for the machine tool only and did not consider services, operator space, gangways etcetera. To be able to obtain the gross area, a comparison was made of the net and gross machine areas in the existing machine shop.

For each of the main sections the machine tools and their net areas were listed (Table IX), grouping machines of similar type and area. The total net area of each section was calculated and divided into the overall section area to give a ratio of net to gross machine area requirements.

This ratio included all services such as operator space, access, inspection, progress, gangways etcetera. The different factors indicated that an overall average factor of 3.3 would be a fair approximation to use. There is one major exception, namely the turning section, with a current factor of 4.5. This section is very loosely laid out at present with considerable space wastage and work-in-progress areas. A factor of 3.3 could no doubt be achieved in a cell system of manufacture for this type of machine.

To test the accuracy of this factor in a G.T. environment, the same calculation was repeated for the West Avenue factory (Cam Cell). The ratio for this plant was high at 3.8. The reason for the high ratio is that excessive space was allowed during the layout stage. There was general disbelief amongst management that there was sufficient space available for all machines specified and there is no doubt that this affected the G.T. engineers' thinking when laying out the machines. Furthermore when the layout was prepared there was some uncertainty as to the specific machine models which would be available and Modulex models for the layout were based on the larger types of machine tools (i.e. the No. 2 horizontal mill model was based on a Cincinnati machine which is substantially larger than the Archdale and Richmond machines actually installed). It was estimated that the allocated space could have been reduced by 20 to 25% without difficulty, indicating a more realistic area ratio of 3.0. This calculation indicated that the factor of 3.3 chosen for the overall layout was probably quite realistic.

Two groups were split up into sub-cells:-

(a) Group 6 was split into a cam cell and a 4" cube steel cell. The detailed analysis for cams was developed in parallel and the overall study is shown in the next chapter.

(b) Group 5 was split into "Cylinders" and "Large Turned Parts" Cylinders are a special type of very complex component and are already partially grouped in cell-like areas.

3.9.3. FACTORY LAYOUT

Once cell areas had been defined (Table IX) it was necessary to allocate these to the existing factory layout. The conventional technique of using block area templates was used to get a rough appreciation of an acceptable layout. Once these areas were roughly allocated, it was possible to detail them on a copy of the plant layout within the constraints of the building shape and adjacent cells. The first layout was based on the following constraints (Fig 42):

(a) Minimise changes and disruption to the existing layout.

(b) Concentrate on the machine shop with minimal effect on other areas.

(c) Maintain existing layout features where possible.

The second layout went somewhat further into the layout problems by attempting to improve material flow but made major changes to a number of departments other than the machine shop, thus avoiding major structural changes (Fig 43). Both layouts were discussed with the Chief Production Engineer to check if any constraints had been overlooked, or if any improvements could be suggested.

The second layout was drawn up to enable the company to implement the first layout fairly quickly, and subsequently over a period of time convert it to the improved second layout. This would allow a minimum-cost G.T. implementation with a long-term factory layout improvement programme.

As a cross check, the cell areas were summed. A total area of 27,933 ft. had been allocated which compared with an existing machine shop area of 27,800 ft. This was a close enough agreement to verify the arithmetic and application of the area factor.

It should be noted that this layout assumed current levels of productivity and there is therefre ample space for expansion. The re-arrangement of certain areas resulted in a spare space of 3,500 ft. in the machine shop and the assembly shop. The spare machine shop area could be used for an expansion of the small turning and 4" cube cells to reduce the current high level of sub-contract. The additional assembly area would be useful for expansion if sales can use up the additional capacity which should be generated from increased productivity in the machine shop.

3.9.4. PROJECT PHASING

Having established the cell layout of the plant, a priority list of cell establishment was drawn up to minimise disruption and provide a logical sequence of progression which would require a minimum of temporary relocation. The following sequence was set up to correspond to the first layout (Fig 42).

(i) Move the drawing office and the spares department.

(ii) Move part of the cam cell into the previous spares area.

(iii) Move the small batch section (B Shop) into an area cleared by the partial transfer of the cam cell.

(iv) Complete the cam cell move.

(v) Move cylinder turning into the cylinder area, moving milling machines temporarily as required, utilising space released by the transfer of the cam cell.

(vi) Lay out the large turning cell No. 5.

(v) Lay out cell No. 1.

(vi) Lay out cell No. 2.

(vii) Lay out cell No. 3.

(viii) Set up the miscellaneous shop incorporating the previous small batch shop (B Shop).

(ix) Lay out cell No. 4.

(x) Lay out cell No. 7.

(xi) Lay out cell No. 6.

(xii) Lay out cell No. 8.

(xiii) Lay out cell No. 9.

(xiv) Complete the cylinder section.

A typical time scale has been suggested in Fig 44.

The plan does not allow for the establishment of the ultimate layout.

3.9.5. MANAGEMENT STRUCTURE AND PERSONNEL

The conversion of the Aylestone Road plant will have to be accompanied by certain changes in the personnel and management structure to be able to cope with the administrative requirements of the cell system.

The cam cell project described in the next chapter had provided certain clues on the production control aspects. There is no doubt that one progress clerk can adequately cope with a very large cell consisting of over 30 machine tools. Also, once the cell order chart could be prepared with computer assistance, the cell planning effort would reduce drastically, and one person could no doubt cope adequately. The store-keeping function would be somewhat more complex however.

Each cell would need a supervisor, but generally this could be a working charge-hand. It was felt imperative that the first level of management should be responsible for one cell only to ensure that each cell had its own management identity.

Following these deliberations and bearing in mind the work done at Ferodo Ltd., a suggested organisation chart was drawn up (Fig 45).

It can be seen that Work Study and production engineering are split over the main areas of activity, namely cams, rotational parts, non-rotational parts and cylinders (plus miscellaneous) respectively. The foremen are allocated in a similar manner, but each cell has a charge-hand reporting to the foreman concerned.

Each foreman also controls maintenance staff, inspectors and scheduling clerks, all of whom receive technical instructions from the relevant department heads. Inspectors, not unlike in the Ferodo case, report to the Chief Inspector on all technical and personal matters but their work allocation is controlled by the foreman concerned.

The cell schedulers receive their documentation i.e. monthly programmes and job cards, from the Machine Shop Scheduler who uses two cell planners to draw up the monthly programme for each cell and monitor the output. The production control procedure should be in line with that developed for the cam cell (see next chapter).

3.10 THE G.T. TEST PLANT

3.10.1. INTRODUCTION

After the G.T. study had proceeded for some months it became apparent that G.T. was the right manufacturing philosophy for Wildt Mellor Bromley. Furthermore the stock situation became quite desperate and some labour militancy was experienced.

At this stage a small factory (8,300 sq. ft. manufacturing area) of a sister company became vacant, some two miles from the main Aylestone Road plant, and the W.M.B. Board of Directors decided to use this opportunity to test the suitability of G.T. in practice, in isolation from the main plant and its influences. Hence this small plant at West Avenue, Leicester was made available to the G.T. team to set up one or more G.T. cells for families of parts of their choosing.

The first indication of the availability of this plant was given end of July 1973 and some very hasty assessments of the scope of G.T. in this plant were made together with a rough estimate of likely capital cost. On this basis approval of the project was given, and the G.T. team were instructed to set up the G.T. pilot plant as quickly as possible.

By early 1974 it was necessary to make arrangements to transfer the cell in this plant back into the Aylestone Road plant and the G.T. project as a whole suffered some delay.

3.10.2. FAMILY SELECTION

Quite early on in the analysis it became apparent that one suitable family would certainly be cams. These items are small, generally plate-type cams with a profiled or plain edge which guides the movement of knitting needles in the knitting machine (e.g. Fig 46). In the order of 400 cams per machine are used, resulting in a total requirement of over 200,000 components per year. The general spread of cams in knitting machines of different types tends to be similar, and a sample study was expected to be suitable for analysis.

It was decided to use cams as a suitable basic family for the test plant at Wigston. Whilst in some respects this may seem to be too easy a criterion, there were inherent advantages in this choice:-

- Cams are easily identified as a family and can be easily extracted from the product range.

- They are labour intensive with a high value to weight ratio, making them suitable for cheap transportation between the test plant and the main plant.

- Production data and tooling are reasonably well established and a transfer of work is relatively simple.

- The concept of a cam cell is easily explained to all levels of personnel and is less abstract than, say, a 'non-rotational 4" cube' cell which was considered as an alternative.

- The thought of a cam production line had been talked of in the past and the idea was not alien to plant personnel.

- There was a bottleneck in the milling shop and this would be relieved.

There are basically two types of cams:-

(a) Flat cams (camplate cams) (Fig 46)

(b) Swaged cams (cambox cams) (Fig 47) which are hot swaged during the production process to provide the curved shape.

3.10.3. COMPONENT SELECTION FOR SAMPLE ANALYSIS

As indicated earlier, all sample parts had been Opitz coded and, together with their production engineering data, recorded on 80 - column punched cards. Furthermore all cams had been marked with a "special parts code" "1"

Selection of cams was initially based on the Opitz code with a back-check against the special parts code to check on omissions.

Cams were generally covered by the following codes:-

(i)	6 x x x 6 - x x x x 7 x x x 6 - x x x x	swaged cams.
(ii)	6 x x 7 x - x x x x 7 6 x x x - x x x x	flat cams.
(iii)	6 x x x x - x x 5 x 6 x x x x - x x 6 x 7 x x x x - x x 5 x 7 x x x x - x x 6 x	cams made from a special high alloy steel only used for cams.

Relative to set (iii) it should be noted that cams are not only made from this high alloy steel and these codes were not suitable as a sole criterion but more as a check on groups (i) and (ii).

There were also a number of rotational cams with deviation which were specifically excluded.

A certain amount of product and process knowledge simplified the choice and made it easier to specify meaningful code parameters for selection.

3.10. 4. CELL ANALYSIS

To be able to gauge the magnitude of the cam cell, and to test its feasibility it was necessary to initially determine the machines required to set up the cell and the capacity utilisation of these machines.

It was intended to do this work as part of the overall systems design and the computer programme mentioned in the previous chapter was to be used for this work.

In the event, management pressure resulted in this single cell being developed earlier than expected and before the computer programme had been completed and tested. An industrial dispute made rapid completion of the programme impossible.

This one cell was therefore developed manually in isolation. In many ways this was preferable since the cam cell suffered more than any other cell from the short-comings of the computer programme.

The input format grouped all milling together and failed to differentiate between copy, horizontal, and vertical-milling. For the cam cell this split was vital and some manual work over and above the computer assisted capacity analysis would have been required in any case.

The capacity requirements of the cell were calculated using two simple part-number machine matrixes.

(i) The first matrix had all processes on cams listed on the horizontal axis and all part numbers in the sample along the vertical axis. Under each process there were two columns, one for the operation number and one for the operation time per part.
For each part the operation number and time per part was recorded under the correct process headings (see table X).
This matrix provided the sequence data for the flow analysis and the basic piece times for the second matrix.
All data was still available from the compilation of the G.T. Data Sheets prepared previously.

(ii) The second matrix was similar to the first one, but under each process there was only one column for total annual hours. Again, from the compilation of the G.T. Data Sheets, the annual quantities calculated for the sample parts were available. Each cam sample component was entered and the process times on the first matrix were multiplied by the annual usage.

The hours per year were entered into the correct column and each process column was totalled (Table XI).

Dividing each total by 2000 gave the approximate number of machines and operators for each process.

The provisional number of machines was generally rounded up, unless the excess over the nearest whole number was very small, in which case it was assumed that the excess in capacity would be absorbed by an increase in productivity.

The total time involved in drawing up the two matrixes was in the order of three man days.

The total hours indicated that probably in the order of 33 direct operatives would be required and, bearing in mind a suitable cell size of say, 6 or 10 people, some sort of grouping into sub-cells was required.

At this stage certain arbitrary splits of the family into separate sub-families were suggested but it was decided to run a flow analysis over the whole sample family first to see if certain logical groupings would suggest themselves during the analysis.

An earlier review of a standard work on factory layout techniques by Muther (106) had shown up the potential usefulness of a "From-To" chart to recognise flow patterns in plant layout projects and it was decided to attempt to use this aid to try to discover the major flow patterns of cams.

On a pro-forma sheet (Fig 48) all machines and major processes were listed horizontally and vertically. The chart interpretation is quite simple. To determine the number of components moving from say a Tracemaster to Fitting, the Tracemaster machine is found on the vertical column (machine No. 8) and the Fitting process is found on the top horizontal row (No. 11). The intersection square of the "8" row and the "11" column shows the number of part numbers moving from Tracemaster to Fitting (i.e. 14 different components).

The chart was compiled by going through each component layout on an operation by operation basis and marking a "tick" in the transfer box for each transfer between two operations. By counting the "ticks" the total number of transfers was obtained. It can be argued that one should not use the total number of different part numbers but the total number of machined components. This would have made the analysis much more complex and since the capacity for individual flow patterns will have to be calculated at a later stage, it was not considered necessary to add this complexity to the analysis.

Bearing in mind that it was necessary to identify primary flow patterns, the From-To chart was analysed for high-frequency work-movement. A flow pattern is easiest identified by a network drawing, and a network was drawn up by dividing flows into three levels:-

(i) Primary flow (Frequency $>$ 8.5)

(ii) Secondary flow (8.5 $\geqslant$ frequency $>$ 3.5)

(iii) Tertiary flow (Frequency $\geqslant$ 3.5)

These values were taken fairly arbitrarily in as far as 8.52 is the average frequency, and approximately 50% of all entries are below a 4 frequency. A network was drawn for the primary flow. This turned out to be highly complex (Fig 49) and became totally meaningless when the secondary and tertiary flows were superimposed. It was felt at this stage that a more methodical approach was called for, and the analysis approach using networks of primary flows was discontinued. This conclusion is incidentally analogous to Burbidge's findings, who realised that an analysis based on major flow routes between any two machines did not form a suitable basis for computerised PFA.

It was next attempted to find the one primary flow pattern and hook onto it subsidiary flow lines, until the majority of parts would be covered leaving only a small proportion of exceptions. This approach proved to be particularly useful.

From first principles, the machines from which the majority of components start their process must be those which have the value for the difference between the "From" totals and the "To" totals. To illustrate this point:

> Considering the "Cut-off Saw" on Fig 48, the total "From" figure is 100 and the total "To" figure is zero. Hence a great number of parts (i.e. 100) start with cut-off. (An obvious conclusion in this instance, which was generated artificially by entering "Cut-off" on every process planning sheet where the part was made from bar).

Thus the machine or process with the greatest From-To Total difference may be taken as the primary flow start. The next major flow step is found by taking the route from 'cut-off' to the next process with the highest transfer frequency (i.e. move along the horizontal 'cut-off' line to the highest frequency figure, which in this case is 'Lumsden' with a transfer of 83 part numbers).

The next flow step is of course found by going to the 'Lumsden' row on the 'From' List and moving horizontally along to the H.M. No. 2 (Horizontal Mill No. 2). This process is continued until no significant further flow is obtained. This may be difficult where the flow is very complex, and care must be taken to ensure that a proper cut-off point is found. Very often, such as in the example, there is a definite terminal point, but this will not always be so. As a guide, it must be recognised that terminal operations are those operations where the difference between the 'To' and 'From' totals is a maximum (the reverse to a starting operation). Where no clear terminal point emerges from the major flow pattern plot, it would be useful to identify terminal points before the network plot, and terminate a flow pattern as soon as any one of these is reached.

The above analysis yields the 'MAJOR FLOW PATH' which forms the basis of the cell design (Fig 50).

Secondary flows can now be linked in by pursuing alternative paths. There are two techniques which are possible:-

(a) Pick up each machine on the major flow path in turn and find the second highest transfer point to see if this is significant. (e.g. the second flow path from the Cut-off Saw leads to the Churchill Rotary Grinder and either to Demagnetising or Horizontal Mill No. 2. At this point, some intuition is involved. It can be seen that the demagnetising operation is a terminal operation. Since there is no flow "Cut-off-Rotary surface grind - Demagnetise" only, it would seem that rotary surface grinding appears twice, namely at the beginning of the process and at the end of the process. This is of course confirmed by Fig 50, the Major Flow Path).

By checking through all major flow machines in this manner, other significant flows can be easily detected.

(b) If all 'boxes' on the matrix are ticked off as they are passed in the analysis, a visual check will detect any significant transfer frequencies which have not been noted earlier. In that case, these can be added by tracking their major path backwards as well as forward to establish their relationship to the major path.

For the cam cell, this procedure yielded quite adequate results as shown on Fig 51, and a good indication of the overall flow pattern was achieved.

At this stage, it was necessary to convert the flow pattern into actual machine tools. Where machines were not split up (i.e. a machine type only occurred once on the chart) this was easy. The number of machines calculated previously could be entered on the chart directly. Where machines were split, this allocation was more difficult.

Sometimes it is possible to allocate these machines intuitively, from product knowledge alone, but in this case a more thorough approach was chosen. The planning sheets were checked individually, and for each component affected, the operation time concerned was multiplied by the annual requirement, and the total listed in a column under the machine concerned on a simple list. On the basis of this breakdown, a clear apportionment was possible. Since further rationalisation was required, this operation was not done with any degree of accuracy. The resulting figure (Fig 52) shows the allocation of machines. It also shows a few early rationalisations:

- Roto-barrelling and certain fitting operations have been removed, to be provided later as a service wherever required.
- A few minor paths have been combined in a group where the flow was so complex as to make cell construction impossible. These machines would not be suitable for a flow-line but would form (part of) a production cell.

At this stage the break-points started to suggest themselves, but a close review of process planning sheets was made, and in conjunction with these observations and the flow chart, certain generalisations could be made:

- Cams fall basically into two groups:-
  - (i) Milled cams, split further into:-
    - (a) Plain milled
    - (b) Profile milled

    Neither require any surface or form grinding beyond initial and final face grinding.
  - (ii) Ground Cams, which required form grinding, surface grinding or both.
- The great majority of cams are made from bar, and these invariably have the same operation sequence start, namely:-

Cut-off

Grind faces

Mill ends to length (and often width)

There would therefore be a useful requirement for a general material preparation cell taking in these operations.

Based on these observations, the final flow chart was designed (Fig 53) which shows a breakdown into four sub-cells:-

- Material Preparation
- Milled cam machining
- Ground cam machining
- Cam finishing

To establish detailed resource requirements, the planning sheets were marked up into the four sub-cells and a capacity balance was repeated. Again only the split machines needed to be calculated, since for the other machines the previously calculated figures remained unchanged. A four-memory desk top calculator was found particularly useful to add up the capacity for the cells. A machine and labour schedule was established (Table VII). This table indicates the small amount of floating labour anticipated and the consequently high level of production planning required to avoid bottlenecks. It further demonstrated the reasonably close adherence to sociologically correctly sized cells.

On the basis of the flow chart the shop layout was developed using plastic "Modulex" models made up by two apprentices.

The flow chart indicated that the material preparation and the cam finishing cells have a unilateral flow and the milled cam section has only one exception. It was therefore decided to use roller conveyors for these sub-cells to progress and store batches. The unilateral flow exception in the milled cam section was simply dealt with by having milling machines grouped around the drilling machine so that by the correct choice of milling machine (i.e. the one preceding or the one following the drilling machine) unilateral flow can be arranged. The remainder of the shop was laid out using conventional layout-practice with frequent reference to Muther's work.

The ground cam cell was kept as a loose group. The complex flow pattern in this group made the use of a conveyor to stream-line the flow impossible.

The final layout is shown in Fig 54 with a photograph of the model layout in Fig 55. It can be clearly seen that there are two transfer points, namely at the end of the material preparation cell, where the work is split and sent to the milled cam cell and the ground cam cell respectively, and at the start at the cam finishing cell where these split flows are combined again.

The swaging of formed cams requires pre-heating and small electric furnaces were specially purchased to fit into the line with a minimum of environmental problems.

Cams are air-hardened during the swaging process and require annealing prior to subsequent machining. It was not acceptable to fit the annealing furnace into the line but the furnace was placed as close to the line as possible.

Also, this furnace is used for annealing only and there are no problems of queuing and different cell priorities.

The material preparation section handles the following operations:-

(i)	Cut off
(ii)	Grind to thickness
(iii)	Mill to width
(iv)	Mill to thickness

Certain parts are made from investment castings and skip some of these operations.

A considerable amount of re-planning was involved to split the milling work over the material preparation and milled cam sections respectively.

The majority of cams are swaged but a proportion do not require swaging. Consequently a conveyor by-pass was arranged along the swaging machines to allow parts to move past this process.

Area allocations for stores and services were made as indicated on the layout. It can be seen that material arrives in the goods receiving area adjacent to the material store. Thus no long distances of material movement are involved. Similarly the cut-off saws are adjacent to the material store. It was initially intended to use the main door closer to the offices for goods dispatch to cut the material flow distances, but bearing in mind the relatively small amount of material weight moved in this plant (estimated at ½ ton per week) and considering limitations of staff, it was decided to combine goods receiving and dispatch into one area and locate the finished part store adjacent to it.

Certain calculations were involved to determine the conveyor length and type.

Approximately 200,000 cams per year are required and without checking in detail all parts involved, about 1,500 part-numbers were expected to be involved, resulting in an average annual usage of 133 parts or about 11 per month (the expected planning period); of these 1,500 part numbers between 600 and 1,000 were expected to be loaded per month, in batches of a minimum of 2 to 3 and a maximum of no more than 75.

Plastic progress containers were planned for, and the smallest size (150 x 90 x 70 mm) chosen as the correct size of progress container. No more than 1,000 containers per month would be used and at a cell throughput time of 2 weeks no more than 500 containers would be in transit at any one time. Allowing say 100 containers in the ground cam section, 50 on machines and a further 100 on progress trolleys or in transit and buffer storage, no more than 250 containers should be kept on the conveyors at any one time. As the conveyors have a capacity of 400 containers, any great excess in throughput time could therefore cause congestion and would be automatically high-lighted for action.

3.10. 5. ASPECTS OF STORES DESIGN

The stores requirements at the West Avenue plant covered the following areas:-

(i) A tool store generally set out along conventional lines.

(ii) A finished part store for gross requirement batches based on a unitised system of storage.

Finished part store design was undertaken as follows:-

A 150 x 90 x 70 mm. container was used and 1,500 containers were allowed for, namely one per part number.

Similarly 1,500 containers were allowed for in the variance stock.

Different container colours were used for these two stores.

The main aspect of stores design was the realisation that small batches require small storage space and valuable space savings can be made when G.T. is introduced by selecting the correct size storage system for the limited variety of parts for each cell.

Once the number of containers has been calculated it was an easy matter to relate this to area requirements.

(iii) Work-in-progress containers.

The same small size container was used for work-in-progress. If a typical cam of 1" x $\frac{1}{4}$" x 2" size is made in a maximum size batch of 75, the weight is only 10 lb. This is quite suitable for manual progressing and a light plastic container could be used.

At one stage the G.T. workers were advised by the chief store keeper at the Aylestone Road plant that cams require heavier, more expensive steel containers. Whilst with current batch sizes this may be so, the reduced batches and narrow range of component sizes made it possible to reduce the container cost and make the handling easier. Furthermore, the use of such a container system allows the use of special trucks to transport a number of containers at a time on a simple little trolley.

(iv) A raw material store was set up using the same type of storage medium with a larger box size for castings, and a simple "pigeon hole" rack for bar stock.

The size of the steel store was based on judgement in comparison with the current Aylestone Road store.

3.10.6. PRODUCTION PLANNING AND CONTROL

It was specified to use a period batch control system since this is probably the only system which is compatible with G.T.

A review of the current production planning system indicated that current batch sizes cover from four to nine months plus requirements (Table XIII). A cycle of three months was initially envisaged but this had to be reduced to one month. A three-months cycle would have given too high an inventory level, bearing in mind that period batch control tends to double inventory when compared with inventory control. Thus a three months cycle would approach a stock holding of 6 month usage batches in the existing system, and no savings would have been achieved. Furthermore, the production planning function could supply three months firm requirements ahead, which provided the correct lead time, (i.e. two months lead time to cover the third month).

The one-month cycle made it imperative to consider group tooling and technological sequencing at an early date.

A two months lead time was made up as follows:-

One month to make requirements
Two weeks cell throughput time
Two weeks component set marshalling and safety time

It was intended to make the system as near self-controlling as possible, to obtain clear indications of any bottlenecks.

Stress was laid on perpetual inventory checking to relate the programme to any previous overproduction to avoid the running-up of excessive stocks. To be able to control this aspect, it was decided to split the finished part store into two sections, one for monthly gross requirements and one for make-variances.

It was decided to specify a small variance stock to control make-variances (e.g. scrap) and spares requirements. This safety stock would initially be set equal to the current emergency stock level, but be gradually reduced in the light of operating experience. Batches would be loaded to include 15% scrap and spares allowance and when received in store, any remaining surplus over the monthly gross requirement would be stored in the variance store. A monthly physical check on the difference between the specified and the actual emergency stock would indicate a necessary batch size correction for the following month. For example:-

Gross requirement	20
Specified emergency stock	4
Actual emergency stock	6
Stock variance	(2)
Net requirement (Batch size)	(20 - 2) + 15% scrap/spare = 18+3 = 21

It was planned to sort all parts into a preferred loading sequence and load every month against this fixed sequence, dropping zero requirement parts.

Capacity calculations and scheduling against time would be based on a "key machine". During start up, the relationship of overall capacity balance in relation to the key machine for the planned sequence would be checked. If acceptable, this would only be rechecked every few months to maintain its validity.

Scheduling would be based on the milled cam and the ground cam cell respectively, and the material preparation and the cam finishing cells would be governed by the loading of these main machining cells.

The milled cam section was, for scheduling purposes, to be split into two sub-cells, for plain milled and for profiled cams respectively.

This was necessary to guard against gross capacity imbalance within the cell, a problem described as "dynamic capacity" balance in the literature survey.

Three scheduling lists were therefore required for the system:-

(i) Plain milled cams:	Key machine:-	Horizontal Mill No.2
(ii) Profile milled cams:	Key machine:-	Profile Mill
(iii) Ground cams:	Key machine:-	Profile/Surface Grinder

The basic steps of the production control system were set out as follows:-

(a) Establish a list of West Avenue parts

This has been described earlier.

(b) Sort parts into preferred Loading Sequence

To be able to load families for common set-ups, it is necessary to split the family into small groups of parts around each of which the group tooling can be designed. The Opitz code was not sufficiently detailed for this purpose and in any case, a code of sufficient complexity to provide sufficient detail for this purpose for all types of parts would be too cumbersome.

It was therefore decided to apply a short scheduling code which was unique for each family of parts, and consisted of 6 digits, three of which made up a component counter to give each parts a unique scheduling number and three made up the descriptive code.

The design of this code was quite simple. The drawings for the approximately 800 plain milled cams were collected and parts were grouped visually. This process is quite useful for small groups of similar parts, where a fine division is required which would normally require a very complex code. Based on the visual grouping, a code was applied to each group and the features concerned were described and listed on a coding chart as shown. The total time for this coding process was less than 12 hours.

Once all drawings were coded, the part numbers were listed in scheduling code order (Fig 56).

(c) Obtain gross requirements

The Company has started to compile a gross and net requirements computer print-out (Fig 57), which consists of a parts-explosion multiplied by a monthly build programme.

The component requirements are listed in approximately monthly periods (four or five week periods) and the requirements specify the numbers used on assemblies during the month in question, i.e. the stated requirements must be available in store at the beginning of that period. The print-out also shows stock levels and suggested orders. Stock levels are important to phase in the G.T. Cell, but this figure will become meaningless in time. The suggested orders relate to the current practice of ordering on E.B.Q.'s and are of no interest to the G.T. work. The print-out also shows the current safety stock level.

To calculate monthly requirements for the G.T. cell, it is only necessary to take the gross requirements off the print-out. It is planned to code the G.T. cell and get a separate print-out for each cell in time.

(d) Setting out the cell order chart

A historical record of usage of parts was established in the form of "Order Quantity charts" (Fig 58). These charts were kept in numerical order of drawing numbers. Each monthly requirements list was entered into this chart and via the catalogue of part number in scheduling code order these quantities could be transferred into a CELL ORDER CHART (Fig 59) in the correct loading sequence.

The Cell Order Chart formed the basis of the cell production planning and control system. One set of charts was made up for each of the three main machining processes, horizontal milling, profile milling and grinding respectively, where the key machines were horizontal milling, profile milling and form surface grinding respectively. To allow for the horizontal milling work on profiled cams one horizontal milling machine had been allocated as profile cam support and was not considered to be part of the key machine capacity.

The cell order chart is self explanatory:-

Batches are numbered consecutively, and the gross requirement called for by the main plant is entered from the order quantity chart. A scrap and spares allowance is added as well as an adjustment equal to the difference from nominal stock level of an emergency stock which is held for each part number.

The material per part and per batch is entered as well as the piece-time batch time and cumulative load (batch time). Rudimentary "tick off" columns to monitor material and tooling availability and progress are provided.

It can be seen that it is exceedingly simple to set up these charts and only clerical effort is involved. Scheduling is simple and delays and shortages are highlighted very quickly. These charts can be easily prepared by computer, and plans have been made to draw up a suitable programme.

It can be seen that parts are loaded in families with the same scheduling code. The gross requirements list is in drawing numerical sequence and to compile the cell order chart, it is necessary to go through the whole parts catalogue in scheduling order and cross-reference to the gross requirements list for each item. This is laborious and steps are taken at the moment to change this procedure as follows:-

- List part numbers, scheduling codes and gross requirements in part number order
- Punch the information onto 80 column punched cards.
- Sort the cards in scheduling code order
- Obtain a tabulation

This system will be expanded by merging the file thus obtained with a file of material data and key machine time. A completed cell order chart would be the output.

(e) Issue batches, Progress the work, Receive into store

For each batch, a job card is issued which accompanies the batch through the cell. For each operation a payment card is made out, which acts as a record to arrange piece-work bonus payment.

The backbone of the progressing system is the Cell Order Chart. A copy of each chart is supplied to the cell scheduler and the storekeeper respectively. The sequence of loading is specified, and the Manufacturing Period column is marked up in working days. As parts are loaded sequentially into the material preparation area, they are ticked off in the "load Prep." column. Three days lag are allowed between material preparation and subsequent machining.

Subsequent machining start is ticked off in the "Load M/c" column. When the batch is completed, the cell scheduler ticks off the "Qty into Store" column. A two week throughput time is allowed for the cell, and the cell scheduler can keep adequate control of the throughput situation by checking on the lag between the "Load prep" column and the "Qty into Store" column.

When batches are received into store, the storekeeper marks the quantity received into store on the cell order chart and the job card. He splits the batch up into the gross requirements which he shelves in the finished part store, and the scrap/spare surplus which he shelves in the variance store. The quantity of the surplus is recorded in his variance stock records and on the cell order chart. No store records other than the cell order chart are kept for the gross requirements finished part store.

If two weeks prior to the build month, based on the cell order chart, there is still work outstanding, the storekeeper informs Production Control accordingly. During the week preceding the Build Month, all gross requirement batches are collected and despatched with part-copies of the cell order charts indicating the gross requirements for the next Build Month. Shortages, if any, are listed separately. The part-copy of the cell order chart acts as a despatch note.

There is a fundamental problem in G.T. scheduling in as far as it is necessary to feed specific machines with specific families of parts. Without adequate planning it is possible that family set-ups have to be broken down frequently, or that some machines stand idle for long periods at a time. Where a limited amount of floating labour only is used and where a high machine utilisation is planned for, this becomes increasingly difficult.

In the cam cell, there is normally more than one key machine. Furthermore, a considerable amount of plain milled cams require more than one set-up and hence, to allow for low buffer storage, more than one machine working on the family at any one time. It is therefore necessary to:-

(i) Feed batches in family sequences to specific machines.

(ii) Ensure a material supply to all machines.

These objectives are easiest achieved by allocating families of parts to specific machines and loading batches into the material preparation area in family rotation.

The problem of scheduling was found to be quite complex and has not yet been fully solved. In order to be able to run the system, a considerable amount of manual control by the scheduling clerk is required, somewhat simplified by the low machine utilisation over the starting weeks. Whilst no proper operating experience exists to date, it is expected that a considerable amount of "panic" chasing in the material preparation cell could be required to ensure an adequate loading of the subsequent cells.

Some fundamental thoughts gave an indication that the concept of family loading could be developed fairly easily.

It is required in a G.T. situation to group small batches of similar parts together to form large batches and achieve some of the benefits of large batch and flow production. This concept can be extended to the scheduling of the cell or flow line.

It is obviously possible to have a number of small batches and group them together, using one "family" job card (Fig 60) and scheduling the "family" rather than its individual constituent parts. This requires just one simple rule i.e. each part in a family must have the same operation sequence where each operation uses one machine set-up for the whole family. In instances where certain parts in the family do not require all operations in the standard sequence, "dummy" operations can be inserted to establish the correct flow pattern and operation numbering sequence.

Once this has been done, the scheduling problem is greatly simplified. When the Cell Order Chart is prepared, parts are listed in family sets anyway, according to their scheduling code.

Each family is bracketed together and cumulative operation times and start and finish dates are calculated on a family-by-family basis.

To schedule families is easiest accomplished using Gannt chart techniques, loading from the due date backwards. Fig 61 illustrates the situation for one five-operation family and illustrates the basic overlap rule. Assuming a minimum inter-operation buffer of, say $\frac{1}{2}$ day, considering operations 4 and 5, buffer periods H and E must both be equal to or ~~less~~ more than $\frac{1}{2}$ day and one of them should approach $\frac{1}{2}$ day.

Mathematically this is expressed in terms of

$$H \geqslant X$$
$$E \geqslant X$$
$$\text{if } H > E \quad , \quad E \rightarrow X$$
$$\text{if } E > H \quad , \quad H \rightarrow X$$

where X = minimum buffer.

Clearly these rules ensure that:-

(a) An operation cannot start earlier than ½ day after the start of the previous operation.

(b) An operation cannot finish earlier than ½ day after the completion of the previous operation.

(c) By letting the start or the finish buffer approach ½ day, the throughput time of the batch is minimised within the constraints of goods machine utilisation.

The total throughput time is:-

$$A + F + G + H + (5)$$
$$= B + C + D + E + (1)$$

Clearly if the operation times are equal

A = B = C = D = E = F = G = H = X. This must be the optimum condition since for all other cases one or more of the buffers must be greater than X. Hence to minimise throughput time, it is advisable to try to balance the operation lengths.

Figure 62 indicates the process of charting a programme on a Gannt chart basis. One useful manual technique used in industry employes a slotted planning board with one horizontal slot for each machine deep enough to accept job cards. Job cards are calibrated with a scale on their top edge which is cut proportional in length to its operation time. These cards are placed in the trays against their machine and slid into suitable positions, observing the rules laid down previously, to form a planning chart. Fig 63 shows a sketch of the planning board involved and Fig60 shows a typical family job card.

This system was chosen for W.M.B. to provide the right compromise between complexity and controllability.

To obtain an indication of the production control effort involved the first month's cell order chart was reviewed. The chart referred to plain milled cams only.

The ratio of cams in the cell was as follows:-

Milled cams	=	35%
Profiled cams	=	45%
Ground cams	=	20%

The cell order for milled cams consisted of:-

215 batches, 31 average batch size for 23 working days.

Extrapolating by ratio over profiled and ground cams and assuming the first month to be typical, a normal cell order chart for the completed plant would consist of 478 batches per 23 working days or 21 batches per day.

There is no doubt that one scheduling clerk can cope with this amount of work.

These figures also indicate that for a two-week throughput time only in the order of 240 batches are in the plant at any one time. This is considerably less than the 500 batches expected, even if an ultimate increase of 20 to 30% of part numbers is allowed for when cam-like parts are introduced into the line. This factor confirms that the conveyor length provides adequate storage space for all batches.

The total system was drawn up using flow charts (Fig 64 & 65) to ensure that a logical sequence of events has been planned.

3.10. 7. CONTROL ASPECTS OF THE SYSTEM

One primary consideration of the production control systems design was the inclusion of adequate feed-back loops to high-light any problem areas.

Fig (66) shows the block diagram indicating two feed-back loops to monitor the work progress.

Loop (A) controls the progress of the work and controls

(i) the extent to which due dates are met and indicates areas where work is held up.

(ii) the issue of further work into the shop by comparison of input/output plans and actual output achieved.

Loop (B) controls the quantity performance and ensures that quantity targets are met. Again the control is two-fold. When a batch is received in store the gross requirement is split off. Any remainder is placed into the scrap/spare variance store. Alternatively any under-make is made up from the scrap/spare variance store. If this store cannot make up the shortages the production controller is informed to take emergency action (i.e. issue a further batch). Secondly this loop controls the scrap/spare variance store. Every month when the new cell order chart is made up, the difference between the planned and the actual scrap/spare variance stock is checked by physical inspection and the next month's batch is amended to allow for any discrepancy. This second control feature firstly ensures that any progressive scrap/spare excess over plan is accounted for and secondly that physical stock is checked sufficiently frequently to minimise any shortages due to poor records.

3.10. 8. PRODUCTION ENGINEERING ASPECTS

Very little has been done to date to implement new methods and tooling in the G.T. cell and the following notes can only give an indication of the work which will be done over the following months.

There are basically three requirements:-

(i) Change the planning sheets to split milling operations between the material preparation cell and the milled cam cell. This is fundamental to the running of the system and requires immediate attention.

(ii) For each group of similar parts a standard planning sequence, must be drawn up and all family plannings must be flow compatible.

It is expected, that common information can be used on the planning sheets and a fixed master with variable additional information will be suitable.

For simpler cams a master sheet with tabulated information for a number of cams should be suitable (Fig 67).

(iii) For each family group-tooling must be designed and made to enable the cell to handle very small batches.

Stress will be laid on permanent fixture set-ups with quick-change locators and cutter setting pieces.

Typical examples are given in Fig 68 & 69.

The examples on Fig 67 to 69 refer to one family of parts of which a typical part is shown on Fig 70. All of these cams have the same manufacturing requirements, but vary in dimension.

(a) To cut the ends to 45°.

Parts are initially machined to a controlled length. They are then slid into the fixture (6 to 10 at a time) to a stop and clamped. The stop is removed and the corner is cut off. Clearly the dimensions of the parts are immaterial and any size parts within the loading constraints of the fixture can be accepted (up to 5" long cams are catered for). This fixture incidentally was in principle designed by a cell operator and marks the start of the kind of co-operation to be expected in a cell system of manufacture.

This operation is preceded by:-

(b) To cut to length and width

For this operation parts are loaded on the special setting block 'A' which determines the height and a block 'B' determining the width. Again several parts are milled in one set-up in a vice.

In order to speed up the introduction of these methods, existing standard machine vices were used for clamping, but these will in time be replaced by pneumatic tooling.

There was nothing new in this method of machining and form cutters were already in existence. The innovation was the use of setting blocks to speed up the change over times.

The tooling employed is quite simple and not as elaborate as could be, to provide an efficient method. It should however be remembered that the plant operates solely with skilled labour, generally of a high calibre, and whilst some of the tooling under development does not represent the most advanced level of production engineering, it has certain advantages:-

(i) It is cheap to make.

(ii) Loose setting pieces offer the shortest change-over times.

(iii) The use of these fixtures requires a certain level of skill and attention which is preferred by skilled operators.

The examples illustrate one area of the work to be done at West Avenue. They do demonstrate that component change-over time within a family should be negligible and small batches of any size can be produced economically.

One limitation of the smallest batch size is incidentally the number of parts machined together in one set-up, and this information must be fed back to production control. Within the concept of the variance store this exception can be dealt with. It should be noted however that this does provide a batch size calculation parameter and whenever possible, fixtures should be designed such that they can accept less than the optimum number of parts per set-up.

The work described is likely to generate a considerable saving in the near future when new machine models are introduced.

Initially this work represents an additional cost since all of the existing components are already fully tooled.

(iii) The current practice of combining several set-ups on one machine into one operation on the planning sheet has to be discontinued.

In the current practice of machining such work, an operator is issued with a batch of components, and machines every set-up on the batch in turn with machine re-setting between batches. Clearly from a G.T. point of view this is not acceptable and different set-ups have to be produced on different machines. Thus a considerable number of parts have to be re-planned.

3.10.9. OBSERVATIONS ON THE EMERGENCE OF A TEAM SPIRIT

As indicated in the last chapter great store is set by the theory of primary sociological groups within a cell system of manufacture. It was therefore particularly rewarding to see the emergence of a healthy team spirit at West Avenue at a very early date.

The initial labour force consisted of four milling operators, one inspector and a storekeeper.

The operators and the inspector had been forced some ten months earlier to join the night-shift at the Aylestone Road plant and were very keen to return to the day shift.

There was therefore a basic good will and eagerness to assist and make the West Avenue project viable. This factor alone was exceedingly beneficial and set the right working attitude.

On the start-up morning a talk was given to the personnel by the Aylestone Road Chief Production Engineer (West Avenue Production Manager Designate) on the aims of the plant, the organisation and the basic principles of G.T. It will be remembered that the plant was at that stage capable of horizontal milling only and a number of batches of pre-machined blank components were ready for work. The operators were led to the progress area where they viewed the work. One operator (Graham) immediately took a lead and checked with a production engineer on available tooling and equipment and then guided the other operators on the choice of work to start with. Graham had a considerable knowledge of cam milling together with a forceful but constructive personality and a particularly well equipped tool kit. He established immediately the respect of his fellow operators and became soon the accepted, self-elected cell leader.

The support staff at West Avenue at that time consisted of a production engineer and a systems analyst acting as production controller, both under the guidance of the author.

By deliberate policy, supervision to the cell members was reduced to a minimum and virtually restricted to a supply of work and procurement of tooling with occasional guidance on work priorities.

The detailed scheduling, allocation of work to specific machines, and general discipline was immediately and enthusiastically taken up by the Group. The pace of working was very active. Despite shortages of tooling and grave limitation of some of the machines available at that time, coupled with delays for tool regrinding, the cell output during the first was approaching that of the Aylestone Road plant (based on allowed times and typical bonus rates), and on the one machine of high power and high quality an output well in line with Aylestone Road plant expectations was achieved.

There was a noticeable shortage of tooling and fixture. A considerable amount of milling work at Aylestone Road is currently done, using the operator's own "lash up" tooling of which no records exist. The Group made up such aids as they went along but agreed at the same time that all tooling aids would be passed into the store and recorded on the planning sheets for future reference.

The morale of the group was excellent and there was a keen desire to prove that West Avenue could compete economically with Aylestone Road.

There were considerable problems with obtaining work from Aylestone Road and arrangements were made to cut off blanks from bar at West Avenue on horizontal milling machines. Once this problem had been discussed with the Group they organised themselves so that one or two members were cutting off at any one time. Cutting off is a boring and monotonous low-skill job and the group members worked out their own rota system to ensure that everyone would get his fair share of cutting-off work.

The concept of floating labour had been resisted at Aylestone Road, but seemed to become more acceptable at West Avenue. Because of the problems of tool-grinding, the Group requested that a tool and cutter grinder should be installed at West Avenue, and they would regrind their own tools. This would have been totally unacceptable at Aylestone Road.

There were initially seven horizontal and one vertical milling machine at West Avenue with only four operators.

The operators therefore kept two machines permanently set-up for frequently recurring operations and fluctuated between the various machines to suit the requirements of the work. This was done with minimal outside instigation or guidance.

During the early weeks the inspector was not much occupied and after about a week he approached the author and asked, if it would be possible for him to cut off material to help out. It was known that Graham was a keen trade unionist and the thought of an inspector operating machines was certainly totally unacceptable to any operator at Aylestone Road. The matter was discussed with Graham and his fellow operators, who agreed whole-heartedly with the scheme, as long as there was nobody from the Aylestone Road site at West Avenue to observe.

Other examples of this kind of team spirit and pride in the new plant became apparent.

The store keeper, out of his own initiative, used his spare time to brush up, clean toilets and do a whole host of minor jobs which made the conditions and appearance of the plant more acceptable.

A further example occured at Christmas when a representative of the Group approached the author about Christmas drinking. He pointed out, that at Aylestone Road it was common practice to take alcoholic drinks into the factory and celebrate. They, the Group, felt that this was dangerous and represented poor discipline and they would prefer to go to a public house during the lunch break and return to work afterwards. He at the same time invited all staff members to join the operators for a Christmas drink.

Staff-operator relations were exceedingly good right from the onset, which was all the more surprising, bearing in mind the particularly poor relationship at Aylestone Road. The following reasons are probably responsible for this.

(a) The operation of the plant was based on mutual respect. There was a clear division of duties which indicated that the inter-cell aspects i.e. operation of machines, allocation of duties and cell discipline were left to the cell members whilst the staff fulfilled the support functions of overall guidance and supply of resources.

(b) The superior knowledge of the operators on detailed manufacturing methods was openly acknowledged and their advice sought on many occasions. This gave the group members much more job satisfaction and led to a feeling of co-operation with management.

(c) The small size of the cell made it possible for staff members to meet all operators several times a day and talk to them informally about various subjects. Again, this promoted the production team spirit which is so much lacking at Aylestone Road and which cannot be achieved in a large functional layout shop.

Information on the good relationships which are developing at West Avenue started to feed back to the Aylestone Road plant and after about two weeks of operation, management were approached by the Aylestone Road grinding section foreman who mentioned that one of his operators wanted to move to West Avenue, to operate the recently acquired second-hand surface grinder, and that this operator had indicated that he would not object to "doing a bit of drilling" if required. This was even more astonishing if one considers that traditionally grinding is a high status operation whilst drilling a low status job.

It is expected that the group behaviour pattern which is setting itself up at present will provide a useful basis to lead to the ready acceptance and possible even the request for the floating labour principle and group incentives, both major requirements in a G.T. system.

There is no doubt that the observations here are to some extent analogeous to those in the Hawthorne experiments and it will be interesting to see the long term effect.

3.11. COST AND SAVINGS AUDIT

3.11.1. INTRODUCTION

Certain objectives had been set when the project was started, and some of these were of a financial nature. It was therefore necessary at the end of the feasibility study to take a closer look at both the costs and the savings of the G.T. conversion of the Aylestone Road plant to assess the financial feasibility of the project.

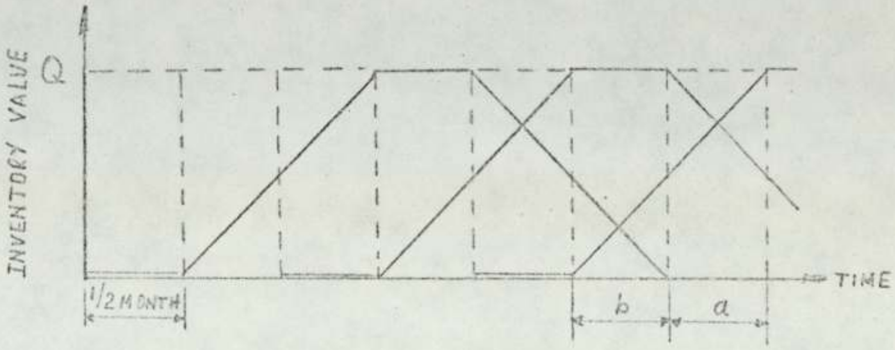
Especially with regard to stock reduction, useful predictions could be made. The calculations were based on October 1973 stock-taking figures, and represented the most recent calculation of physical stocks. The following months' calculations of stocks indicated that inventory was still increasing and that the figures used were not artificially high.

The cost calculations were based on the actual project cost to date as logged on a day to day basis by the G.T. team, and estimated for the conversion of plant based on general practice and experience gained at the West Avenue plant.

3.11.2. SAVINGS ANALYSIS

(a) Finished Part Inventory

The finished part inventory flow with G.T. is as shown below, based on a one month's cycle with half a month throughput time and half a month safety period.



Over period (a) Average level = $\frac{3}{4}Q + \frac{3}{4}Q = 1\frac{1}{2}Q$

Over period (b) Average level = $Q + \frac{1}{4}Q + \frac{1}{4}Q = 1\frac{1}{2}Q$

Thus average finished part stock level is $1\frac{1}{2}Q$, where Q is the monthly shop output.

(i) Current Finished Parts Inventory at W.M.B.

Machined parts inventory = £550,000

Percentage bought out, 25%

Net Finished parts = £412,500

(ii) G.T. Finished Parts Inventory

Monthly plant output = £120,000

Ideal stock = $1\frac{1}{2}$ x monthly output

= £180,000

Allow 30% excess and scrap/spare allowance

Practical G.T. finished part level

= £234,000

SAVING = £178,000

(b) Work in Progress

(i) Current work in progress

£400,000

(ii) G.T. work in progress

Machine shop output £1,400,000 at works cost

Raw material content of current work

$= 38\%$

Average work in progress value based on year's output

$= \frac{1}{2}$ (Raw material + Fin. Part Cost)

$= \frac{1}{2}\left(\frac{38\%}{100} + 1\right) \times 1,400,000$

$=$ £966,000

Average throughput time is two weeks

G.T. work in progress value

$= \frac{2}{52} \times$ £966,000

$=$ £37,153

Allow 50% excess:

Total G.T. Work in Progress

$=$ £55,700

SAVING = £344,300

(c) Shortage Inventory

This item consists of assembly kits awaiting shortages. The figure should reduce to insignificance with a proper system of period batch control. Assuming a reduction of 75% :

(i) Current level

Units with shortages	£72,052
Machine build (shortage book)	£466,558
	£538,610

(ii) G.T. level

Saving = .75 x £538,610

= £404,000

(d) Spares Inventory

With a throughput time of only two weeks and the introduction of a scrap/spare variance store, the spares stock can be reduced considerably.

Current Spares stock level: £102,606

Assuming a 50% reduction,

SAVING = £51,300

(e). Productivity

It is difficult to predict productivity savings with any degree of confidence, and any figures which can be quoted will be based on judgement only.

Improvements from 10% to 30% plus are quite feasible, and for Aylestone Road the following items were suggested:

1. Morale improvement 10%

2. Improved methods and use of group tooling, power clamping etc. 8%

3. Setting times may not reduce substantially because of reduced batch sizes

4. Reduced wastage and losses owing to improved control 3%

Suggested total saving 21%

Current output at works cost:	£1,400,000
Saving of 21% thereof:	£ 294,000
Less increased labour cost on items (1) and (4) - 13% of £570,000	£ 74,000

NET SAVING PER YEAR = £220,000

(f) Total Capital Released

£977,600

(Work in progress, Finished Parts, Kit Sets and Spares)

(g) Total Saving continued

Annual Saving:

Productivity	£220,000
Interest on capital released, say 12%	£116,950
TOTAL SAVING	£336,950

3.11.3. INDIRECT PERSONNEL SAVING

A direct labour saving in the Machine Shop of 21% has been proposed and costed including Works Overheads. The latter includes indirect labour which must be reduced accordingly for the calculation to hold true. To allocate the saving correctly, it is necessary to apportion indirect labour to machine shop labour:-

i.e.	Total direct labour	=	539
	Total machine shop direct labour	=	220
	21% reduction of machine shop labour	≡	8½% reduction of total labour

Thus indirect labour must be reduced by 8½%, i.e. 31 of 361.

Table XIV shows a list of current indirect labour. Column (A) shows the labour figures, Column (B) shows the 8½% reduction required and Column (C) shows the estimated reduction which should be achieved.

Column (C) includes only estimates and the bulk of the reduction refers to production control. Without a detailed job analysis of all personnel members, it is difficult to calculate exact savings. If it is accepted that half of the department (Production Control and Progress Chasing) are connected with the machine shop, these can be reduced from 29 to 12 persons (7 cell schedulers, 2 cell planners, 2 clerks, machine shop scheduler).

Spares progress can be cut by certainly 2 men, since the concept of spares progress as such will cease to exist. Foremen can be reduced by two, by having a working charge-hand in each cell.

Thus a minimum of 34 direct workers will become redundant (or absorbed by greater output !), and as a good approximation, it can be claimed that indirect labour savings in ratio to the direct labour saving can be achieved.

3.11.4. COST ANALYSIS

(a) Cost of the G.T. Analysis

The cost of the analysis leading to the West Avenue plant layout and the overall Aylestone Road cell layout was logged on a week-by-week basis, and the cost items are as follows, based on direct labour (i.e. excluding all overheads) and expenses only.

(i) Overall Study:-

Training and Consultation (including fees and study cost of author)	£1,578
Sample coding	£1,048
Design Retrieval Coding	£1,562
General Administration	£ 165
Sample Data Collection	£ 327
Data Processing	£ 450
Overall Project Planning	£ 30
Plant Data Collection	£ 65
Paper, drawings, copying, stationery etcetera	£ 440
	£5,665

(ii) West Avenue Analysis:-

The analysis of the West Avenue plant included:- plant layout, project planning, systems design, plant service design and general project co-ordination.

The cost of the analysis was £1,920, but this included a considerable amount of production control systems design which needs only to be done for the first cell (estimated at around £400) and planning of services and implementation of a new plant which would not normally be required for an internal layout change to a cell system (estimated at £500).

The cell analysis cost can therefore be apportioned as follows:-

Total Cost	£1,920	
Less	£ 400	(£400 systems analysis cost apportioned over all cells)
Less	£ 500	(£500 new plant analysis peculiar to the West Avenue project)
NET CAM CELL COST	£1,020	

Adding the £400 systems design cost to the general analysis cost, the overall study cost increased to £5,665 + £400 = £6,065.

(b) Implementation Cost

The only comparison to date was the establishment of the West Avenue plant, which required exceptionally high expenditure and cannot be treated as a normal case.

The cost estimate for internal re-arrangement can be made as follows, based on the experience of the W.M.B. plant personnel and the impressions gained at West Avenue.

Total Aylestone Road conversion:-

130 machines moved at £30 average	£3,900
Analysis cost for eleven cells	£11,000
Duplication of low cost plant items, purchase of racking, conveyors and various plant equipment - allow a budget figure of £3,000 per cell	£33,000
TOTAL COST	£37,900

A further cost of £10,000 should be added to this figure to allow for capital equipment purchased for West Avenue which will aid the establishment of a G.T. system by allowing plant duplication.

(c) Tooling Cost

It was difficult to predict tooling costs at this stage since really no tangible experience existed. There is no guidance on this aspect in the literature, and an estimate must be made. This again is difficult since a lot depends on the amount of sophistication a Company is prepared to pay for. The following estimate should therefore only be treated as a budget item:-

Considering West Avenue:-

30 families were planned for and an estimate of £300 tooling cost per family was made in conjunction with qualified staff at W.M.B. Thus a West Avenue tooling budget of £9,000 would appear to be reasonable.

The West Avenue plant would be responsible for 14% of the total Aylestone Road machine shop output. Assuming linearity of tooling cost, a budget figure of £65,000 should be allowed for tooling up all cells. It is likely that this estimate is high since cams tend to require more than an average amount of tooling. The subsequent costs and savings comparison demonstrated the relative insignificance of this cost figure, and a £65,000 tooling budget was proposed.

(d) Total Cost

The total cost calculation ignores the cost peculiar to the establishment of a separate West Avenue plant. This cost had to be written off anyway as a change in management policy. Thus the total cost breakdown can be given as follows:-

G.T. Analysis : Overall Project	£ 6,065
G.T. Analysis : West Avenue	£ 1,020
G.T. Analysis : 11 further cells	£11,000
Machine movement	£ 3,900
Capital & Revenue plant expenditure	£33,000
Tooling Cost	£65,000
West Avenue Capital	£10,000
	£129,985

4. DISCUSSION

4.1 G.T. Project Feasibility

The prime question in this report is:-

Is the application of G.T. at W.M.B. Aylestone Road

(a) Feasible ?

(b) Desirable?

The following discussion will show why both of these questions can be answered in the affirmative.

Once the Company operation had been analysed, it was possible to specify why G.T. was particularly suitable for W.M.B. Taking initially Leonard and Koenigsberger's criteria (see previous chapter), it would appear that W.M.B. are in many ways eminently suitable for G.T.

(i) A large number of small batches?

W.M.B. certainly have this particular problem. As indicated earlier the average annual usage of parts is very low indeed and this causes great difficulties. To have acceptable setting-to-machining-time ratios, batches must cover 3 to 9 months of usage, and this of course is totally unacceptable from a stock-level point of view. This factor is the most crucial one in confirming W.M.B.'s G.T. suitability, and it is in fact doubtful that in their environment any other manufacturing system could adequately cope within acceptable cost and capital levels.

(ii) Accurate production information?

An accurate production plan has not been available in the past, but with between 6 and 18 months sales well known in advance, there is no reason why a very stable and accurate production programme could not be established.

A considerable amount of work is being done in this area and within a short time, firm production plans should become available, which will allow the use of fixed cycle ordering techniques with full confidence. Since the plan prepared so far only required in the order of five or six months lead time from cell planning date to shipping date, it is likely that a firm production programme over this period can always be made available. Other production data such as methods, plant data and times are very poor, and a considerable amount of work needs yet to be done in this area. This does not of course invalidate the G.T. concept for W.M.B., but does require a greater effort during the establishment of the cell system than would be necessary if adequate information had been held in the past.

(iii) Customer delivery requirements?

W.M.B. are required to supply to promised delivery dates, and there have been many problems in this area, largely due to poor control of available capacity and a never-ending list of shortages in the assembly shop. Whilst the product excellence of W.M.B. has in the past ensured that poor delivery did not seriously affect sales, one cannot be certain that this situation can be maintained in the future.

(iv) Company control of raw material?

Like most companies, W.M.B. purchase their raw material and do not control it directly. Whilst this is a potential threat to a G.T. system, it is possible to compensate for this by good material planning, and techniques for this are well established throughout the engineering industry. Indeed, it can be argued that the demand for improved planning set by G.T. will provide the necessary data and planning consciousness which will reflect favourably on the material planning at W.M.B.

(v) Light Components?

Components at W.M.B. are comparatively light by general engineering standards.

(vi) Minimum inspection?

Inspection is quite extensive at W.M.B. caused by the component complexity involved. This certainly makes the G.T. concept at W.M.B. more difficult and challenging than in such companies as Ferodo or Serck Audio, but probably no more difficult than at say, Herbert.

(vii) Simple jobs and flexible labour?

Jobs tend to be complex and floating labour is not generally favoured. This sets up major problems which make G.T. complex at W.M.B. but by no means impossible. As the study on the pilot plant has shown, it is quite possible to build up a system which can cope with complex parts. Again the example of Herbert comes to mind as a company producing a complex product (i.e. machine tools) using a G.T. system. Constraints of this kind become increasingly less significant as more experience is gained throughout industry to cope with more complex situations.

(viii) Inexpensive plant?

The plant at W.M.B. is standard, light to medium engineering plant with the majority of items of low to medium capital value. Machine depreciation is only a small fraction of total cost, and underutilisation of machines is not a great cost item. A more serious consequence is the shortage of floor-space, and a reduction in machine utilisation would have to be accompanied by an improvement in productivity. This would not appear to be a major problem since the productivity level at Aylestone Road tends to be quite low.

(ix) Similarity of components and production operations?

Components at W.M.B. tend to be wide spread with many different types. They do however appear to fall into suitable families for cell establishment.

Some of these families are very similar (e.g. large turned parts or cams), others are more complex but still group together into a relatively small number of production processes. The problem on a wide range of different specialised machine tools which have to be spread over a small number of cells does not exist. By virtue of the grouping taking place and the general nature of the processes used, it is fairly easy to allocate virtually all machine tools to specific cells.

(x) A balanced machine utilisation?

The overall plant capacity analysis seems to indicate that in most cells an acceptable level of machine utilisation with reasonable balance can be achieved. There are instances of poor utilisation in some areas, but these will always exist within a G.T. system. It is quite surprising to see the high degree of average machine utilisation generally achieved in the suggested cells.

(xi) Maximum advantage of classification system?

Little can be said about this factor at this stage. There is no doubt in the author's mind that the Opitz code used in this analysis is very suitable for the overall cell design, and could be used to advantage for design retrieval work. There have been certain shortcomings which will be discussed later, but in general the advantages of the classification system have been considerable. Hardly any use has been made of the system in the area of design retrieval, but this is not so much a fault of the code but more a problem of acceptance and apathy in the design office.

A review of the company's problems in relation to the factors mentioned above leaves no doubt that the use of G.T. in the Aylestone Road plant of W.M.B. is not only feasible, but that indeed G.T. is probably the only manufacturing philosophy which can adequately cope with the particular problems met.

We face here an almost "classic" example of the dilemma of a batch producing plant. Average annual usage rates are very low, but the complexity of the parts requires relatively high batch sizes to achieve acceptable set-up time levels. The result is a high inventory level. This high inventory level is further aggravated by the "uncontrollability" of an incredibly complex manufacturing pattern. One has only to look at the current inventory figure of £2.6 million, which could be reduced by £1 million, using G.T. It is difficult to envisage any other manufacturing philosophy which could cope efficiently with this kind of problem.

The "uncontrollability" of the current system has often seriously limited output, because shortages have held back the assembly shop. There is therefore always the situation of the plant operating at a low level. The assembly areas are operating below their theoretical output rate owing to shortages holding up the programme, and in turn the machine shop is not called upon to produce to capacity, owing to the inability of the assembly shop to absorb the output. Two examples can be given to illustrate this problem:-

(i) Up to early 1972 the plant produced as a considerable proportion of its output one particular model of machine, with only very minor variations. The controllability of this machine was high, since a small number of different parts constituted a major proportion of the plant output. Also batch sizes were generally high. During the period of building this machine, the Aylestone Road factory was financially in a much healthier position and at the same time operator piece work earnings were considerably above current levels.

(ii) The author recently conducted a brief study of the cambox assembly area. This department has been a bottleneck for a period of time and despite staff increases, has been hard pressed to make an output of 50 machine sets per month. A capacity analysis indicated a theoretical capacity of 75 sets per month, a high current proportion of waiting times for shortages and relatively low earnings levels.

There can be no doubt that there is severe difficulty in controlling the current system. From a review of the G.T. literature, this is not surprising, and one cannot imagine any system other than G.T. having the capability to cope with this complex environment.

There is currently a lack of accurate data of any kind, and whilst this did seriously hamper the project at times, it did not make the study impossible and valid results were achieved, largely in keeping with expectations. The capacity data used in the project was in fact used by the Cost Controller as a basis for plant capacity planning. There would appear to be a useful opportunity here to set up a good level of information on a cell-by-cell basis. This would firstly break down the huge task into manageable proportions and secondly provide the opportunity to prove out systems on the first cell before the whole of the plant information system was updated.

It was expected that poor labour relations would be a serious obstacle. In the event this proved not to be so. Of course a considerable amount of discussion was involved during the initial stages, but once labour was transferred into the cell at the West Avenue plant, the cell team spirit made itself noticed. There is little doubt that with good management of the first cell, G.T. would "sell itself" and even floating labour and the mixing of skills would be acceptable to the Unions. As regards the latter point, W.M.B. are particularly favoured by having only one grade of labour and pay (i.e. skilled). This removes one of the major obstacles to floating labour. Furthermore, the indication at the West Avenue plant was that the high grade of labour at W.M.B. would lend itself to operator participation in cell management and production engineering, which would further improve morale, whilst at the same time giving the company the opportunity to take advantage of the considerable amount of production know-how existing amongst the operators.

W.M.B. are further favoured by their stable and long order book. With a suitable production planning system, which has been set up recently, and is now going through the stage data improvement, very accurate gross requirement lists can be established. This favours the use of period batch control, which requires better production forecasting than inventory control.

To obtain the real productivity benefits of G.T., it would be necessary to change the payment system. The current allowed times would either greatly limit the potential improvements in productivity or else escalate earnings to a ridiculously high level. There is therefore a need to negotiate a fair sharing of productivity improvements. Furthermore, the current operation-by-operation piece work system is not suitable. G.T. will require an increase in the number of operations where several set-ups have been grouped within one operation, and require a considerable increase in the number of batches issued. This might well raise the paperwork involved in the piece-work system to an unacceptably high level. A group bonus system with a suitable productivity improvement bonus would probably be the answer.

A look at the objectives of this project is required to see how these were met during the study. Naturally at this stage the objectives have not been fulfilled, but it should be possible to decide more clearly if it is possible to do so. This is the key to the feasibility of the project, and will help Management to decide if a continuance should be authorised.

I <u>Simplify Management Control</u>

The study on the pilot plant leaves no doubt that Management control will be simplified and improved. The key is the cell order chart tied to gross requirements for specific assembly periods. It has been demonstrated how with simple clerical effort a very high assurance can be given that the assembly requirements will be met. The simple feed-back loops included in the control system make it virtually certain that the current problems of stock uncertainties and shortages will be overcome. It should be noted, that with an increase in the number of cells the system's complexity does not increase. There are merely parallel additions of near identical systems. The G.T. production control would therefore exhibit horizontal growth, rather than vertical growth. The inherent departmentalisation of a G.T. system ensures that each production control clerk controls an area well within his capability.

II Reduce inventory?

This objective is well met and a look at the cost/saving audit in the previous chapter should dispel any doubt that in purely financial terms the project must be a success. The initial target of a 50% work in progress and finished part stock reduction can clearly be met and even improved upon.

III. Reduce progress effort?

In view of the increase in batch issues, it is unlikely that the number of clerks will be reduced significantly. The progress control will of course be greatly improved. When the objectives were initially set it was not appreciated to which extent batch issues would need to be increased, and the objective was set under false assumptions.

IV Rationalise sub-contract policy?

No work has been done in this area to date, largely because the prototype cell was planned with a component type which is not sub-contracted (i.e. cams). A review of the type of components sub-contracted seems to indicate that there is ample scope for a small turning cell, which in view of the wide range of parts required, should compete profitably with outside suppliers.

V Revised methods as a basis for improved productivity?

A start has been made with the design of group tooling using quick change setting pieces and power clamping. The work to date indicates that the revision of methods and tooling is not only desirable, but is in fact mandatory if the cell system is to achieve the flexibility to cope economically with small batches. A considerable amount of work is still required in this area, but there is no doubt that the cost could be recovered quickly by productivity improvements alone.

VI Improve working morale?

The observations on operator morale at the West Avenue plant indicate clearly the great potential for improvement of working morale. If other cells only achieve a small proportion of the good working spirit of the West Avenue plant, the benefit to Management in terms of labour relations and consequently output must be considerable. It is hard to guess at a productivity improvement due to improved morale, but providing an acceptable productivity sharing scheme is negotiated, one would expect a substantial increase in output from the improvement in morale alone, bearing in mind the slack piece-times at W.M.B. The working morale in all areas is particularly poor at present due to the production control problems indicated earlier. In this area G.T. should assist greatly to relieve the great amount of frustrations currently felt in most departments.

VII Reduce floor-floor times?

A prediction of a 21% productivity improvement has been made. This is of course purely an estimate but in the author's opinion, based on his observations at the West Avenue plant, and a review of currently allowed times, it is likely that this figure can be exceeded in an environment of high motivation.

VIII Form a design retrieval catalogue?

A design retrieval catalogue has been set up to date but has not been used. Further work is required in this area.

IX Ultimately study the total manufacturing/assembly system?

This is a long term objective and has not yet been developed.

X Develop proper management controls?

The work started at the West Avenue plant in the areas of production engineering and production control indicates that the G.T. project represents a good opportunity to improve the current level of control. The provision of proper data bases (i.e. planning data sheet, improved process planning, Cell Order Chart etcetera) and the use of simple feed-back loops in the control system provide a simple and effective method of ensuring that acceptable methods of management control are set up and maintained. One should note how simple and basic the techniques are. There is not necessarily any need for complex computer based management information systems to achieve adequate control of the manufacturing system. The correct manufacturing philosophy coupled with a systematic and logical approach to the problem can ensure a great improvement.

The above notes indicate that in general the objectives of the initial study are feasible and can be met quite easily. Only one objective (i.e. reduced progress effort) cannot be met, but this is offset by the improvements which can be achieved by meeting the other objectives. Certain areas (e.g. design retrieval) require further work, but there is no reason to suggest that improvements cannot be made.

4.2. Production Control Aspects

There is no doubt in the author's mind that in this project and probably in other G.T. projects, the key problem is one of administrative control. There are relatively few problems in the cell design. The analysis stages are well defined, there are a number of publicised techniques available, and a considerable amount of literature can be consulted to obtain detailed know-how. Certain aspects of the analysis can be obtained from standard production engineering and plant layout text books, and once a worker is clear on the issues involved, he should have little difficulty in designing a suitable cell system.

For the administration systems design, the situation is not as simple. There is very little guidance on the design of, say, production control systems for a G.T. analysis. There are a host of references to choose from on general production control methods for batch production, mass production or any other kind of production. Curiously enough, though, the G.T. workers have tended to skate around this problem in their discussions. Connolly discusses production control to some extent in relation to the Ferodo project, but the control aspects of this company were less demanding than those in a complex multi-product environment. Burbidge of course gives a good lead by demonstrating that period batch control is a pre-requisite of G.T., but he does not go into problems of capacity balancing and ensuring reasonable machine utilisation. In fact, most G.T. workers brush the problem of line balance aside by referring to the use of floating labour to cope with bottlenecks. A fundamental analysis of the problems involved was made in this report, and they brought up important aspects of production control in a G.T. environment, which are fundamental and must be considered when designing a system for a G.T. plant.

The theoretical work done for the West Avenue project also demonstrates the importance of relative operation batch times on total throughput times. It has been shown that for a minimum throughput time in a high plant and labour utilisation shop, the total batch time for individual operations should be as near equal as possible.

This is no easy problem where a number of families are scheduled, since by the same criterion the cumulative batch times for individual operations for each family should be near equal. Clearly this is not possible, especially where the cell deals with a number of families with different component features. This is a useful area for further research.

A further problem of G.T. which is fundamental and has been generally overlooked, is that of excess capacity while the cell is started up. Unless the whole plant is converted at the same time, the reduced throughput time for the cell components results in a capacity gap. This problem occurred at W.M.B., where only a proportion of all components were included in the cell, whilst the remainder of the plant maintained the functional layout. There was thus some problem in defining an adequate cell load over the initial months, since a considerable proportion of the gross requirements for the months had already been fully or partially produced. This problem poses a serious threat to the cost advantages of G.T. If the system is not planned carefully it is possible to lose a major proportion of the potential saving in the form of operator idle time. There are three methods of dealing with this situation:-

(i) Increase plant output slightly and accept increased labour mobility over the total implementation period.

(ii) Cut overtime and week-end working across the plant (without naming G.T. as the cause !), and again float labour across the plant during the total plant conversion period.

(iii) Plan the conversion of the whole or major proportion of the plant over a fairly short period, and maintain existing stock levels over this period. After the whole or substantial conversion, there will be an across the board excess stock, which can be disposed of by increased sales or planned expansion without capacity increase.

No work has been done to determine the financial merit of different strategies, and this could be the basis for further research. It should be noted however that a problem does exist and requires careful thought if the cost benefits of reduced stock levels are not to be lost. This problem does particularly refer to multi-product assembly plants where the cell output has to be combined with parts from the existing functional shop for assembly, before the product can be sold. Naturally where the cell produces its own saleable product, the problem does not exist. The argument presented here also indicates the common fallacy that buffer stocks must be set up to tide the plant over the low production period during the change-over.

4.3. Various Aspects of the Project

In a G.T. project of any reasonable magnitude, it is imperative to set out a detailed project plan. The W.M.B. study showed clearly that a G.T. analysis is a fairly complex project with many individual project stages. A project plan was found useful for the following reasons:-

(i) It ensured that a time-scale could be predicted which gave an indication to management when the separate phases would be completed.

(ii) It was found that data acquisition was the most time consuming activity. The project plan ensured that labour could be obtained and data collection started at an early enough date to ensure data availability when required. Furthermore, additional clerical labour was limited and the various data collection stages (drawings, planning sheets, times etcetera) had to be phased to maintain an acceptable level of labour at any one time.

(iii) At times there was Management pressure to reduce the support clerical labour. The project plan gave the G.T. team the opportunity to demonstrate how this would increase the project time. Generally the project plan proved to be a useful document to justify the labour input into the project.

A particular problem in specifying the amount of data for card punching was the correct compromise between cost and usefulness. It will be recalled that in this study the number of processes was, for recording purposes, reduced to six, namely turning, milling, drilling, surface grinding, cylindrical grinding, others. The detailed specification of machine tools was to be done by matching the processes with the Opitz code of the parts in the family, and this was moderately successful. By mainly relating to the component class and size range in each family, a good indication of the machine tools required was obtained, and it was possible to specify machine tools for each group of parts. There were however short-comings in this method which were overcome by the author's knowledge of the product and the methods employed, as well as by discussions with production engineering staff and foremen. More important, the limited card layout caused a duplication of work. This is easiest explained with reference to the cam cell. Considering milling, there was a choice of horizontal milling, vertical milling and profile milling, generally not interchangeable. Similarly for surface grinding, there was a choice of rotary surface grinding or plain surface grinding (used for different operations and from an economic point of view with only limited interchangeability), and profile grinding. In both cases it was not possible to split these processes out by investigation of the Opitz code. The Opitz code is, especially for non-rotational parts, not sufficiently detailed to give a clear relationship between the code and the specific process. As a result it was necessary to draw up a separate component/machine matrix for the detailed analysis of the cell. It would have been more suitable to specify a larger number of processes to get a more detailed split and use a free format data recording system as employed by Hunt (98), to record the data. This would have caused three problems:-

(i) There would probably not have been enough line space to get a fixed format tabulation which is easy to read.

(ii) The programming effort would have been greater.

(iii) There would have been the need to use more than one card per part, which would have made machine sorting more elaborate, manual sorting much more difficult and processing more error prone.

Another possibility would have been to split the processes over two or three cards and obtain a corresponding number of print-outs, each one recording all sample components, but only a fixed proportion of all the available processes. Two cards would have allowed the use of 12 processes on the existing format or probably 14 processes with a more condensed format. For the W.M.B. project and probably most other cases, this would have been sufficient.

The method indicated still does not require the detailed specification of machine tools for individual operations, but specifies processes sufficiently closely to allow a confident allocation of machine tools by comparing the Opitz class and size digits with the process in question. It would certainly have avoided the necessity for the manual writing up of the two component/machine matrixes.

Beyond the above reservations, it appears that component class and component size are quite adequate to define the specific type and size of machine within a defined process. This seems to tie up with suggestions in the literature that class, size, material and raw material shape are the key features of the code for cell design. This would indicate that, where the cell system of manufacture is the sole G.T. objective (i.e. total exclusion of design retrieval and variety reduction aspects of G.T.), a three or four digit code would be quite adequate, especially if specific components (e.g. cams and cylinders at W.M.B.) are further identified by a special parts code. These observations seem to indicate why certain workers such as Williamson advocate a very simple code.

There exists often a problem of lead time which was experienced in this project. In order to cut the project lead time, it was decided to start coding all current components before the sample had been analysed. Consequently, certain limitations of the code such as its limited identification of features on non-rotational parts were not detected until after the total component range had been coded with more or less the same code as the sample. There is of course no real reason why the sample code and the total component range code should be identical, even though this would be useful. As long as there is a facility to split the total component range in the same way as the sample, there may be wide differences in the two codes.

In practical terms this means that it is essential that the sample code and total component range code have the same class, size, raw material and raw material shape digits. All other digits can be modified for the total component range in the light of experience gained with the sample.

This argument does accept that the Opitz code is used as a guide only and will not be used as a firm standard. This must be acceptable however since the code was based on a specific frequency distribution of component features which does not necessarily apply to all companies.

The argument further demands a specific time scale which ensures that the sample is coded, analysed and split into families before the total component range is coded. Like many other workers, the author accepted the argument that the Opitz code is suitable for most engineering firms. This appears to be an oversimplification and whilst no doubt the Opitz code in its unmodified form will be useful in most cases, there is no doubt that it can be improved to be more specifically suitable to the company in question. Fig 71 shows the project stages in their critical path relationship quoting typical times as they would have applied at W.M.B. The time scale would have suffered by a few weeks, but this would have been worthwhile for the improvement in the design/production code which could have been achieved.

Six stages of analysis had been identified in the literature survey, namely:-

1. Identification
2. Family formation
3. Cell formation
4. Inter-cell flow analysis
5. Tooling analysis
6. Management services

These stages had been adhered to very closely throughout the analysis apart from some overlap to cut the lead time and the precipitated choice of the pilot cell.

There can be no doubt that all of these stages are required in a G.T. study and each stage must be planned carefully, to ensure that its specific execution is matched to the plant in question. As the project experience with classification and coding indicated, it is easy to develop preconceived ideas and consequently produce a less than optimum solution. The same experience seems to indicate that beyond the six main stages, no standardised approach of analysis can be specified and each stage has to be designed within the available range of working tools to ensure that the correct analysis for the plant in question is chosen.

4.4. Management Support

There can be no doubt that a project of this magnitude can only succeed if it has the backing of a senior executive, preferably the Managing Director himself. The W.M.B. project demonstrated a number of problems which can be met and which, unless the project is supported at the highest level, can seriously jeopardise the project. In fact in a subsidiary company such as W.M.B. the project can suffer seriously from decisions beyond the Company Board, and some initial "selling" of the concept by the Company Board to the Group Board is necessary.

There are always going to be problems at middle management caused by the usual resistance to change, but these can be overcome by discussion and the firm committment by top management. More difficult is the situation where senior management (i.e. Board Directors) have certain short term problems and sacrifice G.T. to divert resources into these problem areas. It was felt by the author at W.M.B. that there was a problem of time scale. The G.T. project promised certain results, but these had to be preceded by close to a year's analysis followed by, say, 1½ to 3 years implementation. In many ways this period was too long. It is easy for the Board to lose interest and other problems and projects compete with G.T. for priorities. W.M.B. had certain operational problems during the G.T. analysis, which could ultimately be solved by G.T., but in order to "survive", resources had to be channelled into the immediate short-term solutions, and this detracted at times from the G.T. project.

There were also problems at W.M.B. resulting from the poor economic climate throughout industry. Firstly the West Avenue plant, as indicated earlier, required a certain amount of capital. This requirement coincided with an economic "squeeze", which made capital less available, together with the approach of the end of a poor year for the Aylestone Road plant, with consequent pressure on overhead costs. Furthermore, with the advent of a three day working week across the country, delivery of ordered equipment was prolonged drastically, causing a long start-up time of the West Avenue plant.

The 1974 budget required severe cuts in overhead spending to meet profit targets, and there was pressure from the Group Board to cut costs at the expense of such long term projects as G.T. (which incidentally was not the only major project to suffer). This latter problem is a common one of course, where long term priority is sacrificed for short term gain, and is a particularly damaging policy practised in many companies.

5. CONCLUSIONS:-

The objective of this report was to study the possibility of applying G.T. at Wildt Mellor Bromley Limited, Aylestone Road, Leicester. The study was brought to a successful termination and the following specific conclusions were drawn:-

5.1. The introduction of G.T. into the Aylestone Road plant of WMB would be highly beneficial in terms of financial benefits and management control.

5.2. For a plant such as WMB, with its wide variety of parts with low average annual usage, G.T. is probably the only acceptable manufacturing system.

5.3. G.T. would greatly increase management control by providing better control of batch sizes and a better match of manufactured to assembled quantities.

5.4. G.T. would allow a reduction of batch sizes which would make a one-month based period batch control system of production control workable.

5.5. To be able to use a short manufacturing period (i.e. one month) it is essential at WMB to :-

(a) Load batches in families of similar parts,

(b) Design group tooling which could accept a number of different components,

(c) Use group process planning sheets for each family of parts where each part has the same operation sequence, if necessary by the use of dummy operations.

5.6. The G.T. project should have a major impact on Company profitability (in the area of 5% of turnover) and stock levels (in the area of a £1 million reduction).

5.7. The objectives of the project were generally met.

5.8. Period batch control is an inherently high stock system but provides a basis for the reduction of batch sizes which allows a corresponding reduction in stock levels.

5.9. A period batch control system cannot be used to make exact period requirements. The excess allowances for scrap and spares which must be included require a more elaborate control mechanism.

5.10. If high machine utilisation and low labour flexibility are required, the control requirements are greatly increased.

5.11. In such a case it is desirable to balance the cumulative operation times of families to get total operation times of similar length. Furthermore it is likely that computer assistance is required to cope with the scheduling problem.

5.12. Where lower machine utilisation and labour flexibility are acceptable, the scheduling problems are greatly reduced.

5.13. The Opitz code was suitable for the project but could have been improved by making modifications.

5.14. The distribution of components features and in particular the bias towards rotational parts, claimed by Opitz to be normal for the general engineering industry did not apply at WMB.

5.15. It would appear to be dangerous to accept Opitz's generalisations relating to components statistics, and tests are required to check their validity in each operation.
It is necessary to ensure that a large enough representative sample is chosen for this purpose.

5.16. The cell system of manufacture appears to greatly improve operator morale.

5.17. It is possible to improve morale such that operators work towards the company's goals, at times to the detriment of long-standing Trade Union rules.

5.18. The cell members can stretch their capability in terms of technological and organisational ability far beyond that expected from them in a functional layout.

5.19. The increased autonomy and responsibility in a cell system increases work satisfaction and morale and provides for a level of responsibility which will require a much reduced management effort to maintain output and discipline.

APPENDIX

1.2. The Use of the Classification System

The component drawing must be referred to when a component is to be coded. The main shape, the shape as machined, the initial shape, the material, accuracy and the dimensions are coded. If this information is not available from the drawing, then the planning of the work must also be taken into consideration.

Basically, the final shape of the component (the shape of the component after machining and before assembly) is comprised in the geometrical code. The initial shape (the shape of the component before machining) is given separately in the supplementary code. The initial shape often shows the essential geometrical elements of the final shape and these are then drawn on for the description of the main shape.

The initial arrangement of a component into one of the component classes depends on the dimensional ratios according to the overall shape of the component. The geometrical overall shape of a component is the least circumscribing cylinder or rectangular prism, orientated according to the axis of the main shape of the component.

The overall shape of rotational components, with and without deviations, is given by a cylinder with the dimensional ratio of length *L* to diameter *D*.

For rotational components without deviations and rotational components with deviations with only one axis of rotation, it is the *L/D* ratio of the cylinder whose geometrical axis coincides with the rotational axis of the component and that envelopes the finish-machined component being coded.

For rotational components with deviations and several axis of rotation, the *L/D* ratio is that of the longest rotational axis to the largest relevant diameter resulting from the rotation of the component.

Non-rotational components are enclosed in the rectangular prism of least volume, and this is described by the lengths of its edges *A*, *B* and *C*. In this description $A > B > C$.

The individual positions of code digits are arranged in increasing order of difficulty. If a component has several features in a code digit, the position with the greatest degree of difficulty—the position with the highest figure—must always be chosen.

Several features are assembled in groups within a single code digit and are distinguished by being separated with a thick vertical line. If a feature is marked with one positional figure from one of these groups, the lower positional figures within the group may be taken to be included but not those of another group.

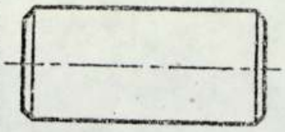
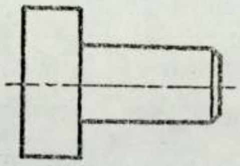
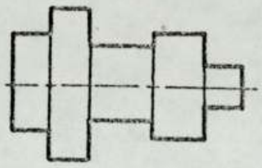
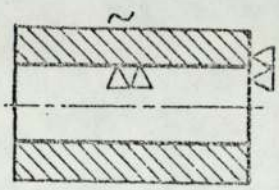
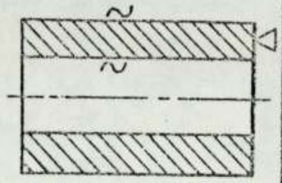
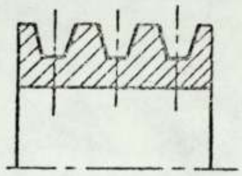
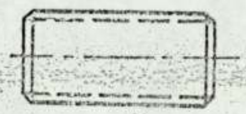
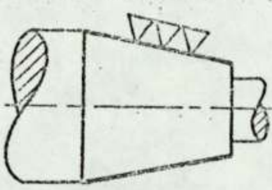
Features that come within the higher concept of a code digit and not separately quoted are comprised in position 9 under "Others" (e.g. surfaces curved in space come within the higher concept in the fourth digit "surface machining"; since they are not described as a feature they are therefore coded in position 9).

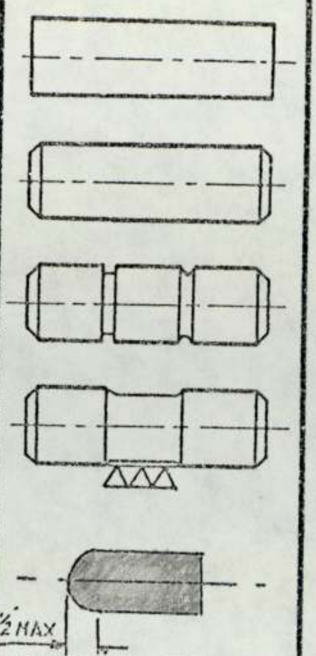
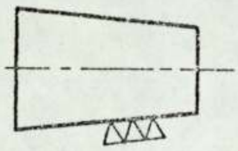
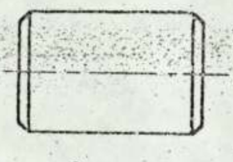
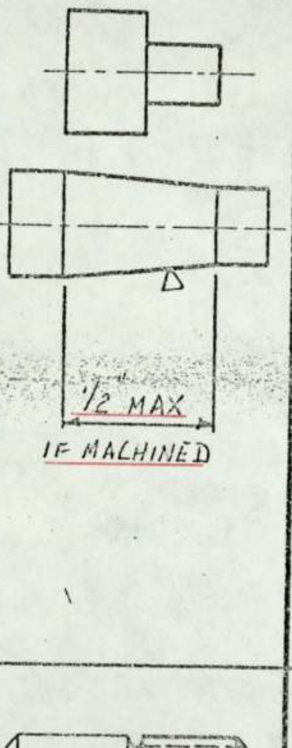
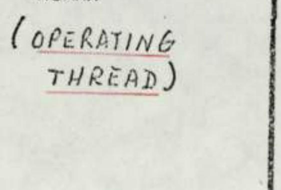
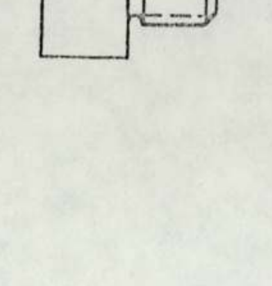
1.3. Example of Coding (Rotational Component)

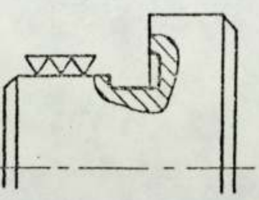
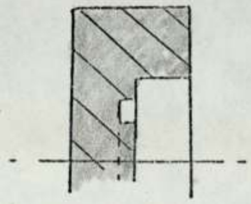
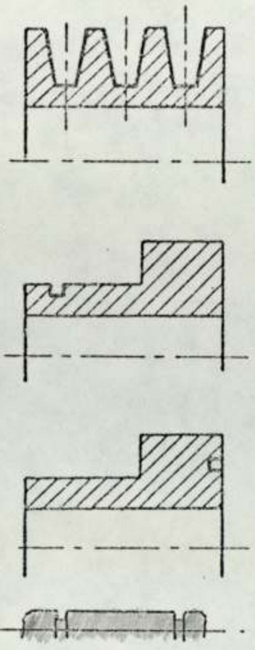
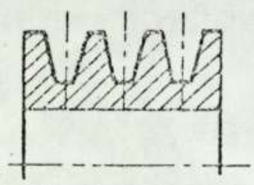
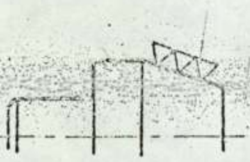
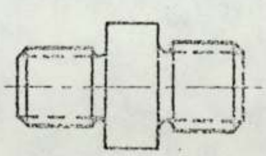
1.4. Example of Coding (Flat Component)

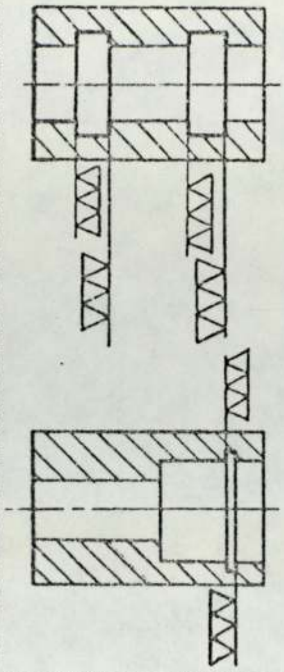
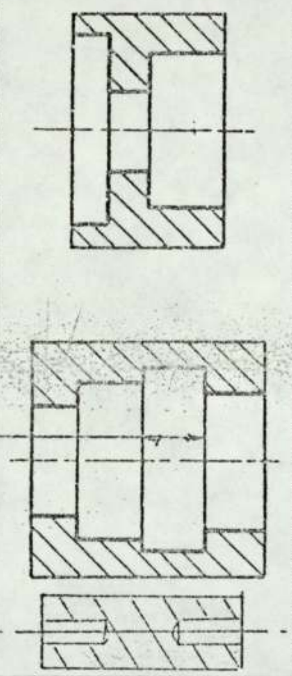
1.5 Rotational and Non-rotational components:

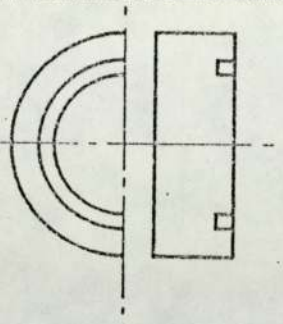
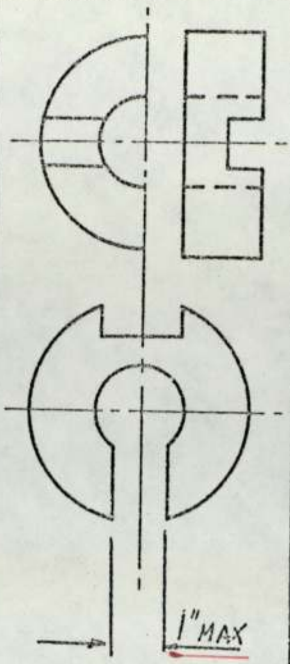
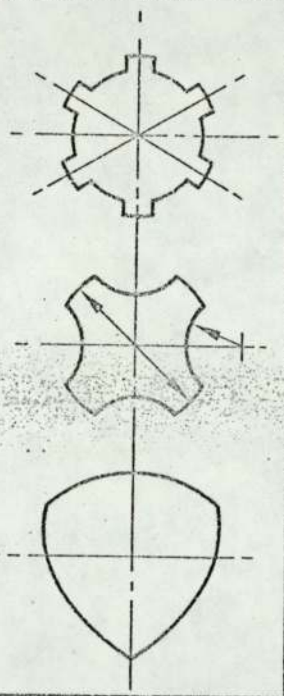
The rotational component rotates during circular shape generation (e.g. on a lathe). The non-rotational component remains stationary during circular shape machining (e.g. copy milling machine and horizontal borer.

No	Yes	Designation
	  	*External shape* The external shape of a rotational component without deviations is cylindrical, consisting of the curved outer surface and plane surfaces. The cylindrical shape must appear in the initial shape. Plane surfaces count in the external shape, except with unmachined external cylindrical surfaces and a machined shape internally.
 x01xx	  	*Shape element* Shape elements are such as by virtue of their shape perform a quite definite function and pose definite requirements on production (e.g. grooves for V-belts and sealing rings, functional tapers and threads). Relief grooves, oil ways, chamfers and bevels are not included under this heading.
		*"Others" in Position 9* Components that have more than about 10 machined diameters distributed along the entire length and differing in steps are comprised under position 9. Chamfers, bevels, grooves, etc., are disregarded in assessing the diameter. Components which have a shape which is generated (profiles wider than 1/2")

No	Yes	Pos.	Designation	Coding digit
		0	*Smooth, no shape elements* Rotational components that have a uniform diameter along the entire length. Chamfers, grooves, provided that they are not functional are disregarded. Profiles up to andincluding 1/2" width which can be formed in one cut with a form tool are ignored or classed as stepped where according diameter changes take place.	2
 x7xxx  x0xxx		1	*Stepped to one end, no shape elements* Rotational components with several diameters distributed along the entire length and increasing in one direction.	
 x8xxx (OPERATING THREAD)		2	*Stepped to one end or smooth, with screw threads* All threads except those mentioned under operating threads.	

No	Yes	Pos.	Designation	Coding digit
 x1xxx  xx3xx		3	*Stepped to one end or smooth, with functional groove* Only grooves fulfilling a definite function and imposing rather high demands on production; e.g. grooves for V-belts, labyrinth glands, circlips, etc. In contrast, undercuts for threads, chamfers, etc., do not come in this position. Grinding relief and oil grooves are ignored unless rigorous machining requirements are called up. Any turned groove on the periphery or the faces unless faces are internal.	2
 x3xxx  x7xxx		4	*Stepped to both ends (multiple increases), no shape elements* Rotational components with several diameters distributed along the length and alternately increasing and decreasing.	
		5	*Stepped to both ends (multiple increases), with screw threads* All threads except those mentioned under operating threads.	

No	Yes	Pos.	Designation	Coding digit
		3	*Smooth or stepped to one end, with functional groove* Only grooves fulfilling a definite function and imposing rather high demands on production; e.g. grooves for labyrinth glands, circlips, etc. In contrast, undercuts for threads, chamfers, etc., do not come in this position.	3
OVER ½'		4	*Stepped to both ends (multiple increases), no shape elements* The internal shape of a rotational component is stepped to both ends if bores of several diameters are distributed along the entire length and alternately increase and decrease in the direction of the axis. Blind bores on both sides are included under this heading. A recess in the centre of width greater than 1/2" is included, if this is functional. Cast relief or relief to aid production is not considered.	
		5	*Stepped to both ends (multiple increases), with screw threads* All threads except those mentioned under operating threads.	

No	Yes	Pos.	Designation	Coding digit
		3	*External groove and/or slot*	
		4	*External spline and/or polygon* A polygon is defined as a number of curvilinear surfaces related to one another by graduation around a circle. Also included are components with milled features related to one another by graduations around a circle, where these consist of more than 6 divisions (e. g. ratchet wheel cylinder, dial)	4
		5	*External plane surface and/or groove and/or slot, spline* (Combination of any two or more of positions 1,2,3 and 4)	

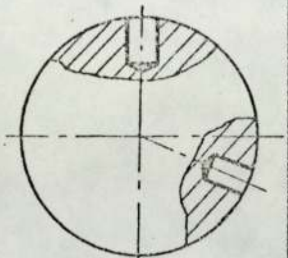
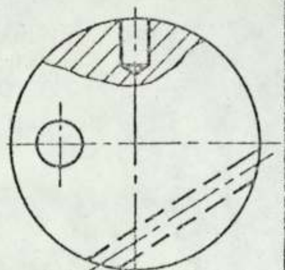
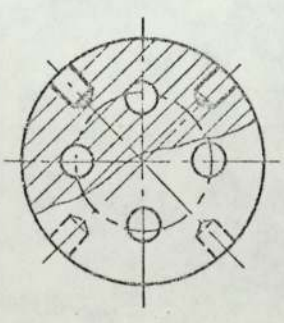
No	Yes	Pos.	Designation	Coding digit
		3	*Radial hole(s) not related by drilling pattern, no gear teeth*	
		4	*Holes, axial and/or radial and/or in other directions, not related, no gear teeth* Holes not axial or in more than one direction none of which are related by drilling pattern.	
		5	*Holes, axial and/or radial and/or in other directions, related by drilling pattern, no gear teeth* Holes not axial or in more than one direction. At least two of these must be related by a drilling pattern. A drilling pattern either relates holes in one plane (e.g. axial) or holes by an angle between them with the hole centre line meeting in one point on the part axis (e.g. radial)	5

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TABLE I SMALL SAMPLE OPITZ CODE FEATURE DISTRIBUTION

Opitz First Digit (Class)	Number of Components	Sample %	
0	11	11	53%
1	20	21	
2	20	21	
3	2	2	6%
4	4	4	
6	15	16	41%
7	9	9	
8	16	16	
	97	100%	

TABLE II PUNCHED CARD LAYOUT

Column	Used for
1-5	Opitz geometry
6	/
7-10	Opitz supplementary
11	Blank
12	Source code
13	Blank
14	Special parts code
15	Blank
16-18	No. per machine
19-20	Blank
21-27	Turning, ie: 21 - sequence code 22 - frequency of process 23-26 - operation time 27 Blank
28-34	Milling
35-41	Drilling
42-48	Grinding straight
49-55	Grinding circular
56-62	Others
63	Additional operations
64-65	Spare
66-75	Part No.
76	Blank
77	Machine code
78	Blank
79-80	Spare

TABLE III (a) FREQUENCY DISTRIBUTION OF COMPONENT FEATURES

First Opitz Digit	Digit Value / Subseq. Digits	Frequency of Occurrence in Sample 0	1	2	3	4	5	6	7	8	9
0	2nd Digit	98	44	3	10	16	-	3	2	-	-
	3rd Digit	21	129	5	3	5	1	1	-	-	-
	4th Digit	105	5	1	24	12	1	13	1	2	1
	5th Digit	59	11	43	11	2	23	12	4	-	-
	6th Digit	34	48	28	13	8	2	27	5	-	-
	7th Digit	109	40	7	5	4	-	-	-	-	-
	8th Digit	37	11	54	18	30	-	1	10	2	3
	9th Digit	32	61	10	-	-	4	-	50	2	6
1	2nd Digit	33	52	32	8	12	13	7	2	2	4
	3rd Digit	7	69	14	1	6	-	1	-	-	-
	4th Digit	104	9	8	31	-	6	4	1	2	-
	5th Digit	103	2	9	18	2	12	13	3	3	-
	6th Digit	95	47	18	3	2	-	-	-	-	-
	7th Digit	72	69	21	2	1	-	-	-	-	-
	8th Digit	11	2	72	24	43	2	1	5	-	5
	9th Digit	34	98	13	2	-	-	-	13	-	5
2	2nd Digit	90	29	41	19	22	26	9	3	-	-
	3rd Digit	161	31	27	1	8	9	2	-	-	-
	4th Digit	164	17	7	41	2	8	-	-	-	-
	5th Digit	151	9	3	47	4	22	2	1	-	-
	6th Digit	198	28	9	-	2	1	-	1	-	-
	7th Digit	39	73	49	32	20	10	7	7	2	-
	8th Digit	6	-	137	36	54	1	-	4	1	-
	9th Digit	47	140	36	7	-	2	-	6	1	-
3	2nd Digit	10	3	4	29	3	3	-	9	-	-
	3rd Digit	12	17	11	2	-	-	12	6	1	-
	4th Digit	25	6	-	8	-	14	6	-	2	-
	5th Digit	22	3	7	21	8	-	-	-	-	-
	6th Digit	15	26	7	2	1	-	5	2	3	-
	7th Digit	17	32	11	1	-	-	-	-	-	-
	8th Digit	12	-	13	2	15	4	15	-	-	-
	9th Digit	5	8	17	-	-	-	1	24	-	7

TABLE III (b) FREQUENCY DISTRIBUTION OF COMPONENT FEATURES

First Opitz Digit	Digit Value / Subseq. Digit	Frequency of Occurrence in Sample: 0	1	2	3	4	5	6	7	8	9
4	2nd Digit	14	2	4	2	1	–	7	7	5	–
	3rd Digit	5	7	18	1	–	–	2	6	2	1
	4th Digit	31	1	4	3	1	1	–	–	–	1
	5th Digit	30	1	8	1	2	–	–	–	–	1
	6th Digit	33	5	3	1	–	–	–	–	–	–
	7th Digit	6	19	10	1	1	5	–	–	–	–
	8th Digit	3	–	26	5	6	–	1	1	–	–
	9th Digit	3	15	19	1	–	–	–	4	–	–
6	2nd Digit	63	27	77	57	110	7	14	64	8	2
	3rd Digit	424	2	–	–	1	1	–	1	–	–
	4th Digit	104	–	1	4	131	26	98	65	–	–
	5th Digit	48	63	5	234	78	1	–	–	–	–
	6th Digit	27	166	164	34	20	9	7	2	–	–
	7th Digit	401	16	8	3	1	–	–	–	–	–
	8th Digit	51	–	117	13	168	1	70	4	2	3
	9th Digit	–	8	182	1	–	88	3	73	6	68
7	2nd Digit	54	16	6	19	14	64	50	39	15	2
	3rd Digit	279	–	–	–	–	–	–	–	–	–
	4th Digit	63	–	4	1	88	27	53	43	–	–
	5th Digit	26	48	2	139	64	–	–	–	–	–
	6th Digit	9	33	104	63	39	14	10	4	–	3
	7th Digit	244	13	16	2	2	1	–	–	1	–
	8th Digit	31	1	81	13	111	–	31	5	5	1
	9th Digit	1	7	153	1	2	37	–	35	6	37
8	2nd Digit	25	53	11	8	1	110	9	15	–	1
	3rd Digit	211	13	3	1	1	1	3	–	–	–
	4th Digit	45	2	11	–	90	16	45	24	–	–
	5th Digit	34	32	9	43	115	–	–	–	–	–
	6th Digit	42	112	37	17	13	8	4	–	–	–
	7th Digit	130	61	30	5	5	1	1	–	–	–
	8th Digit	65	–	78	14	50	–	20	2	4	–
	9th Digit	–	3	64	–	–	12	–	119	20	14

TABLE IV   PERCENTAGE DISTRIBUTION OF COMPONENT SIZE RANGE WITHIN SPECIFIED OPITZ CLASSES

Class	Size Range	% of Total Class		
0	D ≤ 2"	50%	(D ≤ 0.8"	21%
			(0.8" < D ≤ 2"	29%
	2" < D ≤ 4"	17%		
	4" < D ≤ 16"	14%		
	D > 16"	19%		
1	D ≤ 2"	86%	(D ≤ 0.8"	58%
			(0.8" < D ≤ 2"	28%
	2" < D ≤ 4"	13%		
	4" < D ≤ 16"	1%		
2	D ≤ 2"	95%	(D ≤ 0.8"	83%
			(0.8" < D ≤ 2"	12%
	2" < D ≤ 4"	4%		
	D > 4"	1%		
3,4	D ≤ 2"	76%		
	2" < D ≤ 4"	10%		
	4" < D ≤ 16"	4%		
	D > 16"	10%		
6,7,8	A ≤ 4'	74% *		
6,7	4" < A ≤ 16"	19% *		
8	4" < A ≤ 16"	4% *		
6,7,8	A > 16"	3%		

* Percentage of total 6,7,& 8

TABLE V   FAMILY CAPACITY SUMMARY (FIRST TRIAL RUN)

(HOURS PER YEAR)

Family	Description	Turn	Mill	Drill	Surf.Grd.	Cyl.Grd.	Other
1	Rot'l 0,1,2 0" - 2" dia.	8,165	2,189	2,123	1,009	1,927	72
2	Rot'l 0,1 2" - 4" dia.	3,767	828	1,426	328	1,085	207
3	Rot'l 0,1 4" - 16" dia.	4,586	418	5,084	1,263	990	35
4	Rot'l 2 2" - 4" dia.	665	153	292	9	138	0
5	Rot'l 2 4" - 6½" dia.	0	0	0	0	0	0
6	Rot'l 0 16" + dia.	10,727	3,612	5,012	980	1,728	12
7	Rot. Dev. 3 0" - 2" dia.	892	1,067	1,239	1,265	191	16
8	Rot. Dev. 4 0" - 2" dia.	374	153	126	51	0	0
9	Rot. Dev. 3 2" - 4" dia.	0	223	9	37	19	0
10	Rot. Dev. 3 4" - 16" dia.	414	35	118	0	0	0
11	Rot. Dev. 3 16" + dia.	4,197	1,648	4,641	79	0	0
12	Rot. Dev. 4 2" + dia.	42	56	14	14	7	0
13	Non Rot. 6,7,8 0" - 4"	1,493	67,574	28,901	19,298	809	343
14	Non Rot. 6,7 4" - 16"	2,264	25,876	34,855	5,565	88	137
15	Non Rot. 8 4" - 16"	1,046	4,313	4,175	615	65	42
16	Non Rot. 6 16" +	696	1,448	2,106	691	0	0
17	Non Rot. 7 16" +	0	360	259	93	0	193
18	Non Rot. 8 16" +	541	1,202	1,726	0	0	2
TOTAL		39,869	111,135	92,106	31,297	7,047	1,059

TABLE VI FAMILY CAPACITY SUMMARY (SECOND TRIAL RUN)

(HOURS PER YEAR)

Family	Description	Turn	Mill	Drill	Surf.Grd	Cyl.Grd	Other
1	Rot. 0,1,2 0" - 2" dia.	8,165	2,189	2,123	1,009	1,927	72
2	Rot. 0,1 2" - 4" dia.	3,767	838	1,426	328	1,085	207
3	Rot. 0,1 4" - 16" dia.	4,586	418	5,084	1,263	990	35
4	Rot. 2 2" - 4" dia.	665	153	292	9	138	0
5	-	-	-	-	-	-	-
6	Rot. 0,3 16" + dia.	14,924	5,260	9,653	1,059	1,728	12
7	-	-	-	-	-	-	-
8	Rot. 3,4 0" - 2" dia.	1,266	1,063	1,345	1,065	106	16
9	Bolt Cams	-	158	20	252	85	0
10	Rot. 3,4 2" - 6½" dia.	42	278	23	51	26	0
11	Rot. 3 3" - 10" dia.	414	35	118	0	0	0
12	Non Rot. 6,7,8 0" - 4" Steel	0	55,126	22,013	20,850	559	383
13	Non Rot. 6,7,8 0" - 4" Misc.	0	6	44	0	0	0
14	Non Rot. 6,7,8 0" - 4" C.I.	0	12,240	6,190	494	0	0
15	Non Rot. 6,7 4" - 16"	0	21,003	33,094	3,954	88	98
16	Non Rot. 8 4" - 16"	0	2,476	3,201	206	65	0
17	Non Rot. 6 16" +	0	459	1,526	691	0	0
18	Non Rot. 7 16" +	0	360	259	93	0	193
19	Non Rot. 8 16" +	0	1,202	1,320	0	0	0
20	Non Rot. 6,7,8 0" - 2" with turning	1,047	676	623	16	250	0
21	Non Rot. 2"-4" with turning	445	322	332	0	0	0
22	Non Rot 4"-16" with Turning	3,307	5,913	2,436	1,292	0	42
23	Non Rot. 16" + with turning	1,237	988	986	0	0	0

ABLE VII RATIONALISATION OF FAMILIES INTO CELL GROUPS

roup	Families	Description	Turn	Mill	Drill	Surf.Gd	Cyl.Gd
1	1	Small Rotational	8,165	2,189	2,123	1,009	1,927
	8	up to & inc. 2"	1,266	1,063	1,345	1,065	106
	20	Diameter	1,047	676	623	16	250
	TOTAL		10,478	3,928	4,091	2,090	2,283
2	2	Short Rotational	3,767	828	1,426	328	1,085
	21	2" - 4" dia.	445	322	332	0	0
	TOTAL		4,212	1,150	1,758	328	1,085
3	3	Short Rotational	4,586	418	5,084	1,263	990
	11	4" - 16" dia.	455	91	132	14	7
	22		3,307	5,913	2,436	1,292	0
	TOTAL		8,348	6,422	7,652	2,569	997
4	4	Long Rotational 2" - 4" dia.	665	153	292	9	138
5	6	Large Rotational	14,924	5,260	9,653	1,059	1,728
	23	16" dia. +	1,237	988	986	0	0
	TOTAL		15,161	6,248	10,639	1,059	1,728
6	9	4" Cube - Steel	0	380	29	289	103
	12		0	55,126	22,013	21,139	1,562
	TOTAL		0	55,506	22,042	21,139	1,562
7	14	4" Cube - Cast Iron	0	12,240	6,190	494	0
8	15	16" Cube	0	21,003	33,094	3,954	88
	16		0	2,476	3,201	206	65
	TOTAL		0	23,479	36,295	4,160	153
9	17	80" Cube	0	459	1,526	691	0
	18		0	360	259	93	0
	19		0	1,202	1,320	0	0
	TOTAL		0	2,041	3,105	784	0

ELL NO: 1

TABLE VIII (a)

ESCRIPTION:

mall turned parts, rotational and rotational with deviation up to and ncluding 2" diameter.

(Opitz Codes 0xxxx, 1xxxx, 2xxxx, 3xxxx, 4xxxx, diameter codes 0 & 1)

ACHINE TOOL LIST

YPE	QUANTITY	AREA EACH (SQ.FT.)	TOTAL AREA (SQ. FT.)	OPERATORS
erbert No.4 Capstan	3	30	90	3
ard No.7 Capstan	1	70	70	1
ard No.3A Capstan	1	30	30	1
o.1 Horizontal Mill	1	40	40	1
-Spindle Drill	2	15	30	2
& S 540 Grinder (Surf.)	1	30	30	1
& S 1300 Grinder (Cyl.)	1	35	35	1
o.2 Horizontal Mill	1	40	40	1

ACHINE AREAS: 365 sq. ft.	DIRECT LABOUR:
ERVICE AREAS: 840 sq. ft.	INDIRECT LABOUR:
THER AREAS:	STAFF:
OTAL CELL AREA: 1,205 sq. ft.	TOTAL LABOUR:

ELL NO: 2

TABLE VIII (b)

ESCRIPTION:

hort rotational 2" - 4" diameter

Opitz Codes 0xxxx/2xxx, 1xxxx/2xxx)

ACHINE TOOL LIST

YPE	QUANTITY	AREA EACH (SQ.FT.)	TOTAL AREA (SQ. FT.)	OPERATORS
Turret Lathe Ward No.7	1	70	70	1
Centre Lathe	1	140	140	1
Copy Lathe Elliott	1	30	30	
Horizontal Mill No.2	1	40	40	1
2-Spindle Drill	1	15	15	1
J & S 540 Surf. Grd.	1	30	30	
J & S 1300 Cyl. Grd.	1	35	35	1

ACHINE AREAS: 360 sq. ft.	DIRECT LABOUR:
ERVICE AREAS: 828 sq. ft.	INDIRECT LABOUR:
THER AREAS:	STAFF:
OTAL CELL AREA: 1,188 sq. ft.	TOTAL LABOUR:

E L L N O : 3

TABLE VIII (c)

E S C R I P T I O N :

hort rotational 4" to 16" diameter

Opitz Class Code (first digit) 0,1,3)

Opitz Diameter Code (sixth digit) 3,4,5)

ACHINE TOOL LIST

YPE	QUANTITY	AREA EACH (SQ.FT.)	TOTAL AREA (SQ. FT.)	OPERATORS
urret Ward No.7	1	70	70	1
urret Verb. No.9	3	84	252	3
orizontal Mill No.3	2	65	130	2
niversal Mill No.2	1	40	40	1
-Spindle Drill	3	15	45	3
adial Drill	1	30	30	1
& S 1011 Surf. Grd.	1	40	40	1
hurchill Cyl. Grd.	1	50	50	1

ACHINE AREAS: 657 sq. ft.	DIRECT LABOUR:
ERVICE AREAS: 1,511 sq. ft.	INDIRECT LABOUR:
THER AREAS:	STAFF:
OTAL CELL AREA: 2,168 sq. ft.	TOTAL LABOUR:

ELL NO: 4

TABLE VIII (d)

ESCRIPTION:

ong rotational: copy lathe work

ACHINE TOOL LIST

YPE	QUANTITY	AREA EACH (SQ.FT.)	TOTAL AREA (SQ. FT.)	OPERATORS
Gallicop Copy Lathe	1	30	30	1
Universal Mill No.2	1	40	40	1 (Universal Mill No.2 and 2-Spindle Drill)
2-Spindle Drill	1	15	15	

IACHINE AREAS: 85 sq. ft.	DIRECT LABOUR:
SERVICE AREAS: 196 sq. ft.	INDIRECT LABOUR:
OTHER AREAS:	STAFF:
TOTAL CELL AREA: 281 sq. ft.	TOTAL LABOUR:

ELL NO.: 5 TABLE VIII (e)

ESCRIPTION:

rge turned parts (greater than 16" diameter)

CHINE TOOL LIST

PE	QUANTITY	AREA EACH (SQ.FT.)	TOTAL AREA (SQ. FT.)	OPERATORS
bster & Bennett	12	80	960	12
0% spare capacity)				
.3 Universal Mill	2	65	130	2
drotel Mill	1	120	120	1
tonomic Drill	1	122	122	1
dial Drill	5	30	150	5
t. Surf. Grd.	1	55	55	
urchill Cyl. Grd.	1	100	100	1
ss Cylinders				
bster & Bennett	3	80	240	3
dial Drill	1	30	30	1
			270	4

CHINE AREAS: 1,367 sq. ft.	DIRECT LABOUR:
RVICE AREAS: 3,144 sq. ft.	INDIRECT LABOUR:
HER AREAS:	STAFF:
TAL CELL AREA: 4,411 sq. ft.	TOTAL LABOUR:

ELL NO.: 6

TABLE VIII (f)

ESCRIPTION:

Ion-rotational parts falling into a 4" cube: steel only

ACHINE TOOL LIST

YPE	QUANTITY	AREA EACH (SQ.FT.)	TOTAL AREA (SQ. FT.)	OPERATORS
" Cube				
Iorizontal Mill No.2	2	40	80	2
Iorizontal Mill No.3	1	65	65	1
'ertical Mill No.2	1	40	40	
-Spindle Drill	5	15	75	5
omb Mill	2	40	80	1
& S 1011 Surf.Grd.	2	40	80	2
ot. Surf. Grd.	1	60	60	1

ACHINE AREAS: 480 sq. ft.	DIRECT LABOUR:
ERVICE AREAS: 1,104 sq. ft.	INDIRECT LABOUR:
THER AREAS:	STAFF:
OTAL CELL AREA: 1,584 sq. ft.	TOTAL LABOUR:

ELL NO: 7

TABLE VIII (g)

ESCRIPTION:

n-rotational cast iron parts falling into a 4" cube

CHINE TOOL LIST

PE	QUANTITY	AREA EACH (SQ.FT.)	TOTAL AREA (SQ. FT.)	OPERATORS
orizontal Mill No2	6	40	240	6
ertical Mill	1	40	40	–
-Spindle Drill	3	15	45	3
& S 1011 Surf.Grd.	1	40	40	1

ACHINE AREAS: 365 sq. ft.	DIRECT LABOUR:
ERVICE AREAS: 840 sq. ft.	INDIRECT LABOUR:
THER AREAS:	STAFF:
OTAL CELL AREA: 1,205 sq. ft.	TOTAL LABOUR:

ELL NO.: 8 TABLE VIII (h)

ESCRIPTION:

on-rotational parts falling into a 16" cube but larger than a 4" cube

ACHINE TOOL LIST

PE	QUANTITY	AREA EACH (SQ.FT.)	TOTAL AREA (SQ. FT.)	OPERATORS	
o.3 Horizontal Mill	4	65	260	4+2)	4 double shifted
o.3 Universal Mill	4	65	260	4+2)	
adial Drill	2	30	60	2+1	1 double shifte
ero N.C. Drill	2	45	90	2+2	Double shift
-Spindle Drill	7	15	105	7+4	4 double shifte
& S 1011 Surf.Grd.	1	40	40	1	
now Surface Grinder	1	60	60	1	

emarks:

ell must be split into two or three sub cells to achieve correct cell size

ACHINE AREAS: 875 sq. ft.	DIRECT LABOUR:
ERVICE AREAS: 2,013 sq. ft.	INDIRECT LABOUR:
THER AREAS:	STAFF:
OTAL CELL AREA: 2,888 sq. ft.	TOTAL LABOUR:

ELL NO.: 9

TABLE VIII (j)

ESCRIPTION:

on-rotational parts too large to fit into a 16" cube

ACHINE TOOL LIST

YPE	QUANTITY	AREA EACH (SQ.FT.)	TOTAL AREA (SQ. FT.)	OPERATORS
Jo.3 Universal Mill	1	65	65	1
Radial Drill	2	30	60	2
24" Lumsden Grinder	1	30	30	-

ACHINE AREAS:	155 sq. ft.	DIRECT LABOUR:
ERVICE AREAS:	357 sq. ft.	INDIRECT LABOUR:
THER AREAS:		STAFF:
OTAL CELL AREA:	512 sq. ft.	TOTAL LABOUR:

TABLE IX (a)

TABLE OF NET MACHINE TOOL AREAS AND GROSS AREA CONVERSION FACTOR

Section	Machine Type	Qty	Net Area each (sq. feet)	Net Area Total (sq.ft.)	
Turning	Herbert No.4	3	30	90	
	Herbert No.7	1	70	70	
	Ward No.2D	1	20	20	Total Net Area = 866
	Ward No.7	3	70	210	Section Area = 3,910
	Ward No.9	3	84	252	Gross Area Factor = 4.52
	Centre Lathe	2	70	140	
	Copy Lathe	2	30	60	
	Screw cut Lathe	1	24	24	
Boring	W & B 36" & 48"	11	77	847	Total Net Area = 1,297
	W & B 60"	5	90	450	Section Area = 4,250
					Gross Area Factor =
Milling	H.Mill Small	10	40	400	
	H.Mill Large	10	65	650	Total Net Area = 1,910
	V.Mill	14	40	560	Section Area = 5,900
	Hydrotel	1	120	120	Gross Area Factor = 3.28
	Profile Mill	6	30	180	
Drilling	Radial	8	30	240	
	2-Spindle	14	10	140	
	4-Spindle	13	17	221	Total Net Area = 853
	Vero	2	45	90	Section Area = 2,810
	Autonomic	1	122	122	Gross Area Factor = 3.30
	Others	2	20	40	
Grinding	Abwood RSG	1	60	60	
	Glauchau RSG	1	55	55	
	36" Lumsden	1	110	110	
	Snow Small	1	60	60	
	Snow Large	1	140	140	Total Net Area = 1,145
	J & S 1011	7	40	280	Section Area = 3,030
	J & S 540	2	30	60	Gross Area Factor = 2.90
	Heald Int.	1	60	60	
	Churchill Int.	1	50	50	
	J & S 1300	2	35	70	
	Churchill Ext.	2	100	200	

TABLE IX (b)

TABLE OF NET MACHINE TOOL AREAS
AND GROSS AREA CONVERSION FACTOR

Section	Machine Type	Qty	Net Area each (sq. feet)	Net Area Total (sq.ft.)			
West Avenue Plant	Cut off	2	30	60			
	RSG	1	80	80			
	H.Mill	11	40	440			
	V.Mill	2	40	80	Total Net Area	=	1,005
	Profile Mill	4	30	120	Section Area	=	3,730
	J & S 1011	2	40	80	Gross Area Factor	=	3.71
	3-Sp. Drill	5	15	75			
	Swage	2	20	40			
	J & S 540	1	30	30			

Part No.	Opitz Code	M/C Model	No per M/C	Cut Off		Lums.		Rot. Grd.		J & S		Formgrd		H. M.		V. M.		C. M.		Swage		Drill		Fit		Barrel	
				Op No	Hrs. Each	Op No	Hrs. Each	Op No	Hrs. Each	Op No	Hrs. Each	Op No	Hrs. Each	Op No	Hrs. Each	Op No	Hrs. Each	Op No	Hrs. Each	Op No	Hrs. Each	Op No	Hrs. Each	Op No	Hrs. Each	Op No	Hrs. Each
SP 3666/18"	75046/2022	S	4	1	.025	2	.018							3	.067					5	✓	7	.050	4	.010		
SP 3867/18"	75046/2022	S	4	1	.030	2	.006							3	.160					5	✓	8	.050	4	.010		
																								7	.010		
SP 5243/18"	75071/2047	S	4					6	.020					3	.060									4	.010	1	✓
SP4100/18"	75071/3042	S	1	1	.030	2	.022	10	.020									4	.133			3	.069	6	.030		
																								9	.013		
SP4186/18"	75071/3042	S	1	1	.030	2	.010	9	.020					3	.060			5	.060			4	.015	6	.010		
SP4099/18"	75071/3042	S	1	1	.020	2	.020	9	.033							5	.080	4	.080			3	.070	6	.020		
SP 4458/18"	76046/2022	S	4	1	.020	2	.005							3	.040					5	✓	8	.085	5	.010	4	✓
SP4079/18"	76046/2042	S	4	1	.030	2	.010							3	.080					5	✓	7	.045	4	.010		
SP4081/18"	76046/2045	S	4																	3	✓	2	.030	1	.010		
SP4078/18"	76076/3042	S	4	1	.030	2	.012							3	.111					5	✓	8	.030	4	.010		
																								7	.010		
W 2729/18"	76046/3062	S	1	1	.030	2	.016							3	.200	4	.070			6	✓	8	.030	5	.010		

COMPONENT / MACHINE MATRIX I

(TIME PER OPERATION)

TABLE X

PART No.	QUANTITY PER YEAR	HOURS PER YEAR											
		CUT-OFF	LUMS.	ROT. GRD.	J&S	FORM GRD.	H. M.	V.M.	C.M.	SWAGE	DRILL	FIT	BARREL
BROUGHT FORWARD		2380.2	869.2	984.3	1002.8	1832.3	9462.3	623.7	5437.1		3417.8	2156.3	
SP3666/18"	928	23.2	16.7				62.2			✓	46.4	9.3	
SP 3867/18"	928	27.8	5.6				148.5			✓	46.4	18.6	
SP 5243/18"	928			18.6			55.7					9.3	✓
SP4100/18"	232	7.0	5.1	4.6					30.9		16.0	10.0	
SP 4186/18"	232	7.0	2.3	4.6			13.9		13.9		3.5	2.3	
SP4099/18"	232	4.6	4.6	7.7				18.6	18.6		16.2	4.6	
SP4458/18"	928	18.6	4.6				37.1			✓	78.9	9.3	✓
SP 4079/18"	928	27.8	9.3				74.3			✓	41.2	9.3	
SP 4081/18"	928									✓	27.8	9.3	
SP 4078/18"	928	27.8	11.1				103.0			✓	27.8	18.6	
W 2729/18"	232	7.0	3.7				46.4	16.2		✓	7.0	2.3	
(SUB) TOTAL		2531.0	932.2	1019.8	1002.8	1832.3	10003.4	658.5	5500.5	✓	3729.0	2259.2	✓

COMPONENT/MACHINE MATRIX II
(TIME PER YEAR)

TABLE XI

TABLE XII FINAL LOAD ANALYSIS AND LABOUR/MACHINE ALLOCATION

Cell	Machine/Process	Hrs per Yr	No. of Operators	No. of M/cs	Utilisation Man	Utilisation Machine
Material Preparation	Cut-off	4,261	1	2		
	Rotary Surf Grd	2,482	1	1		
	Horiz. Mill	4,043	2	2		
	Roto Barrel	-	1*	1	-	-
Milled Cams	Horiz. Mill	10,956	6	6		
	Copy Mill	7,234	4	4		
	Vertical Mill	1,049	with H.M.	1		
	Drill	2,934	1**	2		
	Fit & Barrel	1,638	1	1		
Ground Cams	Surf. Grind	1,189)	2	2		
	Form Grind	2,356)				
	Drill	1,148	1	1		
	Horiz. Mill	2,355	1	1		
	Slot Mill	1,280	1	1		
	Fit & Barrel	764	1	1		
Cam Finishing	Swage	4,000	2	2		
	Drill	4,281	2	2		
	Horiz. Mill	388	***	1		
	Machine Polish	735)	3	1		
	Fit & Barrel	4,573)		1		
	Stamp & Demag	2,000	1	-		
	Surf. Grind****	-	-	-	-	-
	Harden ****	-	-	-	-	-

* Floating for all Roto Barrels

** Plus one apprentice

*** Apprentice (same as drilling)

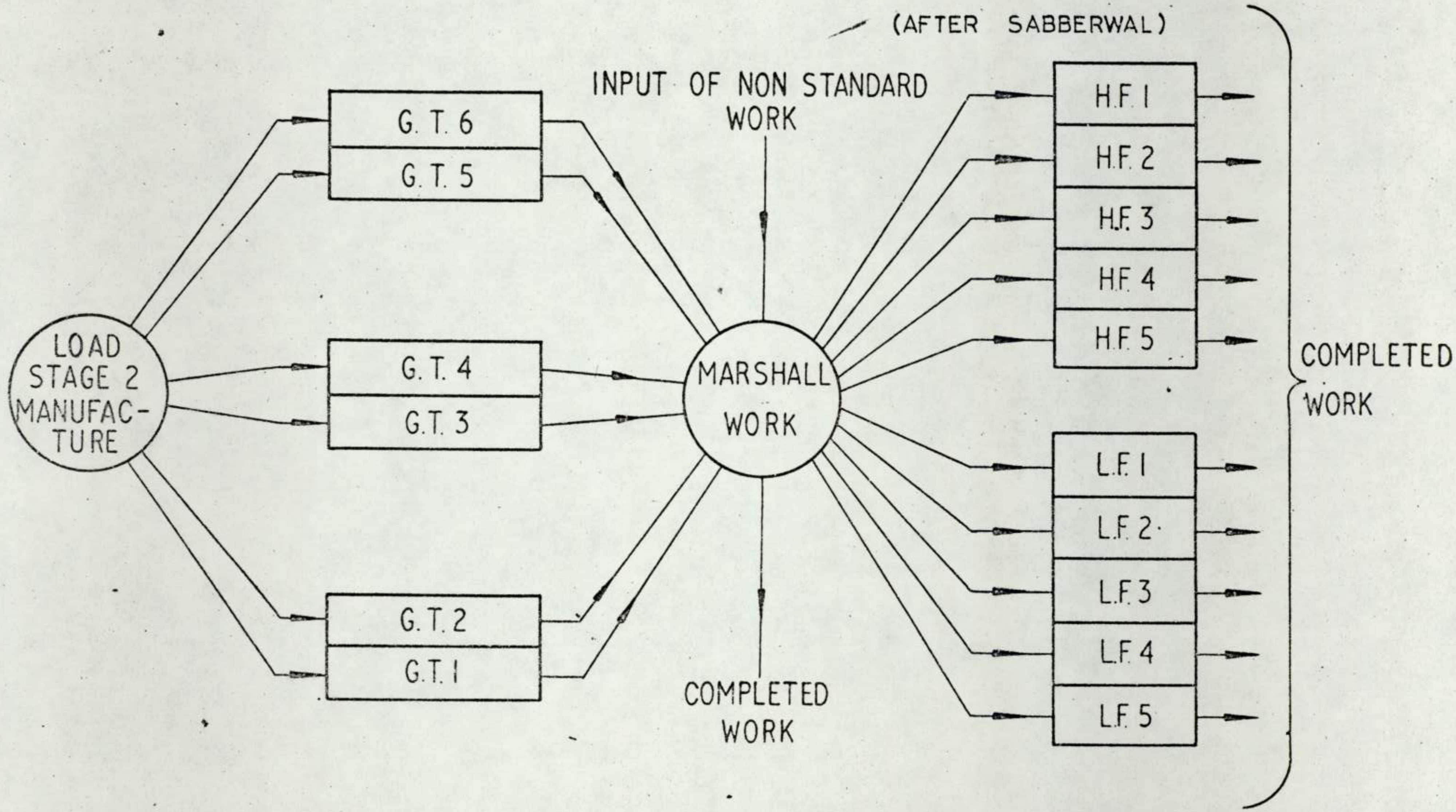
**** Not to be included in cell

Part No.	Description	Annual Usage	No. of Ops.	Current Batch Quantity (EBQ)	Usage Period	Batch 1		Batch 2		Batch 3	
						Qty	Thro'put Time (Years)	Qty	Thro'put Time (Years)	Qty	Thro'put Time (Years)
RTR67	Trapper Slide	100	5	30	.30	30	.25	33	.33	27	.33
RTR225	Striping Slide	550	8	200	.36	200	.30	200	.33	200	.17
RTR693/20	Lever	10	9	20	.50	18		25	.25	25	.29
RTR1535	Pulley	8	6	20	2.50	12	.03				
RTR2124/15	Cam	20	5	30	1.50	30	.25	10	.41	15	.17
RTR2952	Stitch Cam	640	6	100	.16	150	.46	150	.46	100	.10
RTR3360	Yarn Guide	2,000	1	200	.10	1000	.02	200	.06	1000	.03
RTR3864/16"	Cam	30	8	40	1.33	50	.41				
RS2585	Cam	50	7	50	1.00	50	.22	50	.50	50	.38
RS4610	Striping Plate	50	6	50	1.00	70	.41	30	.31		
SP4643/22	Cam	120	9	60	.50	100	.54	50	.46		
SP5085	Punch Pin	600	3	150	.25	150	.33	150	.08	150	.12
W2293/13	Plate	10	7	30	3.00	40	.24	30	.12	59	.02
D473	Drive Bracket	120	10	60	.50	60	.25	60	.16	106	.25
C641	Rack Arm Axle	140	7	30	.21	30	.25	16	.48	15	.17
C894/22	Cam	200	7	150	.75	200	.13				
B1019	Stud	100	4	50	.50	112	.003	52	.10	50	.03
C2286/20	Cam	20	8	20	1.00	20	.33	20	.37		
C2868/33"	Cam	120	7	35	.29	40	.08	35	.25		
C3449/22	Cam	200	6	100	.50	100	.46	100	.23		
C5512	Lever	2,600	4	1000	.38	1000	.46	1000	.30	1000	.64
C5779	Cam	360	4	50	.14	85	.23	150	.17		

TABLE XIV

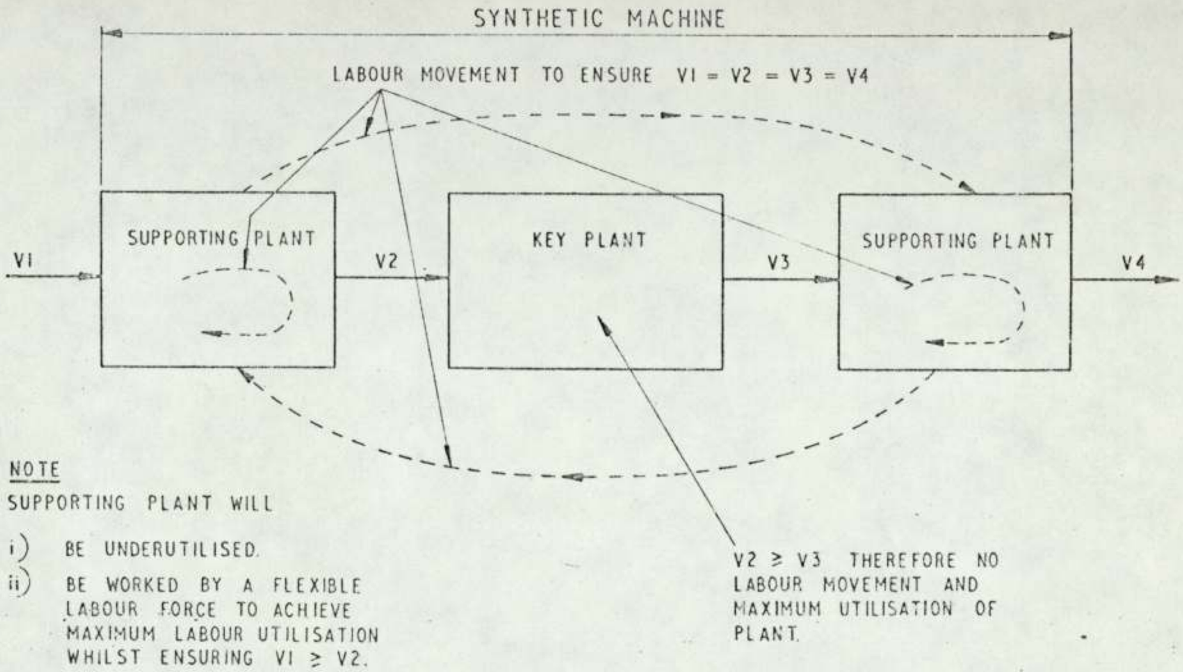
INDIRECT PERSONNEL REDUCTIONS

Indirect Personnel:-	(A) Current	(B) 8½% Reduction	(C) Estimated Rationalisation
Toolroom	22	2	-
Labourers	40	3	4
Inspectors	52	4	5
Internal Transport	5	1	2
Maintenance	22	2	-
Personnel	2	-	-
Nurses	1	-	-
Canteen	17	2	1
Storemen	38	4	3
Apprentice Supervisor	1	-	-
Carpenters & Packers	14	1	-
Spares Despatch	7	1	-
Drivers, Transport Mngr	8	1	-
Time study & Ratefixing	7	1	2
Production Engineering	17	2	-
Production Control	41	3	)
Progress Chasers	17	1	)17
Time Clerks	4	-	) -
Purchasing	8	1	-
Security	2	-	-
Data Processing	1	-	-
Jig & Tool D.O.	3	-	-
Spares progress	3	-	2
Supervision	25	2	2
Works Management	4	-	-
	361	31	38



CELLULAR GROUPS WITHIN THE MANUFACTURING SYSTEM

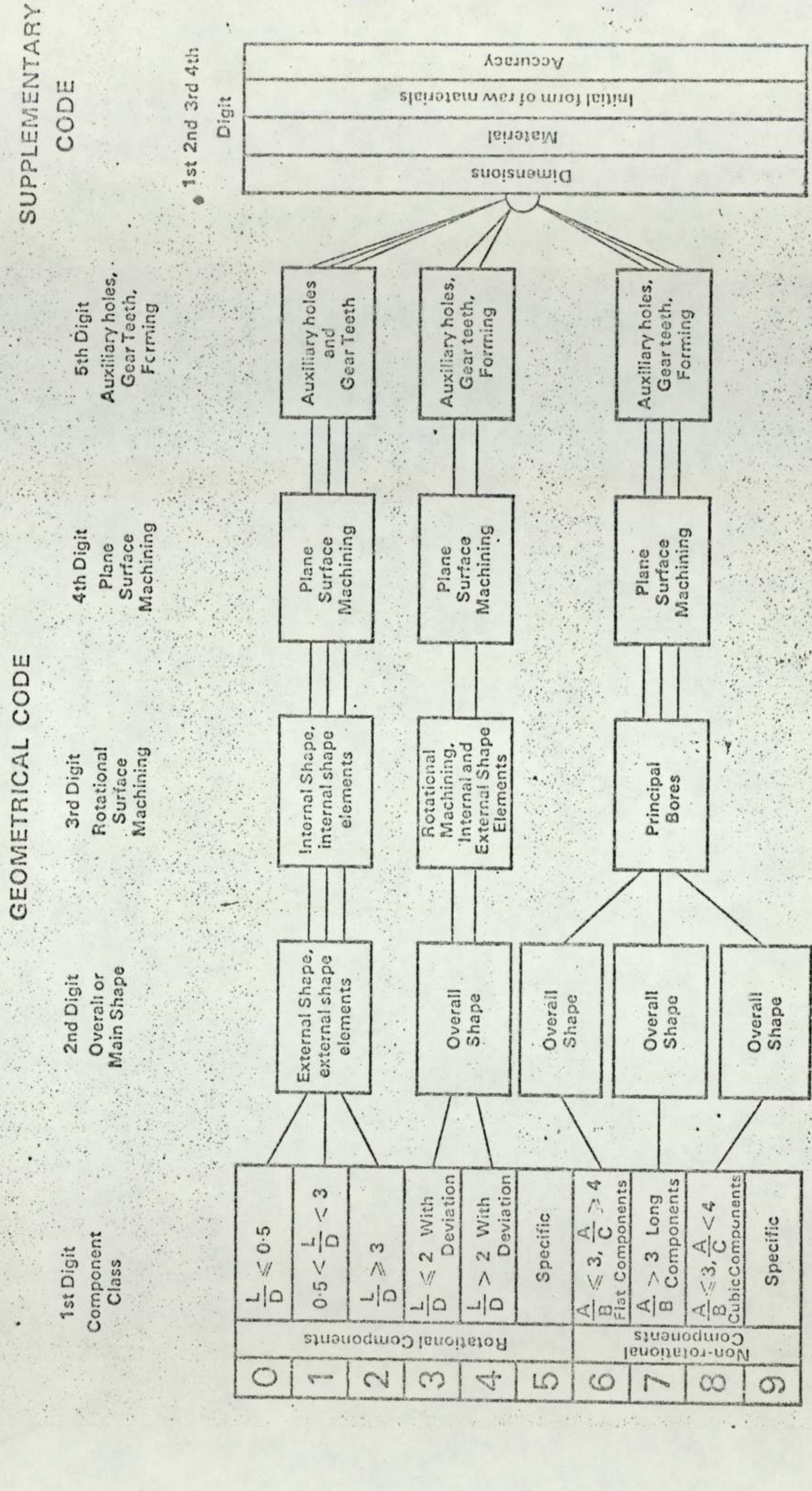
FIG 1



Operative manning to achieve high utilization of key machines

(AFTER CONNOLLY, MIDDLE AND THORNLEY)

FIG 2



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
Dimensions
Material
Initial form of raw materials
Accuracy
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

FIG 3

1st Digit

Component Class		
Rotational Components	0	$\frac{L}{D} \leqslant 0{\cdot}5$
	1	$0{\cdot}5 < \frac{L}{D} < 3$
	2	$\frac{L}{D} \geqslant 3$

2nd Digit

External Shape, external shape elements		
0		Smooth, no shape elements
1	Stepped to one End or smooth	no shape elements
2		with screwthread
3		with functional groove
4	Stepped to both Ends (Multiple increases)	no shape elements
5		with screwthread
6		with functional groove
7		functional taper
8		Operating thread
9		Others (> 10 functional diameters)

3rd Digit

Internal Shape, internal shape elements		
0		Without through bore blind hole
1	Smooth or Stepped to one End	no shape elements
2		with screwthread
3		with functional groove
4	Stepped to both Ends (Multiple increases)	no shape elements
5		with screwthread
6		with functional groove
7		functional taper
8		Operating thread
9		Others (> 10 functional diameters)

4th Digit

Plane Surface Machining	
0	No surface machining
1	External plane surface and/or surface curved in one direction
2	External plane surfaces related to one another by graduation around a circle
3	External groove and/or slot
4	External spline and/or Polygon
5	External plane surface and/or slot and/or groove, spline
6	Internal plane surface and/ór groove
7	Internal Spline and/or Polygon
8	External and Internal splines and/or slot and/or groove
9	others

5th Digit

Auxiliary Hole(s) and Gear Teeth		
0	no gear teeth	No auxiliary hole(s)
1		axial hole(s) not related by a drilling pattern
2		axial holes related by a drilling pattern
3		radial hole(s) not related by a drilling pattern
4		holes axial and/or radial and/or in other directions, not related
5		holes axial, and/or radial and/in other directions related by drilling pattern
6	with gear teeth	spur gear teeth
7		bevel gear teeth
8		other gear teeth
9		others

FIG 4

1st Digit

	DIAMETER 'D' or EDGE LENGTH 'A'	
	MM's	Inches
0	≤ 20	≤ 0·8
1	> 20 ≤ 50	> 0·8 ≤ 2·0
2	> 50 ≤ 100	> 2·0 ≤ 4·0
3	> 100 ≤ 160	> 4·0 ≤ 6·5
4	> 160 ≤ 250	> 6·5 ≤ 10·0
5	> 250 ≤ 400	> 10·0 ≤ 16·0
6	> 400 ≤ 600	> 16·0 ≤ 25·0
7	> 600 ≤ 1000	> 25·0 ≤ 40·0
8	> 1000 ≤ 2000	> 40·0 ≤ 80·0
9	> 2000	> 80·0

2nd Digit

	MATERIAL
0	Cast Iron
1	Modular graphitic cast iron and malleable cast iron
2	Steel ≤ 26.5 tonf/in² Not heat treated
3	Steel > 26.5 tonf/in² Heat treatable low carbon and case hardening steel, not heat treated
4	Steels 2 and 3 Heat treated
5	Alloy Steel (Not heat treated)
6	Alloy Steel Heat treated
7	Non-ferrous Metal
8	Light Alloy
9	Other Materials

3rd Digit

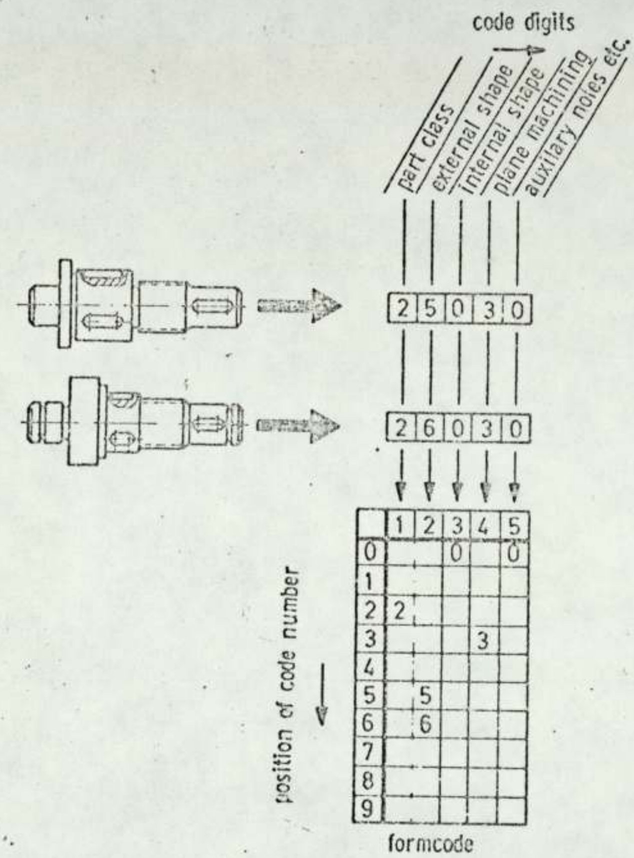
	INITIAL FORM
0	Round Bar, black
1	Round Bar, bright drawn
2	Bar-triangular, square, hexagonal, others
3	Tubing
4	Angle, U-, T-, and similar sections
5	Sheet
6	Plate and Slabs
7	Cast or forged Components
8	Welded Assembly
9	Pre-machined Components

4th Digit

	ACCURACY IN CODING DIGIT
0	No Accuracy Specified
1	2
2	3
3	4
4	5
5	2 and 3
6	2 and 4
7	2 and 5
8	3 and 4
9	(2+3+4+5)

OPITZ SUPPLEMENTARY CODE

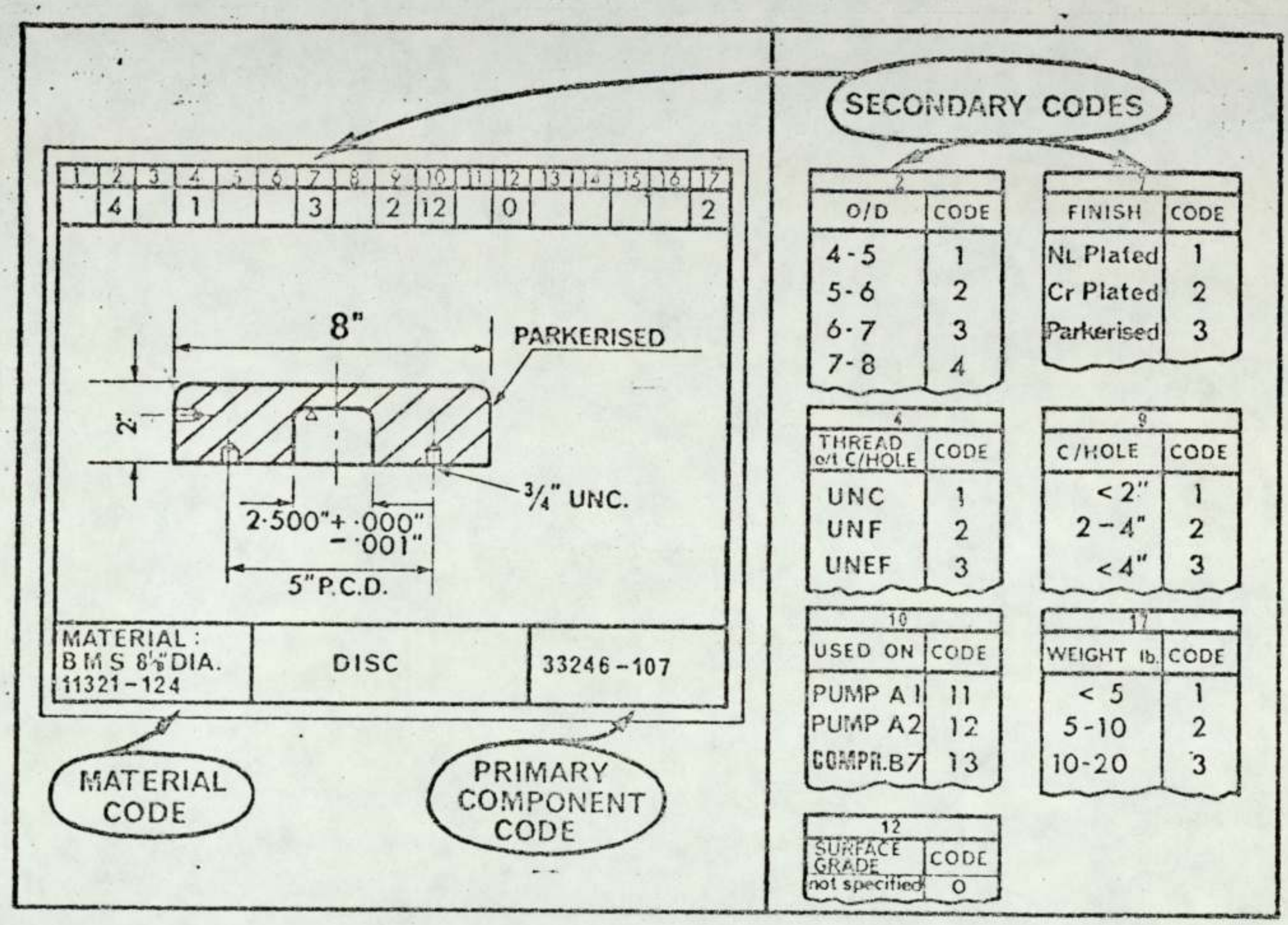
FIG 5



Generation of a code number field.

(AFTER BRANKAMP)

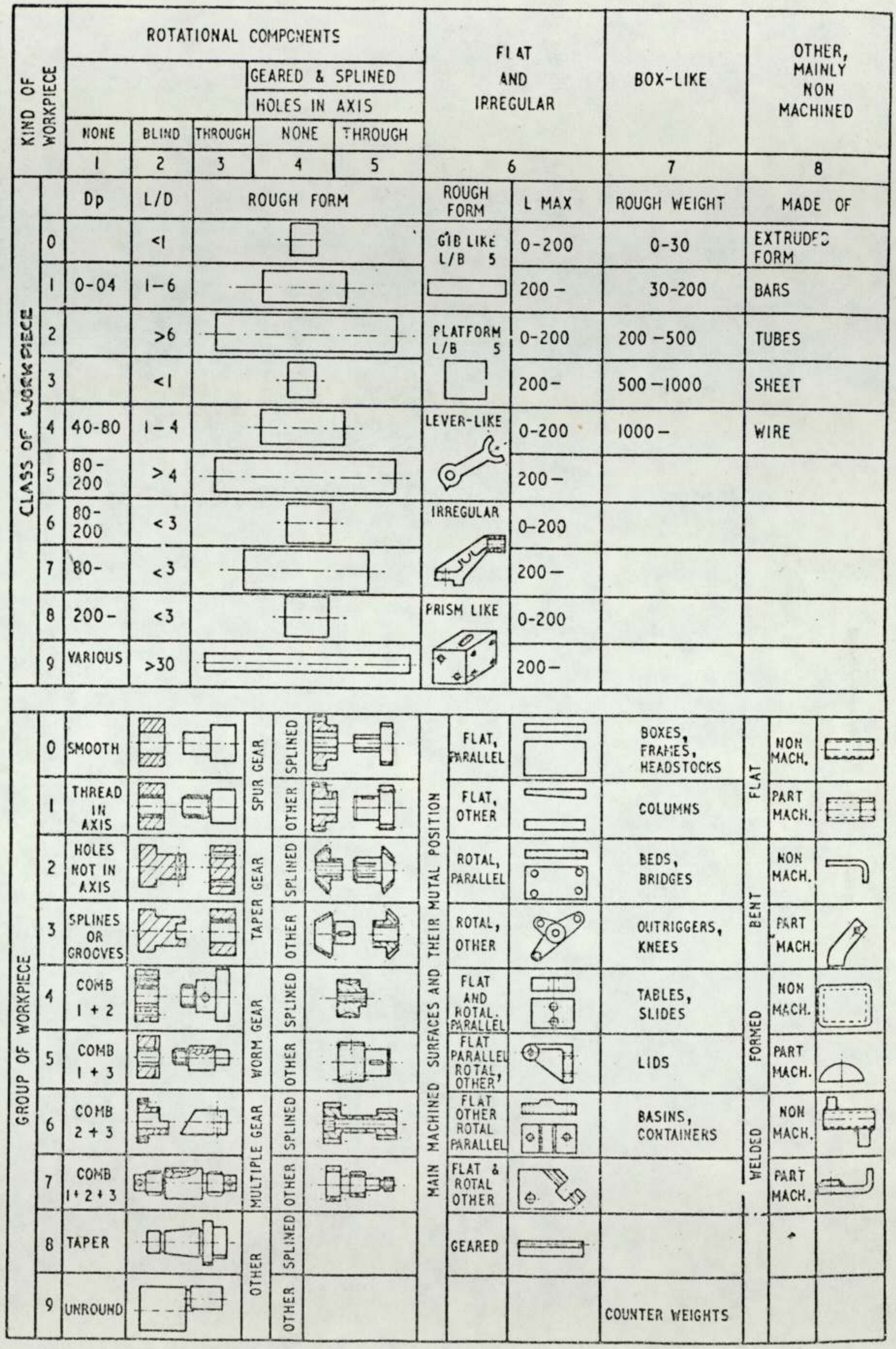
FIG 6



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

(AFTER MACCONNELL)

FIG 7



The Vuoso System

(AFTER MACCONNELL)

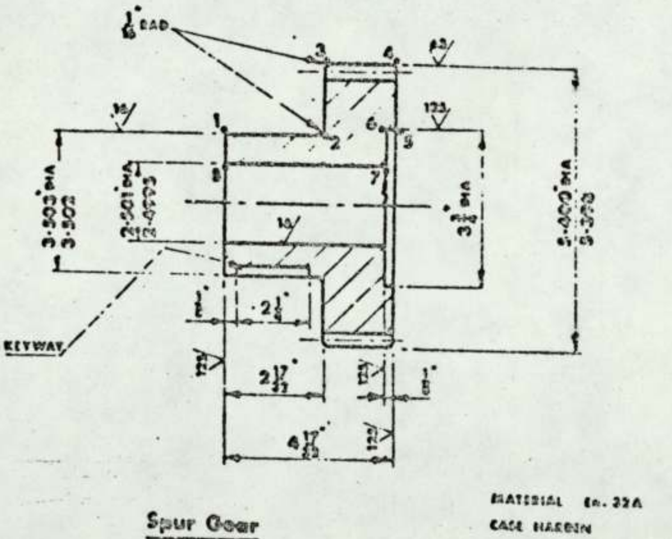
FIG 8

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
G 0		3 0		0 8		0 3		0 4		1	0	0		0 0 0 2

Detailed Statement.

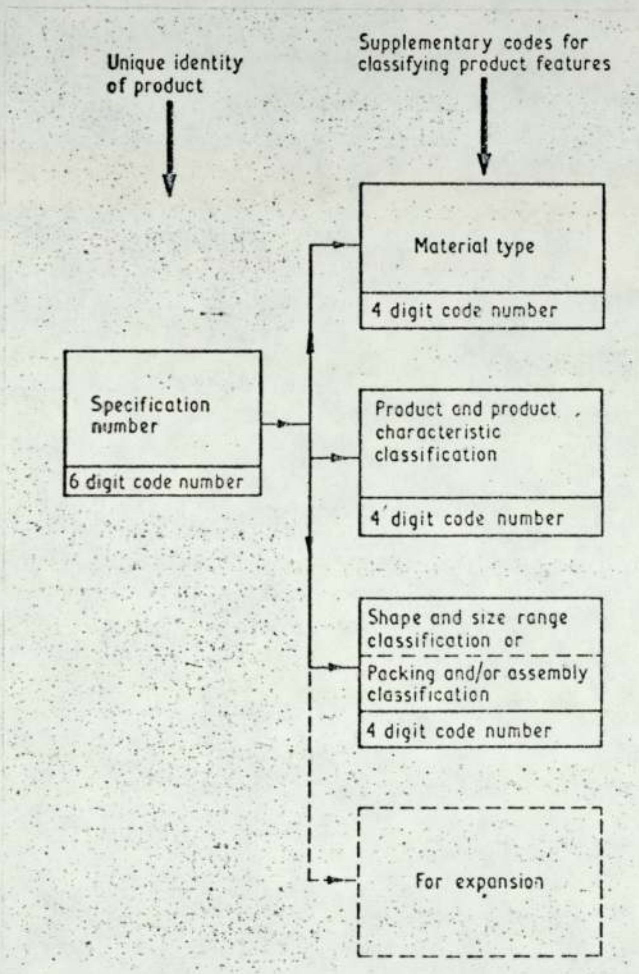
Shape and Dimensions						Surface Elements						
Change Points		x Co-ordinates		y Co-ordinates		Corner Condition	Form	Accuracy	Surface Finish	State of Hardness	Function	Additional Machining Features
0 1		0 0 0 0 0		0 0 1 7 5		1	0	3	3	2	6	7
0 2		0 0 2 5 3		0 0 1 7 5		3	0	9	7	2	1	1
0 3		0 0 2 5 3		0 0 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

(AFTER MACCONNELL)

FIG 9



General form of classification scheme

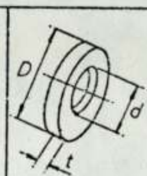
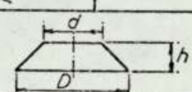
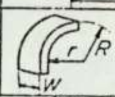
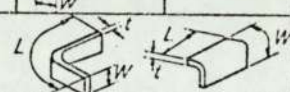
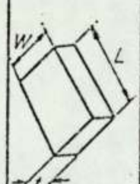
(AFTER MIDDLE, CONNOLLY AND THORNLEY)

FIG 10

Code for shape and size ranges

Code for packing and/or assembly code

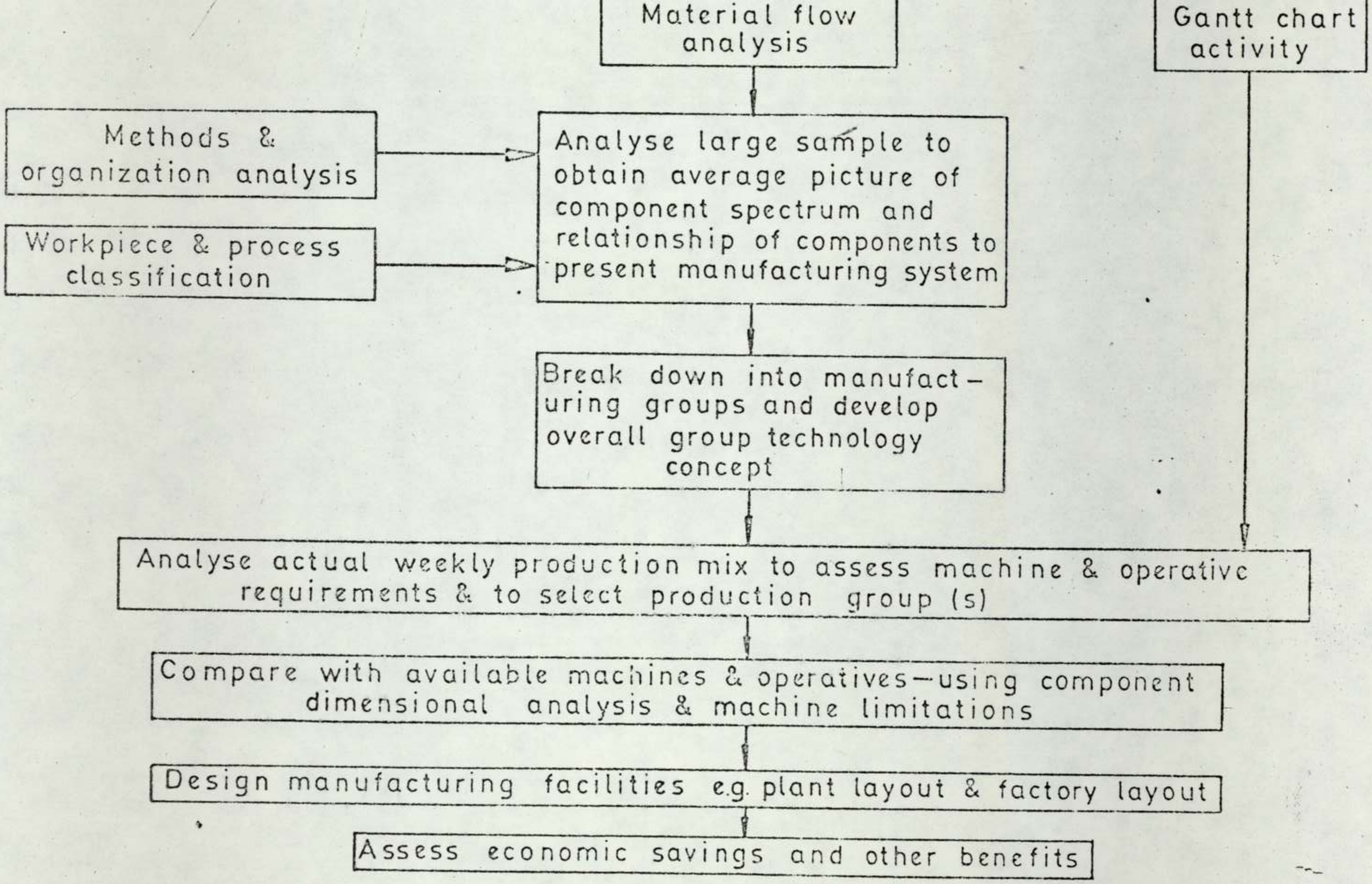
Select first digit below

First digit	Basic shape				Turn up for size range
0	Rotational shapes	Complete or part of a cylinder excluding shapes defined under digit number 3		$\frac{D}{t} \geq 20$	
1				$\frac{D}{t} < 20$	
2		Complete or part of cone			
3		Part of an annulus		$\frac{R-r}{W} \leq 1$	
4	Non-rotational shape	Bent shapes			
5		Spiral or strip			
6		Slots $\frac{L}{W} < 10$		$L \leq 2$	
7				$2 < L \leq 10$	
8				$L > 10$	
9	Other coded products				
	Packing and/or assembly code				

Code for shape and size ranges

(AFTER MIDDLE CONNOLLY AND THORNLEY)

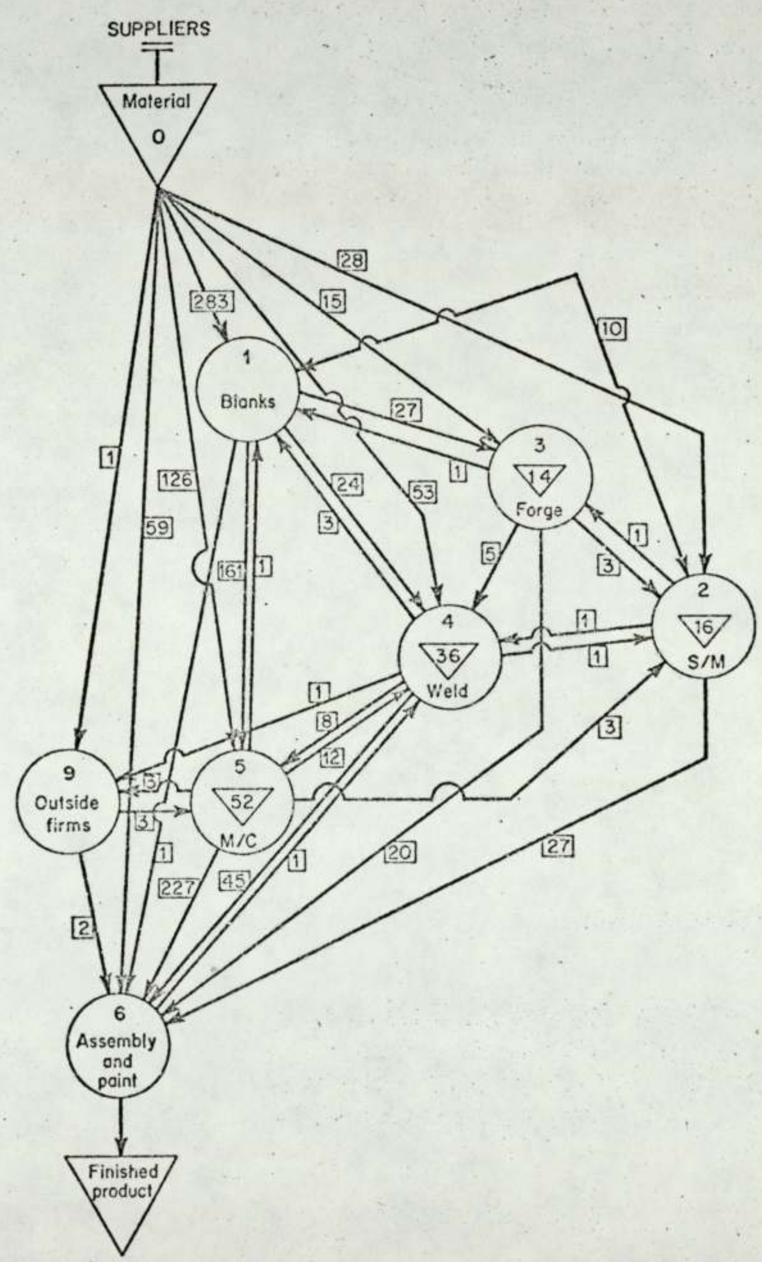
FIG 11



INDICATION OF DATA ANALYSES

(AFTER THORNLEY)

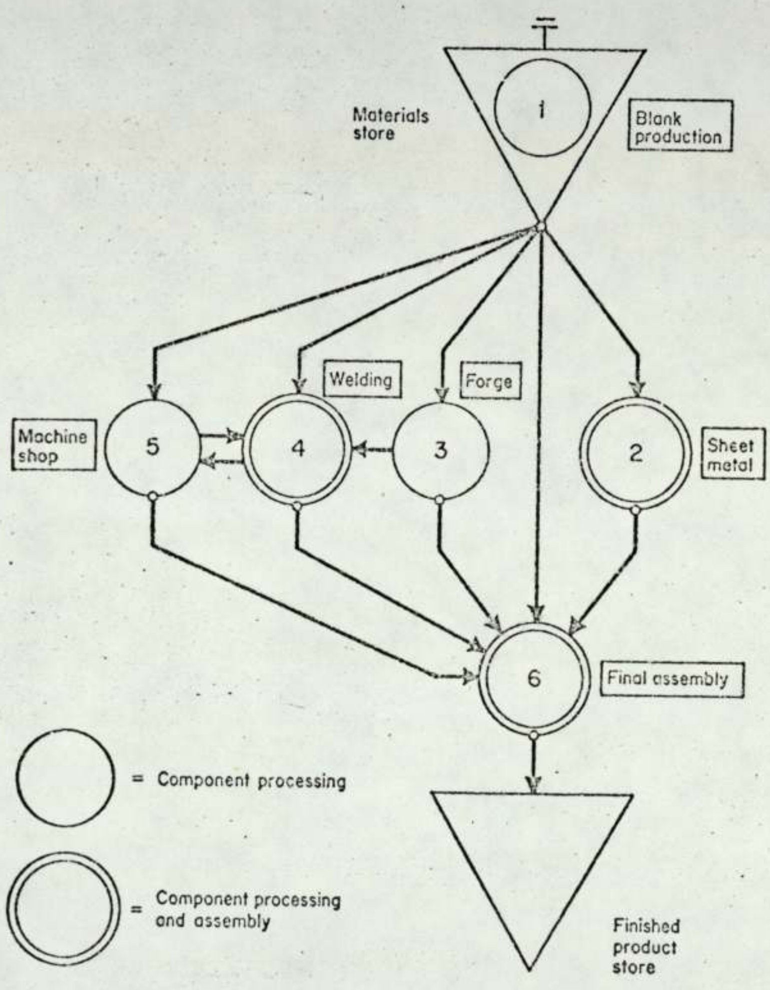
FIG 12



Basic flow chart—original

(AFTER BURBIDGE)

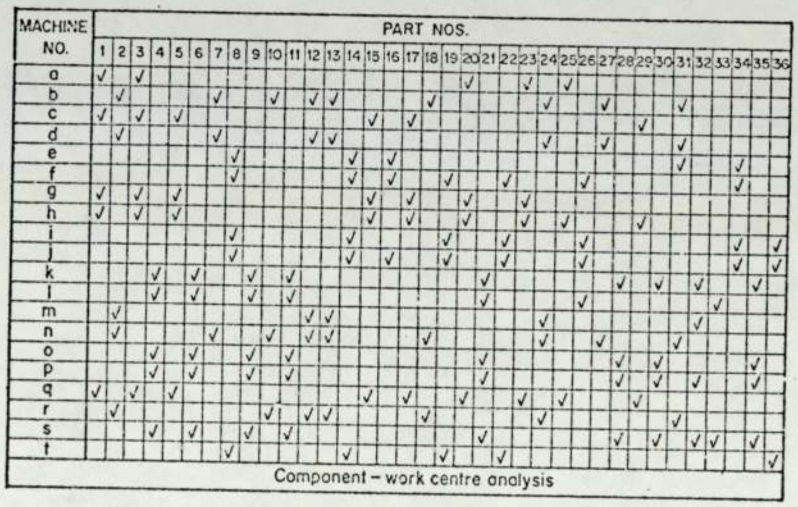
FIG 13



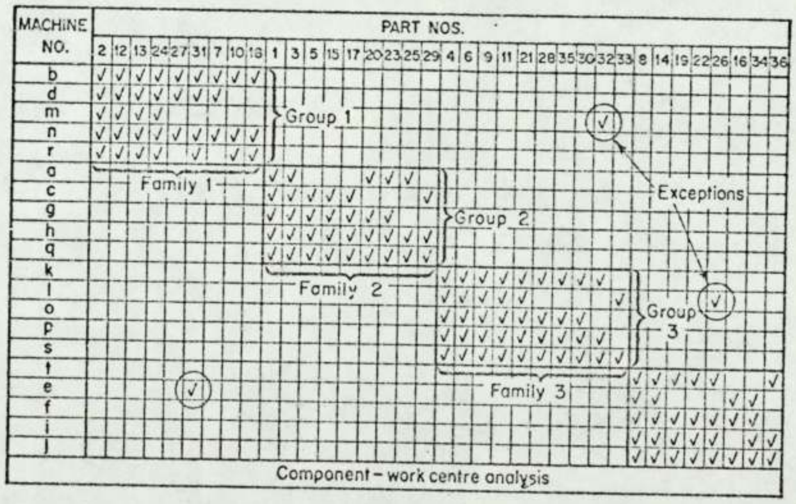
Simplified basic flow chart

(AFTER BURBIDGE)

FIG 14



(a). Original record



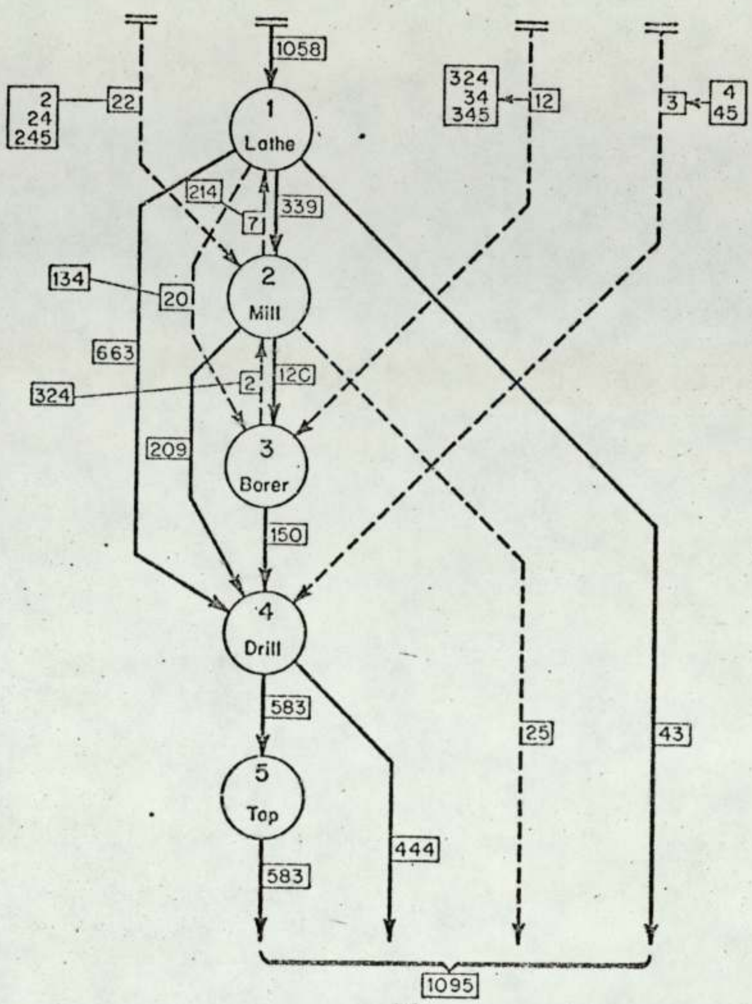
(b) After sorting into 'families' and 'groups'

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

(AFTER BURBIDGE)

FIG 15



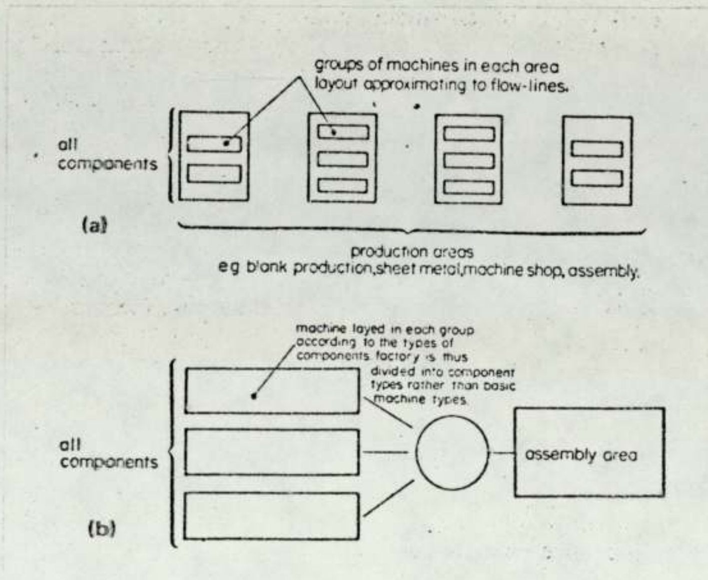
ORN	parts	ORN	parts	ORN	parts
1	43	134 (x)	20	245 (x)	1
12	15	14	230	324 (x)	2
1234	75	145	426	34 (x)	6
12345	45	2 (x)	10	345 (x)	4
124	98	214 (x)	7	4 (x)	2
1245	106	24 (x)	4	45 (x)	1

(x) = ORNs. to be eliminated

Group flow network and O.R.N. frequency chart

(AFTER BURBIDGE)

FIG 16



(a) PRODUCTION FLOW ANALYSIS METHOD FOR FACTORY DIVISION AND GROUPING

(b) COMPONENT FLOW ANALYSIS METHOD FOR FACTORY DIVISION AND GROUPING

(AFTER MALIK CONNOLLY AND SABBERWAL)

FIG 17

COMPONENT DIGIT SELECTION MATRICES

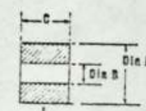
(AFTER PERRINS)

CODE DIGITS 1	2	3	4	5	1	2	3	4	DIGIT NO.	DESCRIPTION
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
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 AND SPROCKETS.
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		
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 $> 1"$ $\leq 4"$
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		
0	0	0	0	0	0	0	0	0		
1	1	1	1	1	1	1	1	1		AS ABOVE BUT DIGIT NO.2 EXTENDED 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 and 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 18

MANUFACTURE BY GROUP TECHNOLOGY

COMPONENT FAMILIES →



CLASSIFICATION — DESIGN — ANNUAL USAGE — PRODUCTION (PLANNING; MANUFACTURE TOOLING ANALYSIS)

GEOMETRIC CLASSIFICATION / DIMENSIONS / SUPPLEMENTARY INFORMATION (Material Form & Accuracy)	DRAWING No.	DIA A	DIA B	C	TITLE	ANNUAL USAGE	TIME IN MINS Setting	TIME IN MINS M/Cing	EXTERNAL FORM (turn)	EXTERNAL FORM (face)	EXTERNAL FORM 45° CHAMFER	EXTERNAL FORM RADII	PART OFF	INTERNAL FORM DRILL	INTERNAL FORM REAMER	INTERNAL FORM 45° CHAMFER	INTERNAL FORM RADII
00100 00 210	20274	.228 .223	.125	.020	WASHER	70	75	3	✓	✓			✓	1/8			
00100 00 210	20343	.301	.189	.020	WASHER	31	30	3	✓	✓			✓	No 12 (.189)			
00100 00 210	21150	.318 .313	.250 .251	.032 .030	WASHER	50	30	5	✓	✓			✓		1/4		
00100 00 210	21094	.335 .330	.250 .251	.032 .030	WASHER	107	30	4	✓	✓			✓		1/4		
00100 00 210	2508	.406	.191	.125	EJECTOR SPRING WASHER	7	30	5	✓	✓			✓	No 11 (.191)			
.. .. 210	20198	.406	.257	.020	SPECIAL WASHER	1	30	5	✓	✓			✓	F (.257)			
.. .. 215	20414	.485 .480	.3755 .3765	.187 .182	SLEEVE	15	45	10	✓	✓			✓		3/8		
.. .. 210	10006	.500	.218	.125	WASHER	1	30	5		✓	1/32		✓	7/32		3/64	
.. .. 210	2494	.500	.257	.125	WASHER - EJECTOR SPRING	36	30	2		✓			✓	F (.257)			
.. .. 215	20391	.570	.5020 .5025	.187 .182	THRUST SLEEVE	1	60	3	✓	✓			✓		1/2		
.. .. 210	20219	.546	.250	.046	SPECIAL WASHER	1	30	5	✓	✓			✓	1/4			
.. .. 210	20218	.546	.390	.031	SPECIAL WASHER	1	30	5	✓	✓			✓	25/64			
.. .. 210	21015	.562	.390	.036	WASHER	1	30	5	✓	✓			✓	25/64			
.. .. 210	031-38064	.620 .615	.218	.156	WASHER	60	30	5	✓	✓				7/32		5/64	
.. .. 410	20837	.625	.390	.048	WASHER	2	30	4		✓			✓	25/64			
.. .. 410	2493	.625	.390	.125	WASHER	17	45	3		✓			✓	25/64			
.. .. 210	031-29502	.687	.251 .252	.245 .240	ROLLER	6	30	15	✓	✓			✓		1/4		
.. .. 210	2187	.705 .700	.257	.093	WASHER-CUP PACKING RETAINER	162	60	5	✓	✓		3/64	✓	F (.257)			
.. .. 410	280	.750	.250	.125	TOP WASHER	9	30	6		✓			✓	1/4			
.. .. 215	21121	.750	.250 .251	.249 .244	ROLLER	6	30	12		✓			✓		1/4		
.. .. 510	20056	.750	.3125 .3132	.300	ROLLER - COLLET VALVE	8	45	10		✓			✓		5/16		
.. .. 210	2580	.750	.390	.250	SPACING WASHER (IDENTICAL COMPONENTS)	87	30	3		✓			✓	25/64			
.. .. 210	20987	.750	.390	.250	WASHER (IDENTICAL COMPONENTS)	1	30	5		✓			✓	25/64			
.. .. 210	031-38171	.750	.531	.062	SHIM	1	30	5		✓			✓	17/32			
.. .. 210	20822	.750	.546	.048	WASHER	1	30	5		✓			✓	35/64			

DIMENSIONS IN INCHES
TOLERANCE ± .003 UNLESS STATED

(AFTER BENNETT)

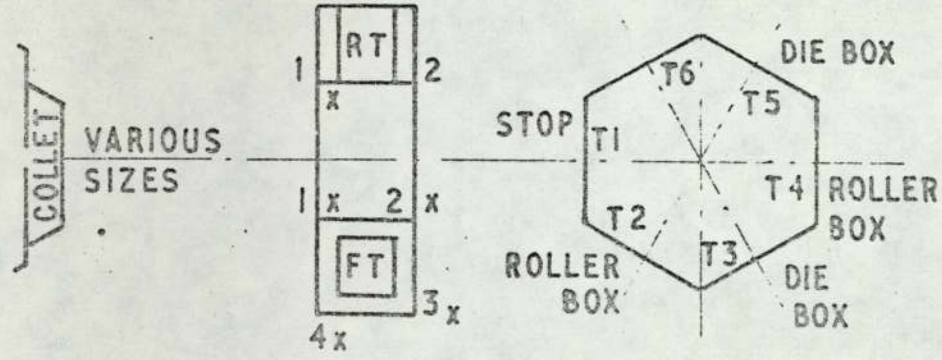
FIG 19

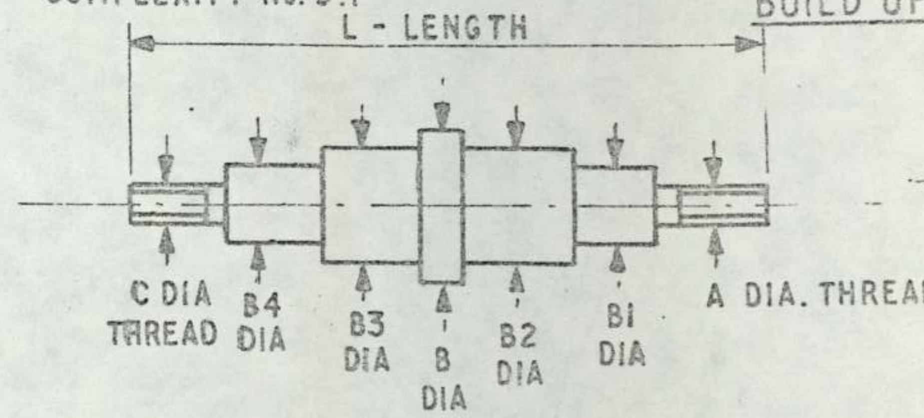
	EXTERNAL						INTERNAL								DRILL			MILL		
DRAWING NUMBER	TURN	FACE	CHAMFER	RADIUS	FORM	VEE GRV.	BORE	SIDE TOOL	CHAMFER	RADIUS	FORM	CTRS GRV	CIR.GRV	BORE SIZE	DRILL	TAP	REAM	FACE MILL	END MILL	FLY CUTTER

FIG 20

COMPLEXITY No. 5.1

BUILD UP





1st. OPERATION	TOOLING REQUIREMENTS		
FT	RT	T	T
1 FACE	1 PART OFF	1 STOP	4
2 TURN		2 ROLLER BOX	5
3 TURN	2	3 DIE HEAD	6
4 CHAMFER			

2nd OPERATION	TOOLING REQUIREMENTS		
FT	RT	T	T
1	1	1 STOP	4
2		2 ROLLER BOX	5
3	2	3 DIE HEAD	6
4			

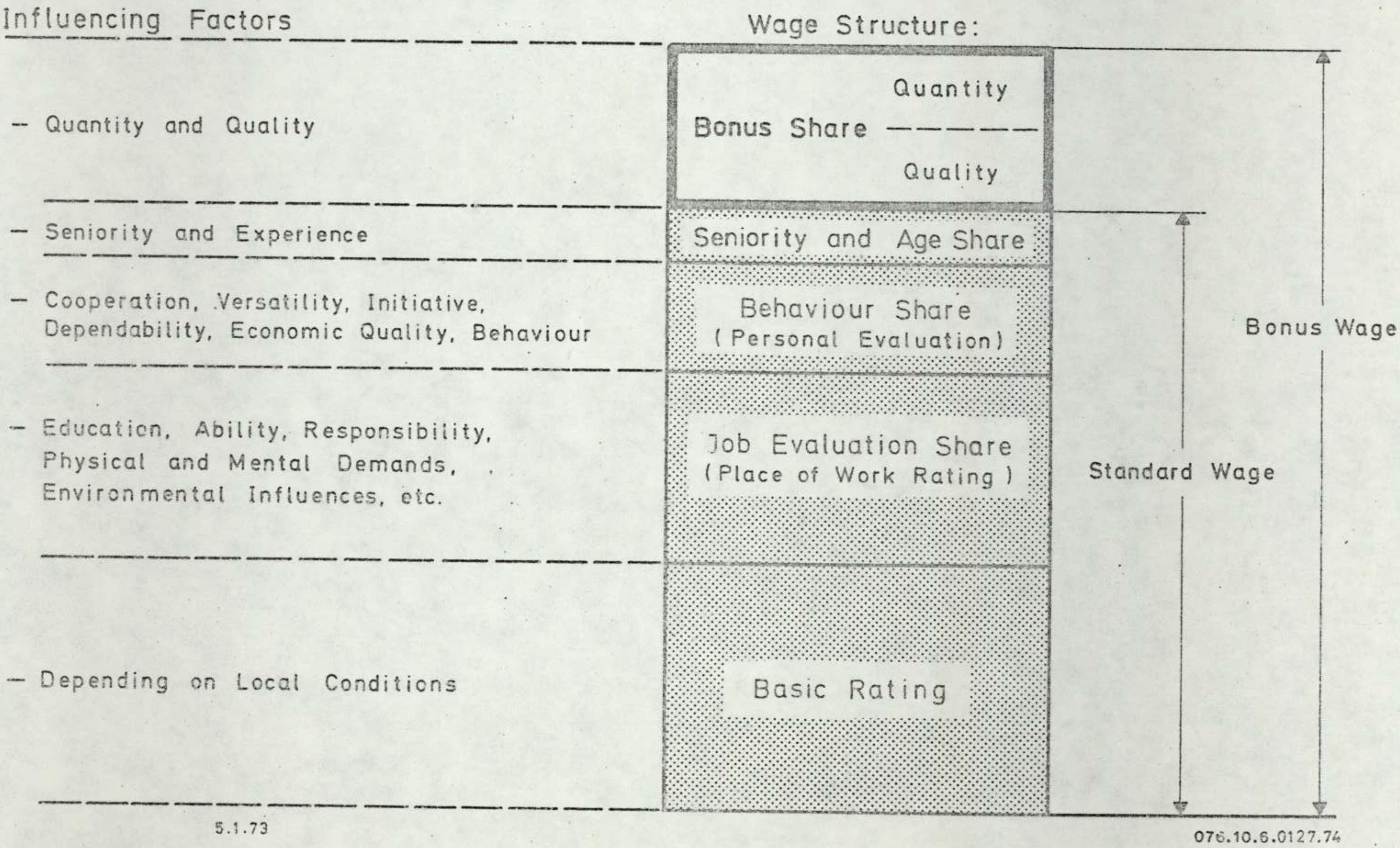
3rd OPERATION	TOOLING REQUIREMENTS		
FT	RT	T	T
1	1	1	4
2		2	5
3	2	3	6
4			

REMARKS

A DIA THRD	B DIA	B1 DIA	B2 DIA	B3 DIA	B4 DIA	C DIA THRD	L LGTH		No. OF COMPS
$\frac{1}{2}$-22	$1\frac{1}{8}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{5}{8}$	—	$\frac{3}{8}$-22	$3\frac{1}{4}$		1
$\frac{3}{4}$ BSW	$1\frac{1}{8}$	$\frac{7}{8}$	1·0	$\frac{7}{8}$	—	$\frac{7}{8}$-22	$2\frac{1}{2}$		1
1-22	$1\frac{5}{8}$	$1\frac{1}{4}$	1	—	—	$\frac{3}{16}$-22	$3\frac{1}{2}$		1
$\frac{5}{8}$-22	$1\frac{5}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	—	2		1
—	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{8}$	1	—	$\frac{13}{16}$-22	$2\frac{7}{8}$		1

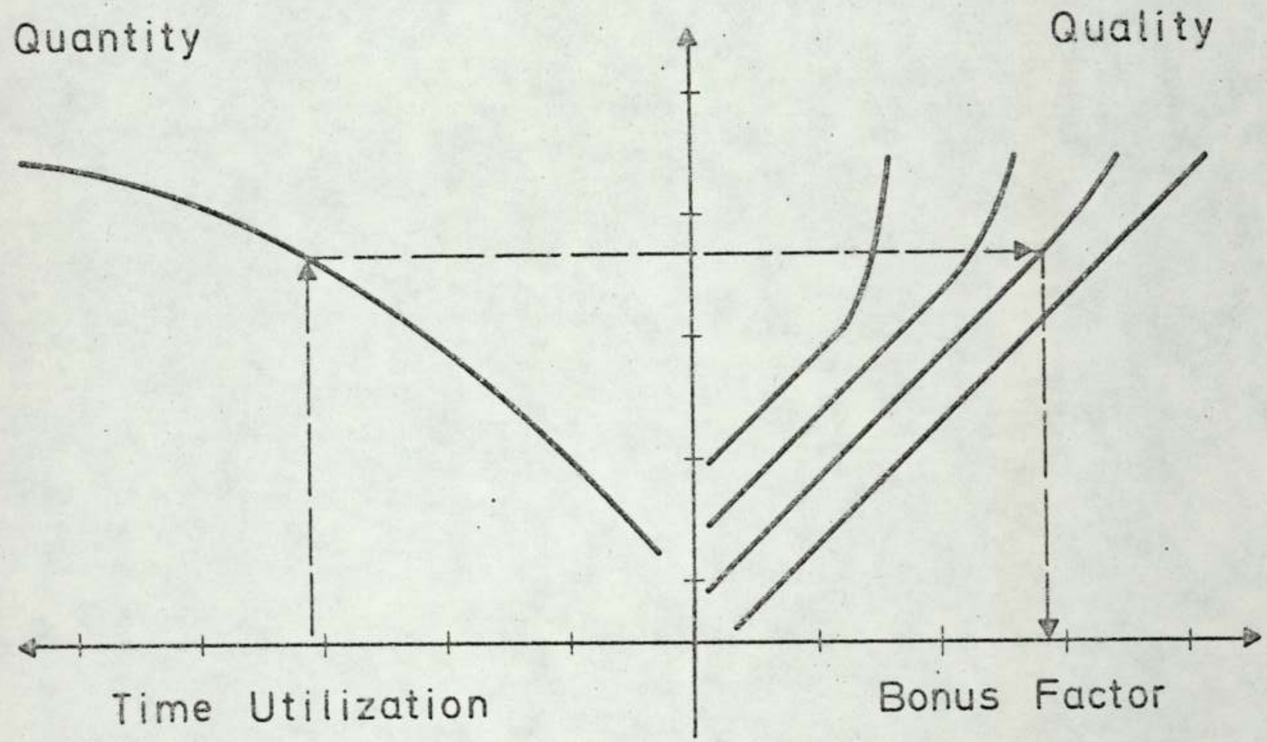
TURNING OPERATIONS ANALYSIS (AFTER PERRINS)

FIG 21



General Structure of the Bonus Wage System (AFTER ARN)

FIG 22



5.1.73

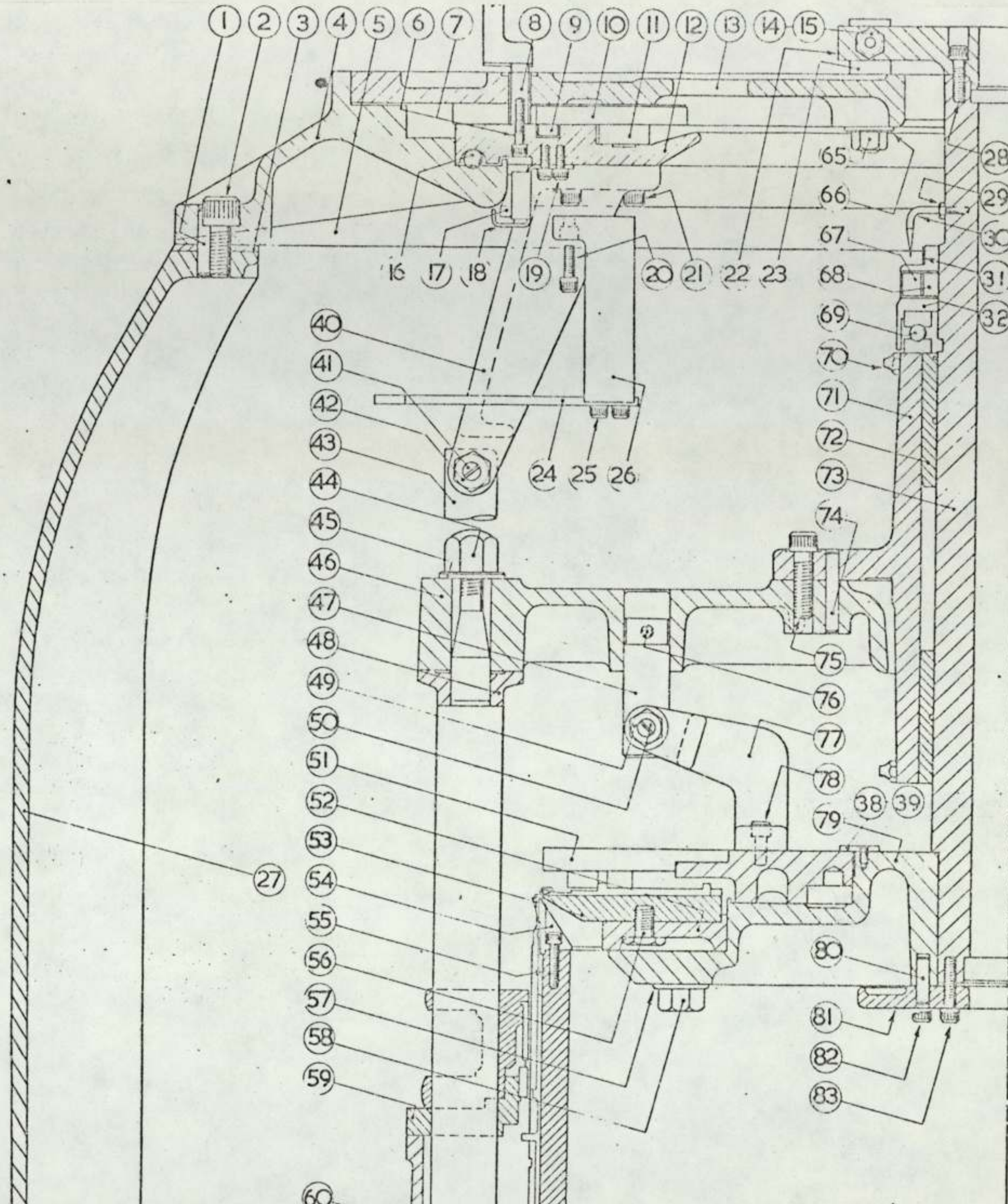
076.10.6.0127.75

Bonus Wage System (AFTER ARN)

FIG 23

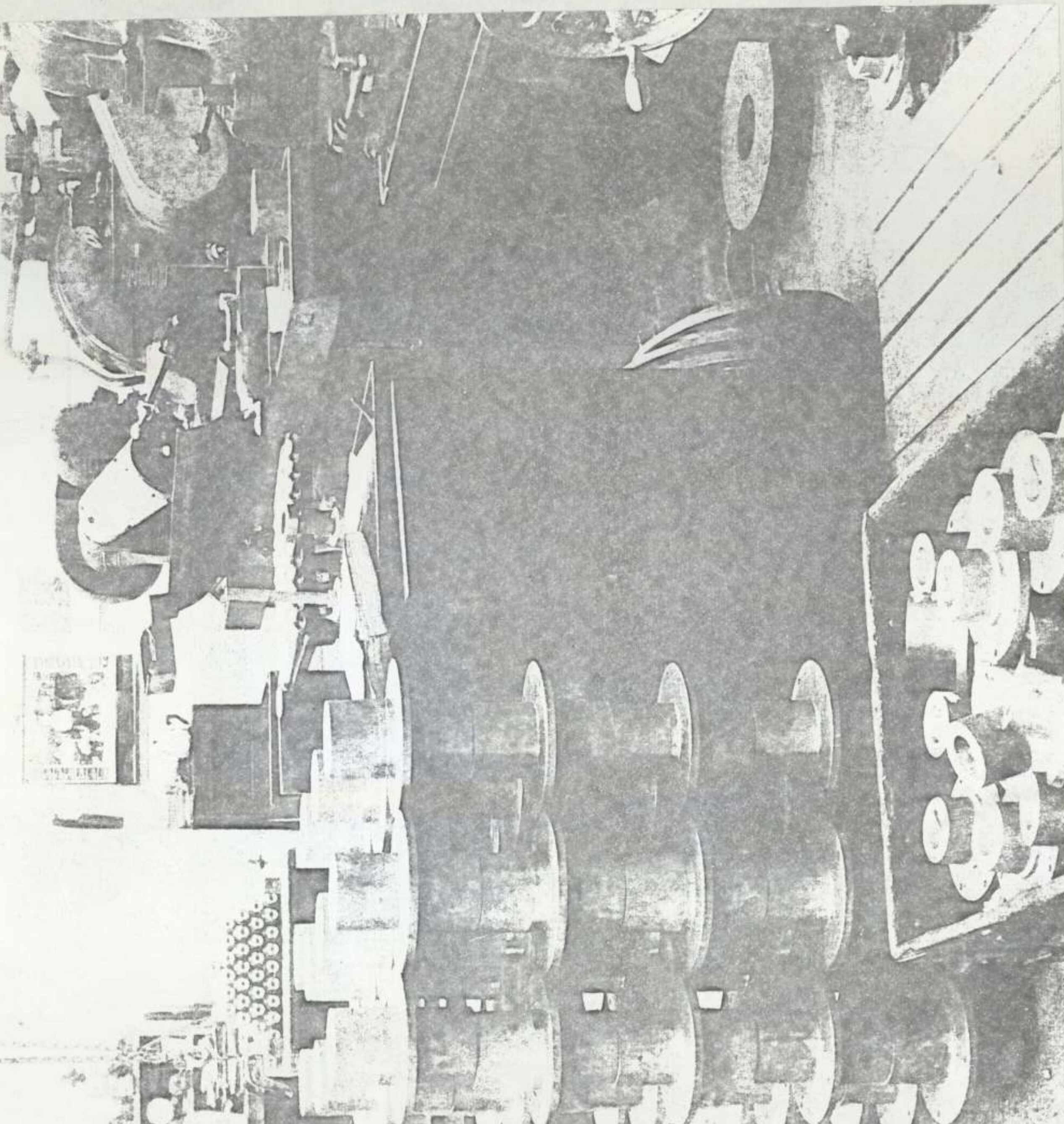
RIB TYPE KNITTING MACHINE

FIG 24



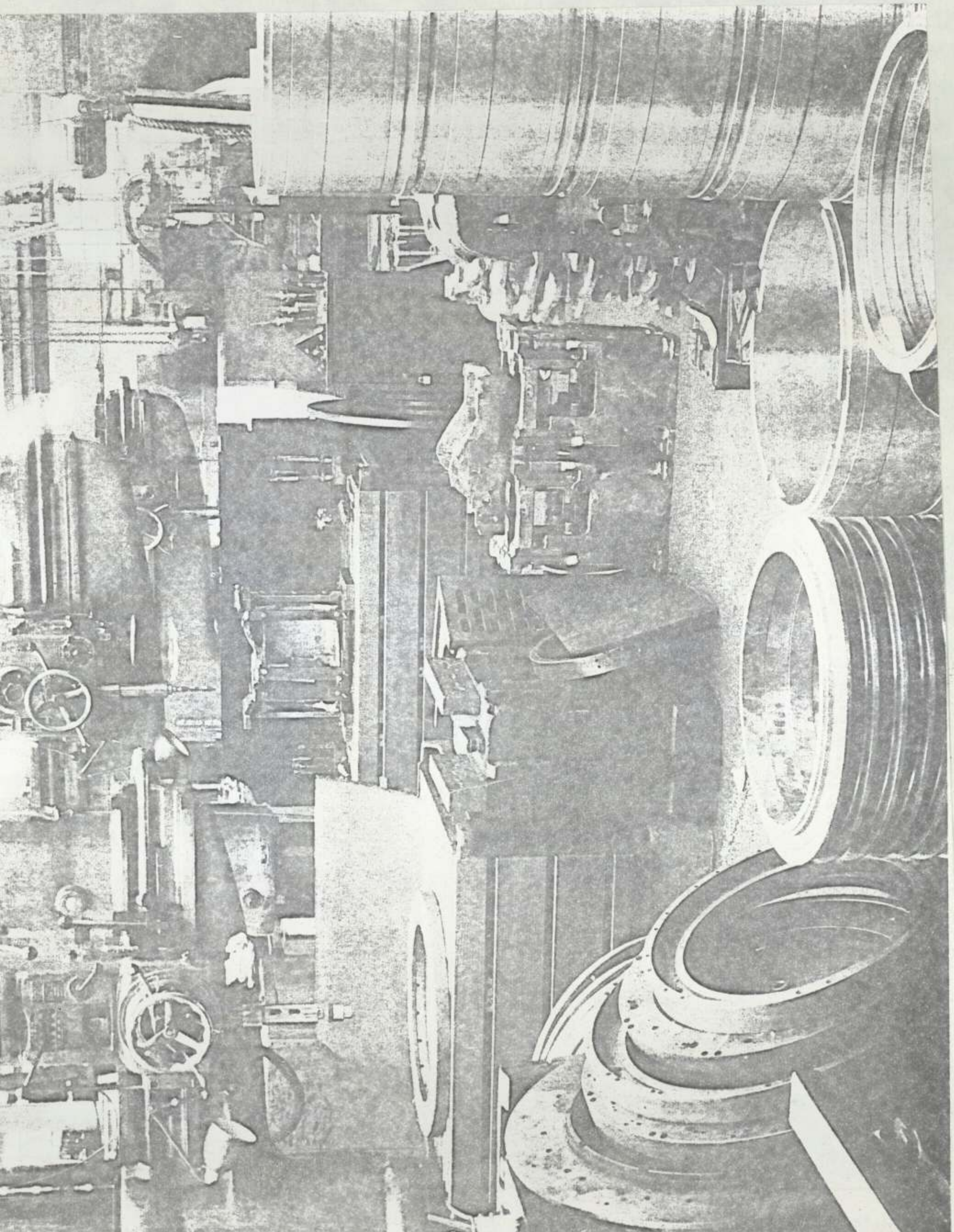
KNITTING HEAD RTR 8 DOGLESS

FIG 25



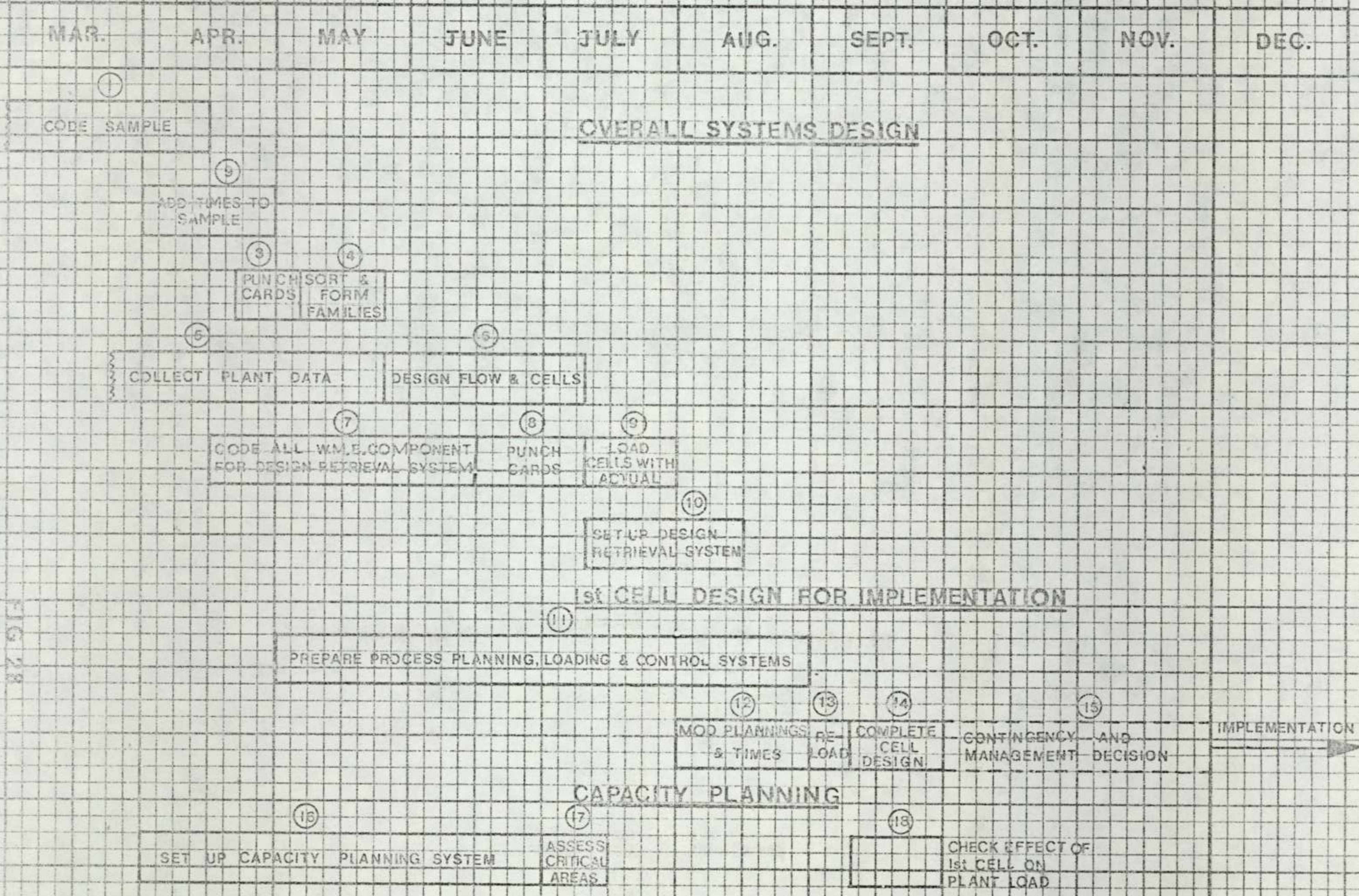
W.M.B. SHOP VIEW

FIG 26



W.M.B. SHOP VIEW

FIG 27



G.T. IMPLEMENTATION PROGRAMME

(CELL DESIGN ONLY)

FIG 28

FIG 29

OPITZ SUPPLEMENTARY CODE (MODIFIED)

1st DIGIT

	DIAMETER 'D' or EDGE LENGTH 'A'	
	MM's	Inches
0	≤ 20	≤ 0·8
1	> 20 ≤ 50	> 0·8 ≤ 2·0
2	> 50 ≤ 100	> 2·0 ≤ 4·0
3	> 100 ≤ 160	> 4·0 ≤ 6·5
4	> 160 ≤ 250	> 6·5 ≤ 10·0
5	> 250 ≤ 400	> 10·0 ≤ 16·0
6	> 400 ≤ 600	> 16·0 ≤ 25·0
7	> 600 ≤ 1000	> 25·0 ≤ 40·0
8	> 1000 ≤ 2000	> 40·0 ≤ 80·0
9	> 2000	> 80·0

2nd DIGIT

	LENGTH 'L' (ROTATIONAL) or EDGE LENGTH 'C' (NON-R)	
	MM's	Inches
0	≤ 20	≤ 0·8
1	> 20 ≤ 50	> 0·8 ≤ 2·0
2	> 50 ≤ 100	> 2·0 ≤ 4·0
3	> 100 ≤ 160	> 4·0 ≤ 6·5
4	> 160 ≤ 250	> 6·5 ≤ 10·0
5	> 250 ≤ 400	> 10·0 ≤ 16·0
6	> 400 ≤ 600	> 16·0 ≤ 25·0
7	> 600 ≤ 1000	> 25·0 ≤ 40·0
8	> 1000 ≤ 2000	> 40·0 ≤ 80·0
9	> 2000	> 80·0

3rd DIGIT

	MATERIAL
0	Cast Iron
1	S.G. Iron, Meehanite
2	Mild Steel
3	Medium/High Carbon & Low Alloy steels
4	2 & 3 Heat Treated
5	High Alloy Steels (Not heat treated)
6	High Alloy Steels (Heat treated)
7	Non-ferrous Metal
8	Light Alloy
9	Other Materials

4th DIGIT

	INITIAL FORM
0	Round Bar, black
1	Round Bar, bright drawn
2	Bar-triangular, square, hexagonal, others
3	Tubing
4	Angle, U-, T-, and similar sections
5	Sheet
6	Plate and Slabs
7	Cast or forged Components
8	Welded Assembly Pre-formed component
9	Pre-machined Components

WILDT MELLOR BROMLEY LTD. LEICESTER.	NAME OF PART Bobbin Stand Support Bracket				PART No. D 7639/16"-22"	DRG.
MATERIAL SPECIFICATION	DESCRIPTION Iron Casting of W.2838D				LENGTH OF PIECE	

PLANNED BY	APPROVED BY	SHEET	DATE OF ISSUE	DATE OF ALTERATIONS				
AEG/LJD		OF	27.2.73					

OP. No.	OPERATION	TOOLS AND GAUGES
1.	Shotblast	
2.	Fettle Fettle suitable for enamel.	
3.	Milling (Vertical) Mill face to clean at 3.3/16" dim. (Note: other dim's) Mill to 3.002"/3.000" and make 1/16" dim.	
4.	Drilling	
	Drill (1) hole 29/64" dia. Spotface 11/16" dia.	8998 DJ
	Drill (1) hole 19/64" dia. Tap 3/8" whit. thd.	
	Drill (1) hole 1/4" dia. Spotface 9/16" dia x 1/32" deep.	3221 CT
	Drill (2) holes 3/16" dia. C/bore 21/64" x 3/16" deep.	3329 CT
	Drill (2) holes No. 23 drill. Tap 2 BA thread.	
	Drill (1) hole No. 42 drill. Tap 6 BA 3/16" deep.	
.	Degrease	
.	Enamel	
.	Fit Clean	

EXISTING PLANNING SHEET

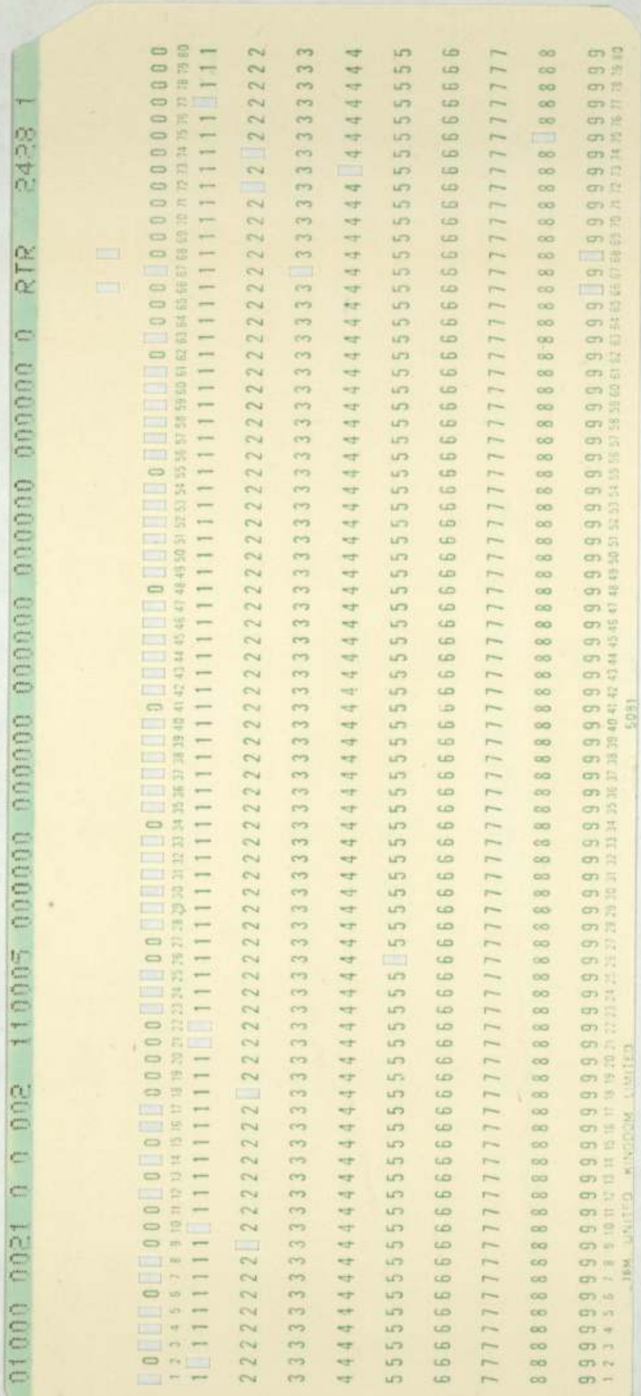
FIG 30

.T. DATA SHEET W.M.B. AYLESTONE ROAD WORKS

PAGE

OPITZ COM. / SUPP.	SOURCE	VALUE	SPEC.	NO PER MAC.	TURNING SEQU / NO OF OP / TIME	MILLING SEQU / NO OF OP / TIME	DRILLING SEQU / NO OF OP / TIME	SURF. GRD. SEQU / NO OF OP / TIME	CYL. GRD. SEQU / NO OF OP / TIME	OTHER SEQU / NO OF OP / TIME	SUPP. OP.	DRAWING NUMBER	MACHINE

FIG 31



PUNCHED CARD USED IN G.T. ANALYSIS

FIG 32

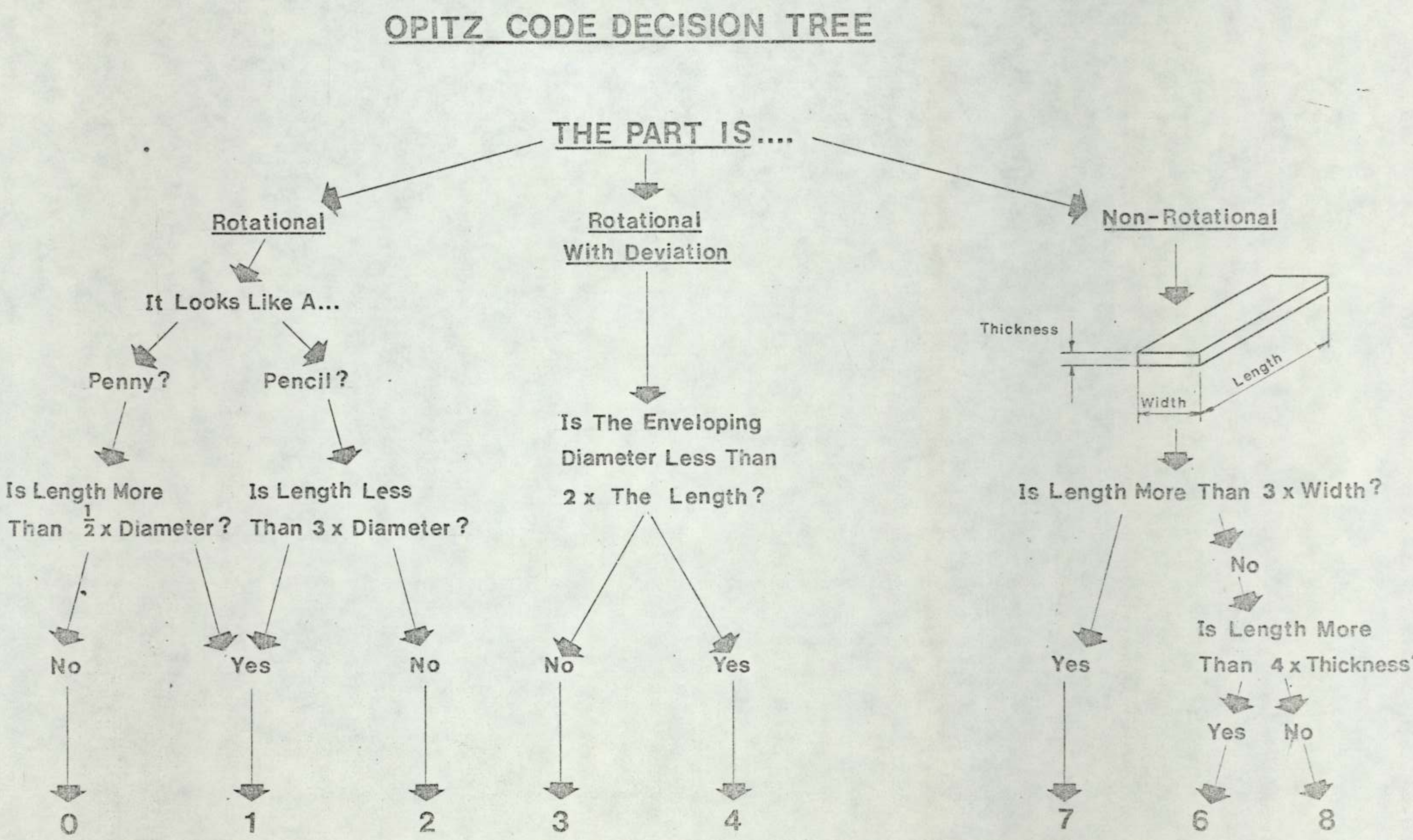

OPITZ CODE DECISION TREE
THE PART IS....
Rotational
Rotational With Deviation
Non-Rotational
It Looks Like A...
Penny?
Pencil?
Is Length More Than ½ x Diameter?
Is Length Less Than 3 x Diameter?
Is The Enveloping Diameter Less Than 2 x The Length?
Thickness
Width
Length
Is Length More Than 3 x Width?
Is Length More Than 4 x Thickness?
No
Yes
Yes
No
No
Yes
Yes
No
Yes
No
0
1
2
3
4
7
6
8

FIG 33

GEOMETRICAL CODE

1st Digit

		Component Class
	Rotational Components	
5		Specific Rotational Components

2nd Digit

	Component Group
0	Spring
1	
2	
3	

3rd Digit

	Component Type
0	Spring, helical
1	Spring, other
2	
3	

4th Digit

5th Digit

FIG 34

GEOMETRICAL CODE

1st Digit	2nd Digit		3rd Digit		4th Digit	5th Digit
Component Class	Component Group		Component Type			
	0	Sheet metal parts	0	No bending No welding		
	1		1	One bend		
	2		2	More than one bend		
	3		3	Welded construction one piece		
	4		4	Multi-part assembly joined.		
9 Non-rotational Components: Specific Non-rotational Components						

FIG 35

GEOMETRICAL CODE

1st Digit	2nd Digit	3rd Digit	4th Digit	5th Digit
Component Class	Component Group			
	0			
	1 Plastic:- Sheet, Cast, Moulded			
	2			
	3			
Non-rotational Components				
9 Specific Non-rotational Components				

FIG 36

```
00100 CC21    SP4257
00100 0021    S1685
00100 0021    S1847
00100 0021    S2026
00100 0021    S2068
00100 0021    S2131
00100 0021    S2150
00100 0021    S2159
00100 0021    S2232
00100 0021    S2286

00100 0021    S2315
00100 0021    S24C9
00100 0021    S2500
00100 0021    S2501
00100 0021    S2513
00100 0021    S2519
00100 0021    S2539
00100 0021    S2758
00100 0021    S2868
00100 0021    S29C3

00100 0021    S31C9
00100 0021    S3223
00100 0021    S3236
00100 0021    S33C7
00100 C021    S3314
00100 0021    S3350
00100 0021    S3394
00100 0021    S3420
00100 0021    S3465
00100 0021    S3634

00100 CC21    S3755
00100 0021    S3758
00100 0021    S3775
00100 0021    S3844
00100 0021    S3910
00100 0021    S4C45
00100 0021    S4C46
00100 0021    S4C47
00100 0021    S4C55
00100 0021    S4C74
```

FIG 37

FIG 38

Z232	27000	0221
Z233	30600	1022
Z234	12030	0121
Z235	50000	0241
Z236	10100	1121
Z237	21000	0121
Z238	10100	0021
Z239	10100	0021
Z240	00100	0021
Z241	12030	0021
Z242	21000	0021
Z243	15020	0121
Z244	10100	0121
Z245	10100	0021
Z246	00010	0031
Z247	27000	0321
Z248	13100	0097
Z249	27030	0121
Z250	10100	0021
Z251	30600	1021
Z252	10100	0021
Z253	00100	0021
Z254	00010	1031
Z255	23030	0121
Z256	23030	0221
Z257	15020	0121
Z258	11000	0121
Z259	21000	0121
Z261	20000	0221
Z262	20000	0221
Z263	20000	0121
Z264	00103	1021
Z266	50000	0141
Z270	12030	0021
Z271	12030	0021
Z272	12030	0021
Z273	12030	0021
Z274	12030	0021
Z275	12030	0021
Z276	12030	0021

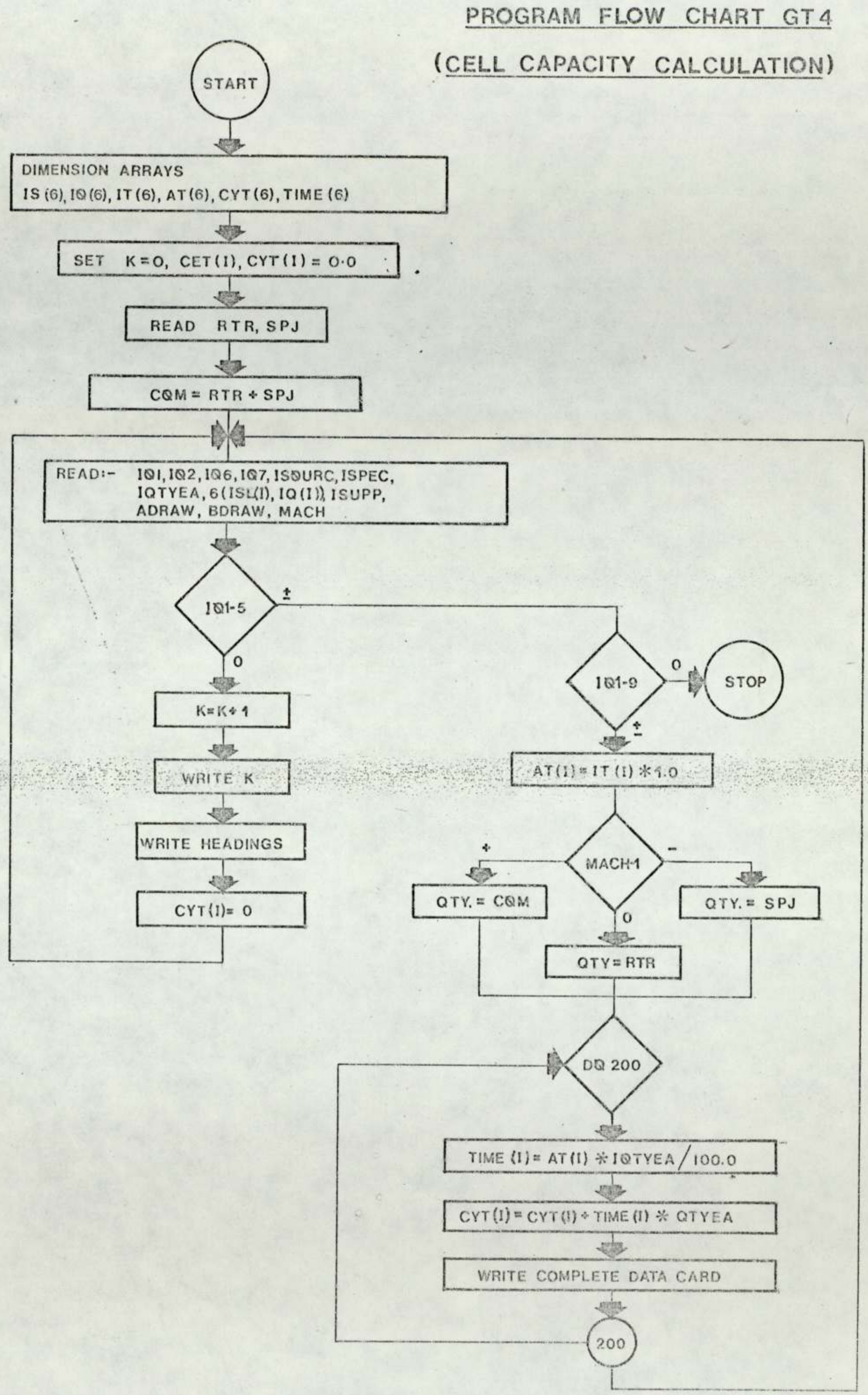

PROGRAM FLOW CHART GT4
(CELL CAPACITY CALCULATION)
START
DIMENSION ARRAYS
IS (6), IQ (6), IT (6), AT (6), CYT (6), TIME (6)
SET K = O, CET (I), CYT (I) = 0·0
READ RTR, SPJ
CQM = RTR ÷ SPJ
READ:- IQI, IQ2, IQ6, IQ7, ISOURC, ISPEC, IQTYEA, 6 (ISL(I), IQ (I)), ISUPP, ADRAW, BDRAW, MACH
IQ1-5
±
0
K = K + 1
WRITE K
WRITE HEADINGS
CYT (I) = 0
IQ1-9
0
STOP
±
AT (I) = IT (I) * 1.0
MACH-1
+
−
QTY. = CQM
QTY. = SPJ
0
QTY = RTR
DO 200
TIME (I) = AT (I) * IQTYEA / 100.0
CYT (I) = CYT (I) + TIME (I) * QTYEA
WRITE COMPLETE DATA CARD
200

FIG 39a

PROGRAM FLOW CHART G.T.4

LIST OF VARIABLES:

I S (±)	=	Operation sequence number
I Ø (I)	=	No. of operations
I T (I)	=	Operations time (1/100 hours) (Integer)
A T (I)	=	Operation time (1/100 hours) (Real)
C Y T (I)	=	Cumulative yearly process time (hours)
T I M E (I)	=	Yearly hours per part (hours)
RTR	=	Number of machines built per year: RTR
SPJ	=	Number of machines built per year: SPJ
C Ø M	=	Number of machines built per year: Both combined
I Ø 1	=	First Opitz Code digit
I Ø 2	=	Second to fifth Opitz Code digit
I Ø 6	=	Sixth Opitz Code digit
I Ø 7	=	Seventh to ninth Opitz Code digit
I S Ø U R C	=	Supply source (e.g. made-in, purchased etc.)
I S P E C	=	Special parts code
I Q T Y E A	=	Quantity used per machine
I S U P P	=	Supplementary operations code
A D R A W	=	Drawing Number
B D R A W	=	Drawing Number
M A C H	=	Machine Model Code
K	=	Family number

FIG 39 b

FORTRAN COMPILATION BY #XFAT MK 4C   DATE 14/01/74 TIME 10/42/16

```
      LIST (LP)
      PROGRAM (FXXX)
      INPUT  1 = CR0
      INPUT  3 = TR0
      INPUT  5 = CR1
      OUTPUT 2 = LP0
      OUTPUT 6 = LP1
      COMPRESS INTEGER AND LOGICAL
      COMPACT
      TRACE 2
      END


      TRACE 1
      READ FROM (CR)
      MASTER KRUSE
      DIMENSION IS(6),IO(6),IT(6),AT(6),CYT(6),TIME(6)
      K=0
      DO 40 I=1,6
      CYT(I)=0.0
   40 CONTINUE
      READ(1,103)SPJ,RTR
      COM=RTR+SPJ
  500 READ(1,100)IO1,IO2,IO6,IO7,ISOURC,ISPEC,IQTYEA,((IS(I),IO(I),
     1IT(I)),I=1,6),ISUPP,ADRAW,BDRAW,MACH
      IF(IO1-5)52,51,52
      K=K+1
      WRITE(2,150)K
   51 WRITE(2,101)
      WRITE(2,102)(CYT(I),I=1,6)
      DO 32 I=1,6
```

FIG 40 a

```
      CYT(I)=0.0
   32 CONTINUE
      GO TO 500
   52 IF(IO1-9)55,30,55
   55 DO 50 I=1,6
      AT(I)=IT(J)*1.0
   50 CONTINUE
      IF(MACH-1)16,17,18
   16 QTY=COM
      GO TO 19
   17 QTY=RTR
      GO TO 19
   18 QTY=SPJ
   19 CONTINUE
      DO 200 I=1,6
      TIME(I)=AT(I)*IQTYEA/100.0
      CYT(I)=CYT(I)+TIME(I)*QTY
  200 CONTINUE
      WRITE(2,104)IO1,IO2,IO6,IO7,ISOURC,ISPEC,IQTYEA,((IS(J),IO(J),
     1IT(J)),J=1,6),ISUPP,ADRAW,BDRAW,MACH
      GO TO 500
  100 FORMAT(I1,A4,A2,A3,A2,A2,I4,1X,6(I2,I1,I4),1X,I1,2X,2A5,1X,I1)
  101 FORMAT(26X,4HTURN,6X,4HMILL,5X,5HDRILL,1X,9HSURF.GRD.,2X,8HCYL.GRD
     1.,5X,5HOTHER,/)
  102 FORMAT(20H CUM. HOURS/YEAR    ,6F10.0,/////)
  103 FORMAT(2F10.1)
  104 FORMAT(4X,I1,A4,A2,A3,A2,A2,I4,1X,6(I2,I1,I4,4X),I1,2X,2A5,1X,I1)
  150 FORMAT(4X,//,8HFAMILY   ,I2)
   30 STOP
      END

END OF SEGMENT, LENGTH   235, NAME  KRUSE
```

FIG 40b

33053	1167	5	2	4	00	0	00	0	00	0	00	0	00	0	00	0	0	SP	3792	2
33053	1169	0	2	4	00	0	00	0	00	0	00	0	11	6	00	0	0	C	5488'	2
33133	2157	4	2	2	00	0	00	0	00	0	00	0	00	0	00	0	0	C	5481	2
33153	2157	5	2	2	00	0	00	0	00	0	00	0	00	0	00	0	0	C	5493	2
33163	2157	0	2	4	00	0	03	12	61	1	21	4	41	2	00	0	0	BK594/2BL		2
33163	2159	0	2	4	00	0	11	12	00	0	00	0	00	0	00	0	1	SP	3810'	2
33033	2167	4	2	4	00	0	00	0	00	0	00	0	00	0	00	0	0	C	5490	2
33033	2167	5	2	1	00	0	00	0	00	0	00	0	00	0	00	0	0	C	5491	2

FAMILY 1

	TURN	MILL	DRILL	SURF.GRD.	CYL.GRD.	OTHER
CUM. HOURS/YEAR	0.	380.	29.	289.	103.	0.

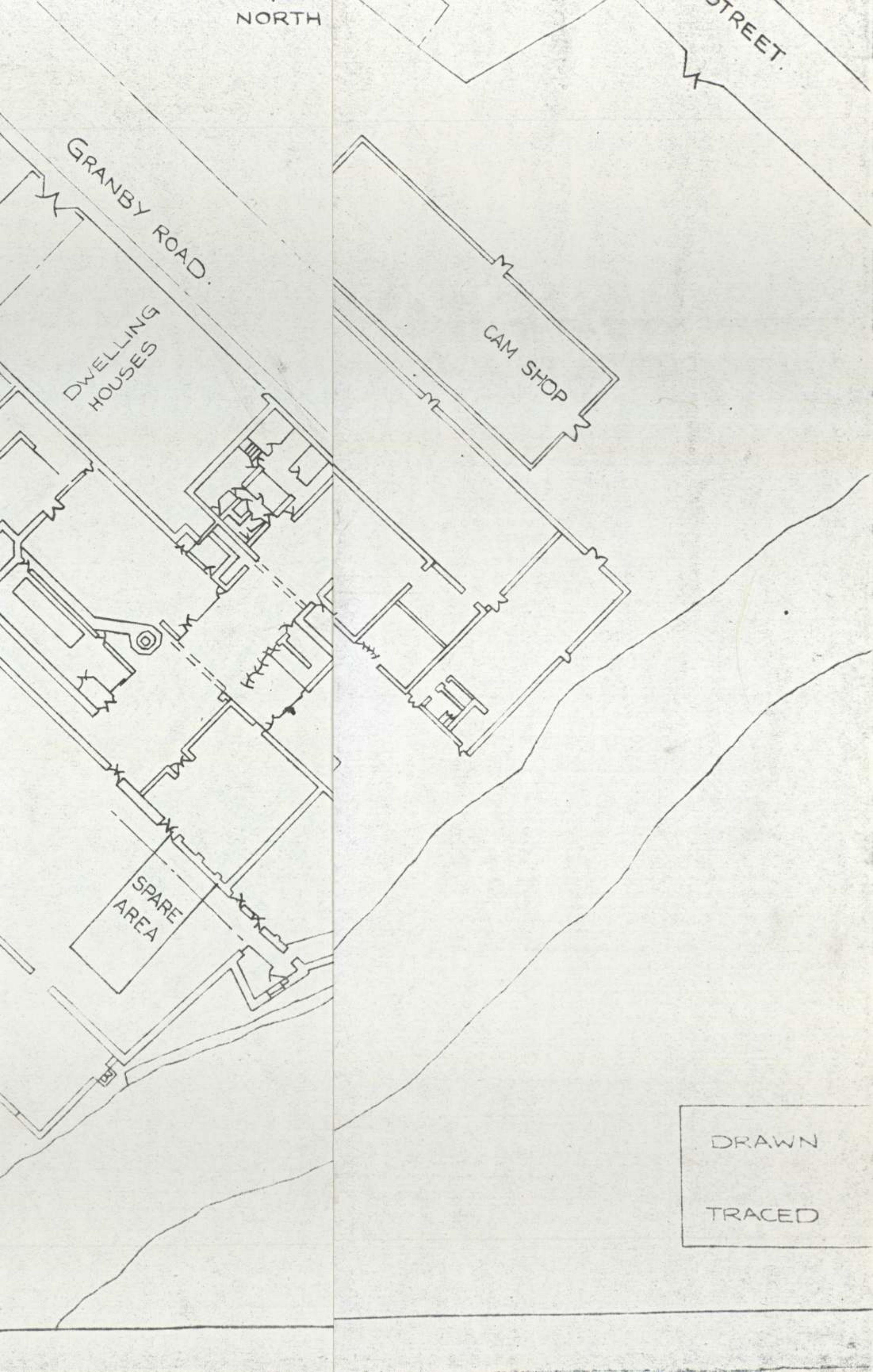
32704	3107	0	0	1	11	50	00	0	21	17	00	0	00	0	00	0	0	RTR	2284	1
32764	3307	4	0	1	00	0	00	0	00	0	00	0	00	0	00	0	0	D	2	0
32611	4107	0	0	1	11	55	31	9	21	13	00	0	00	0	00	0	1	RTR	2282	1
40201/2122		5	0	2	00	0	00	0	00	0	00	0	00	0	00	0	0	B	5026	1
42313	2107	0	0	3	00	0	00	0	11	2	00	0	00	0	00	0	0	AS	10252	2
43190	2042	0	0	1	41	18	03	24	00	0	21	6	51	3	00	0	3	SP	4873	2
44604	3170	4	0	4	00	0	00	0	00	0	00	0	00	0	00	0	0		100598	0

FAMILY 2

	TURN	MILL	DRILL	SURF.GRD.	CYL.GRD.	OTHER
CUM. HOURS/YEAR	455.	91.	132.	14.	7.	0.

FIG 41

G.T.4 PROGRAM OUTPUT



NORTH
STREET.
GRANBY ROAD.
DWELLING HOUSES
CAM SHOP
SPARE AREA
DRAWN
TRACED

CELL IMPLEMENTATION

SUGGESTED TIME SCALE

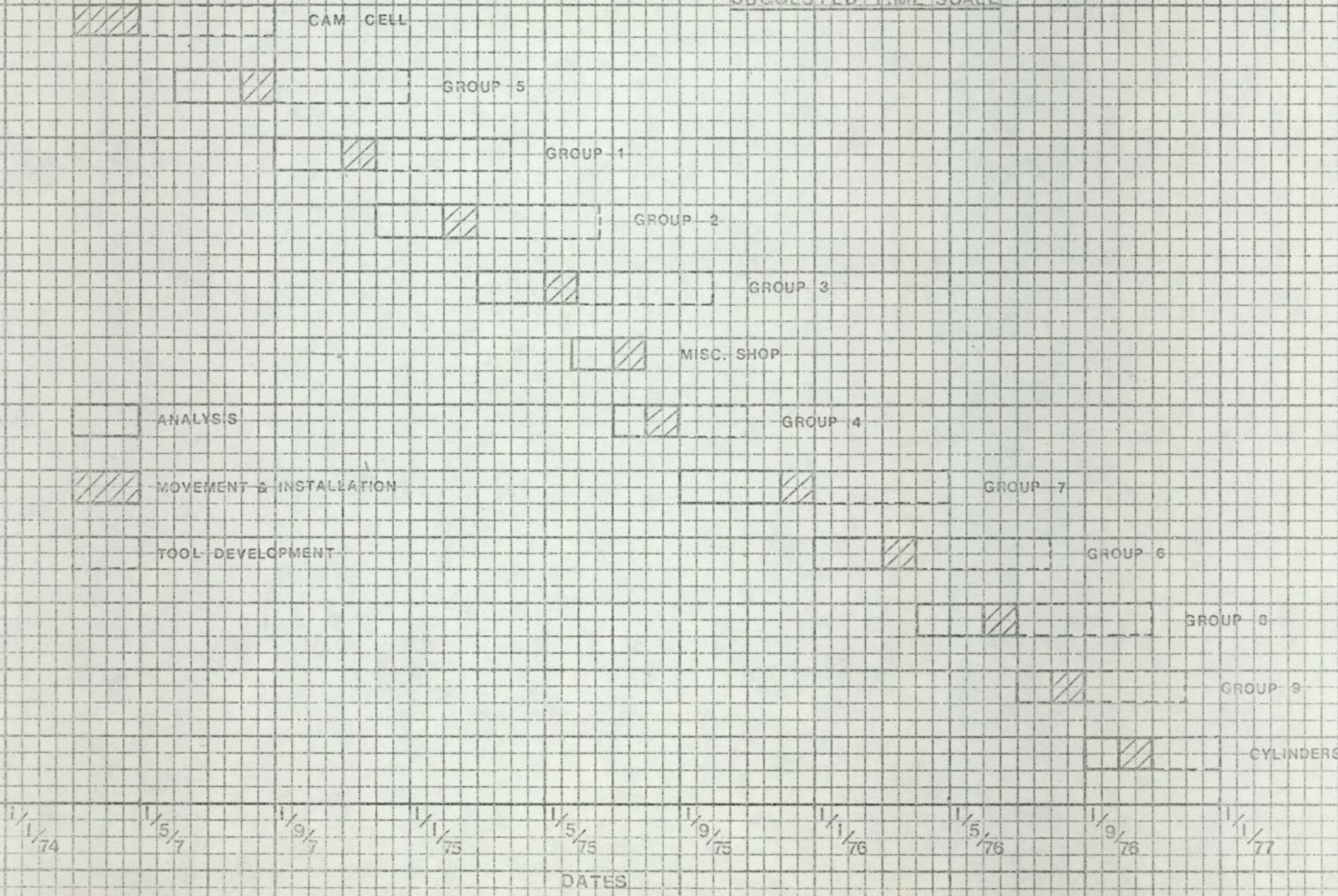
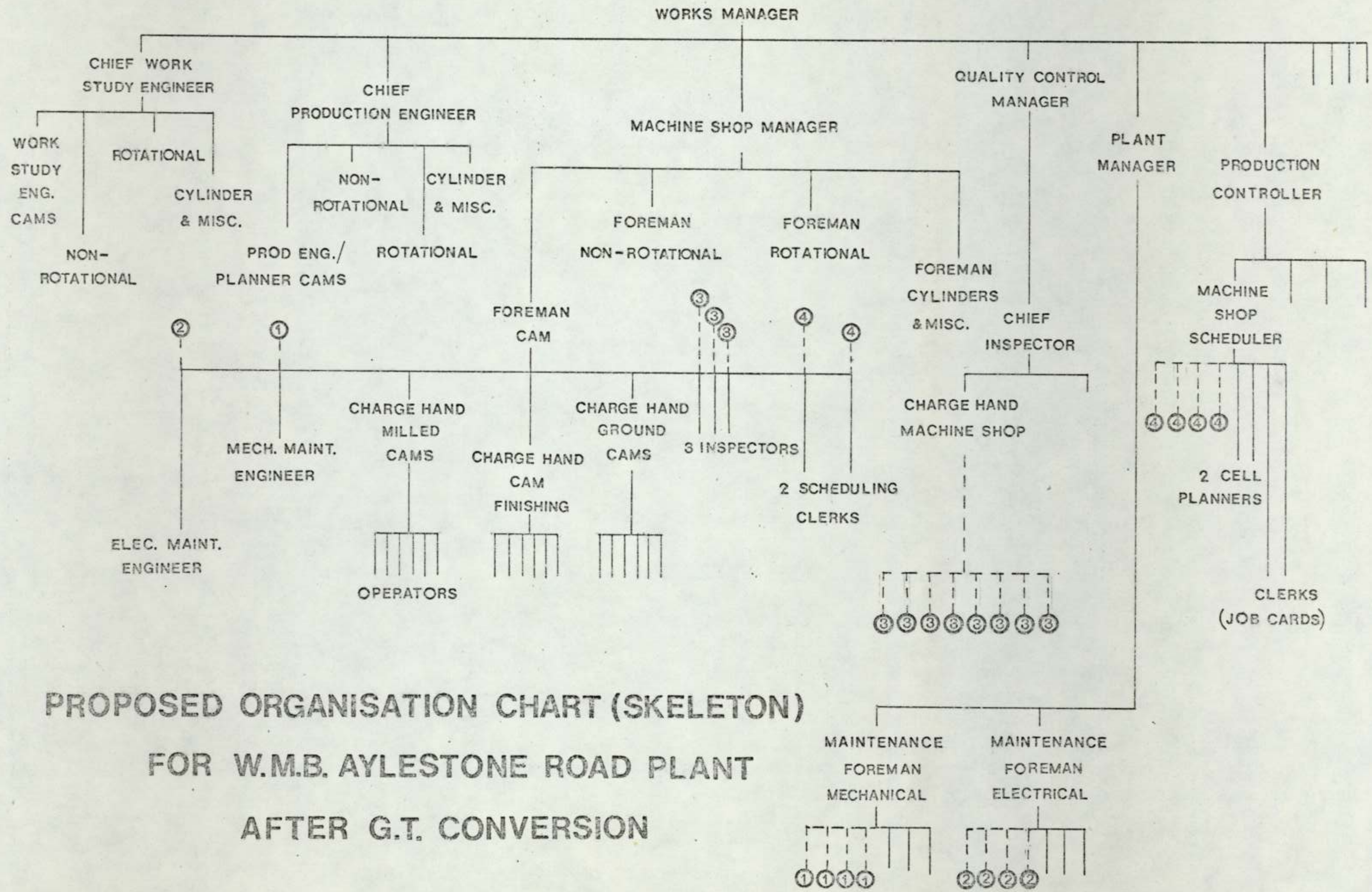
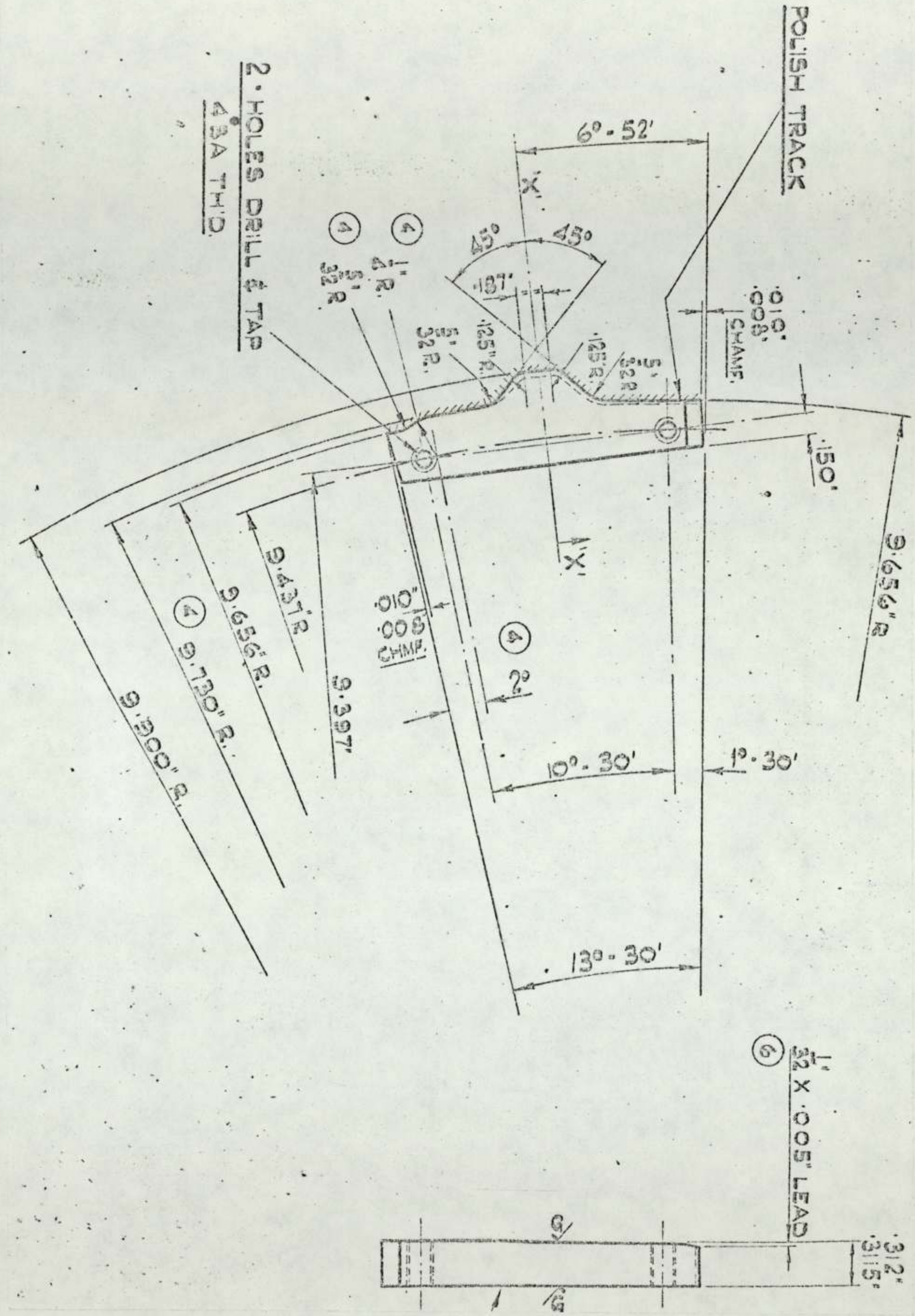


FIG 44



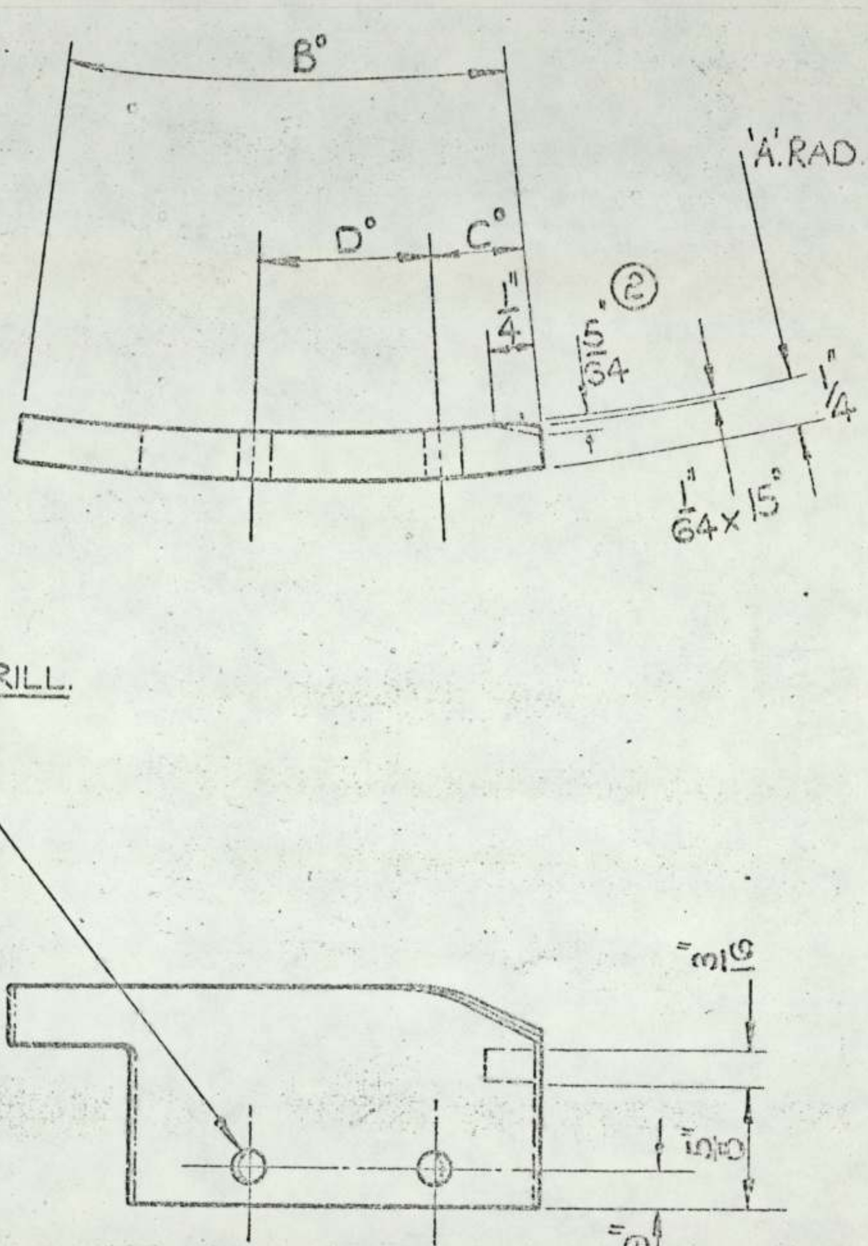
PROPOSED ORGANISATION CHART (SKELETON)
FOR W.M.B. AYLESTONE ROAD PLANT
AFTER G.T. CONVERSION

FIG 45



FLAT CAM

FIG 46



SWAGED CAM

FIG 47

Item(s) Charted: Cam-like Components   Basis of Values: Operations   By: G. Kruse   With: ____   Date: 30.7.1973   Page 1 of 1

Activity or Operation FROM \ TO	Cut-off Saw 1	Churchill Rot. Grind 2	Lumsden 3	J & S 540 4	J & S 540 Dia 5	H.M. No.2 6	V.M. No.2 7	Tracemaster 8	Swaging M/c 9	3-Sp. Drill 10	Fitting 11	Rot. Barrel 12	Harden 13	Stamp/Etch 14	Demag. 15	M/c Polish 16	Bridgeport 17	18	19	20	TOTALS
Cut-off Saw 1		13	83								2	2									100 *
Church.Rot.Grd 2				1	3	11				4	3	1			16						39
Lumsden 3				2	6	70				17	1	3			1						100
J & S 540 4				1	1	4				2	4			1	1						14
J & S 540 Dia 5					1	4			1		4			1	2						13
H.M. No.2 6				2	1		12	13	1	17	47	10		3	1						107
V.M. No.2 7									2	1	11			1							15
Tracemaster 8						1	1		1	13	14	3		1			6				41
Swaging M/c 9		1		3						2	1	3				65					75
3-Sp. Drill 10				3		7	1	28	6	2	23		1	55			5				131
Fitting 11		1	1						55	18			8	50							133
Rot. Barrel 12		4	3					1	5	9	1			6							29
Harden/Weld 13		21		1	1						2	2		2		1					30
Stamp/Etch 14		1			1	1	1	1	10	2	4		26			1					48
Demag. 15						1			1					1							3
Machine Pcl. 16						2				52	5		1	5	1						66
Bridgeport 17											9	2			1						12
18																					
19																					
20																					
TOTALS		41	87	13	14	102	15	43	82	139	131	26	36	126	23	67	11				956

NOTES:

FIG 48

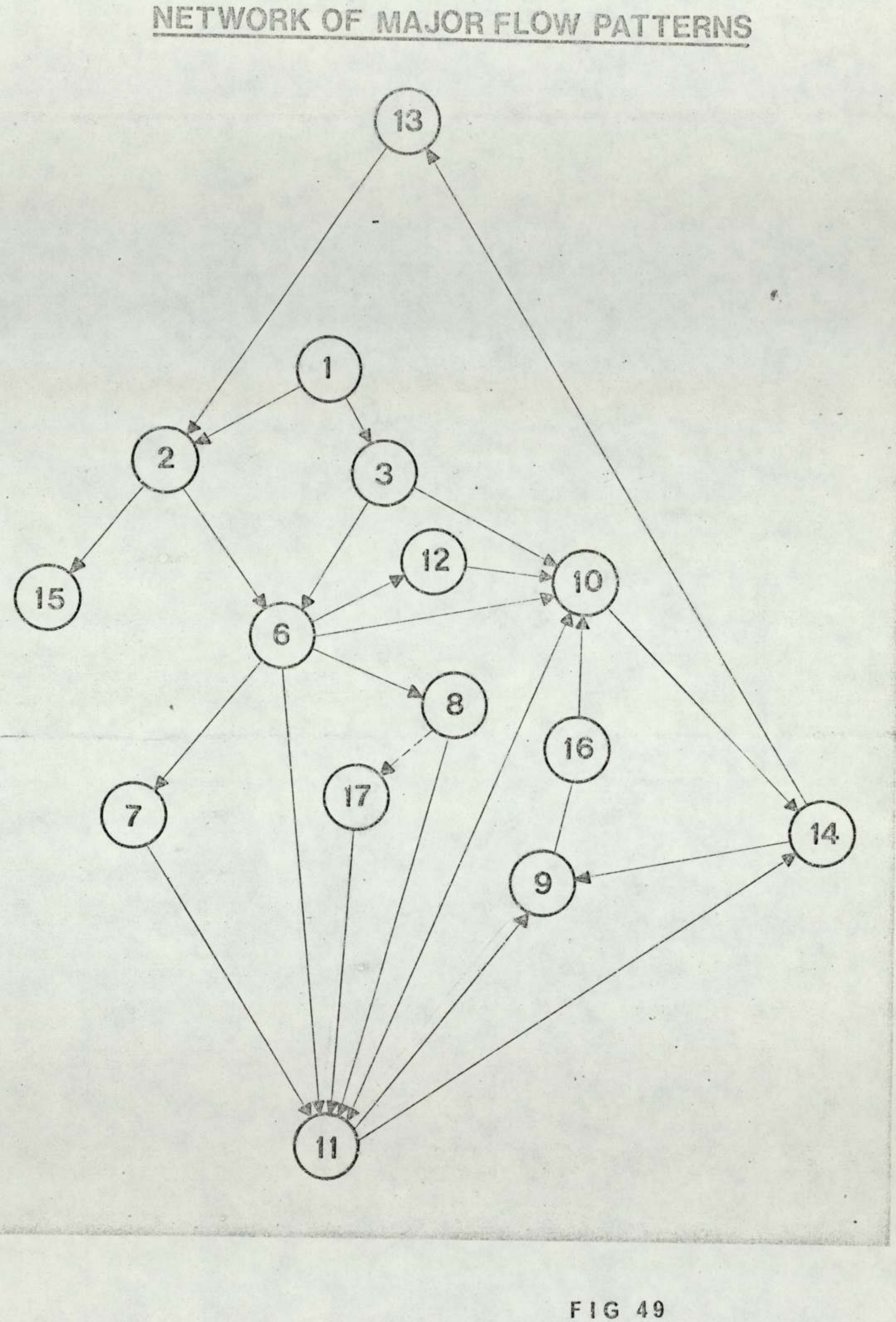


FIG 49

MAJOR FLOW PATH

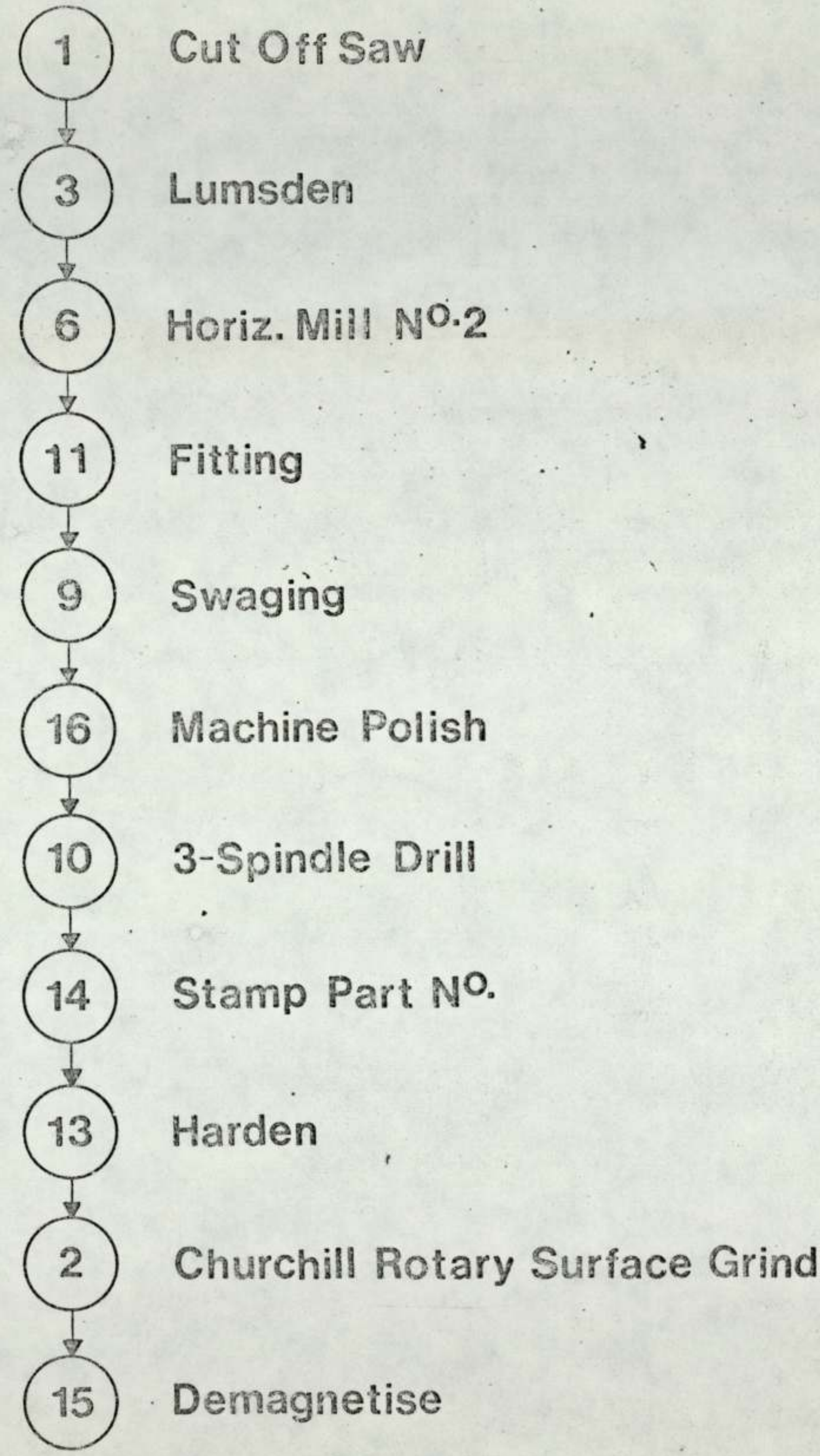


FIG 50

MAJOR FLOW PATH WITH MINOR FLOW PATTERNS ADDED

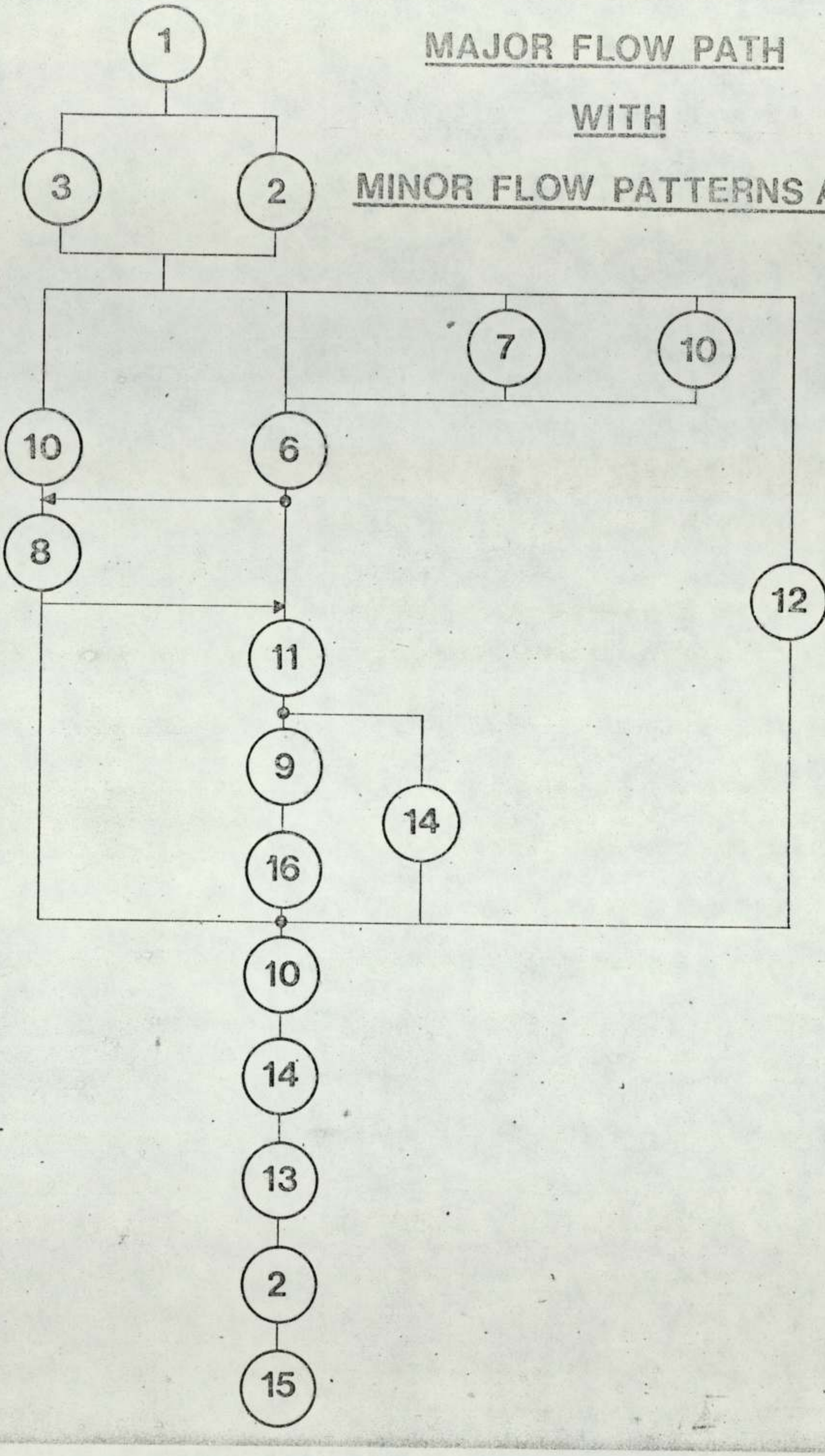


FIG 51

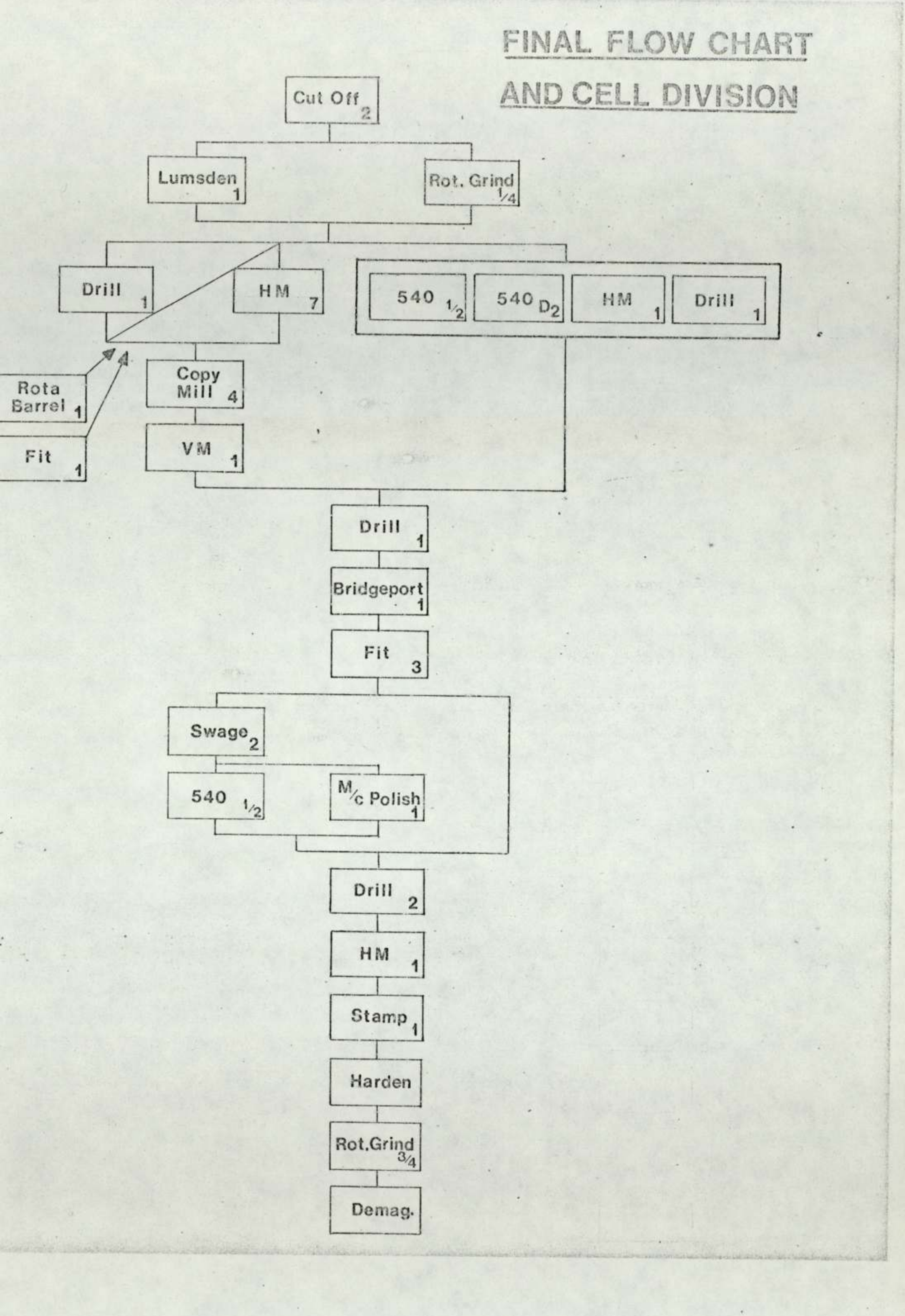

FINAL FLOW CHART
AND CELL DIVISION
Cut Off 2
Lumsden 1
Rot. Grind 1/4
Drill 1
HM 7
540 1/2
540 D2
HM 1
Drill 1
Rota Barrel 1
Fit 1
Copy Mill 4
VM 1
Drill 1
Bridgeport 1
Fit 3
Swage 2
540 1/2
M/c Polish 1
Drill 2
HM 1
Stamp 1
Harden
Rot.Grind 3/4
Demag.

FIG 52

CELL BLOCK DIAGRAM AND FLOW CHART

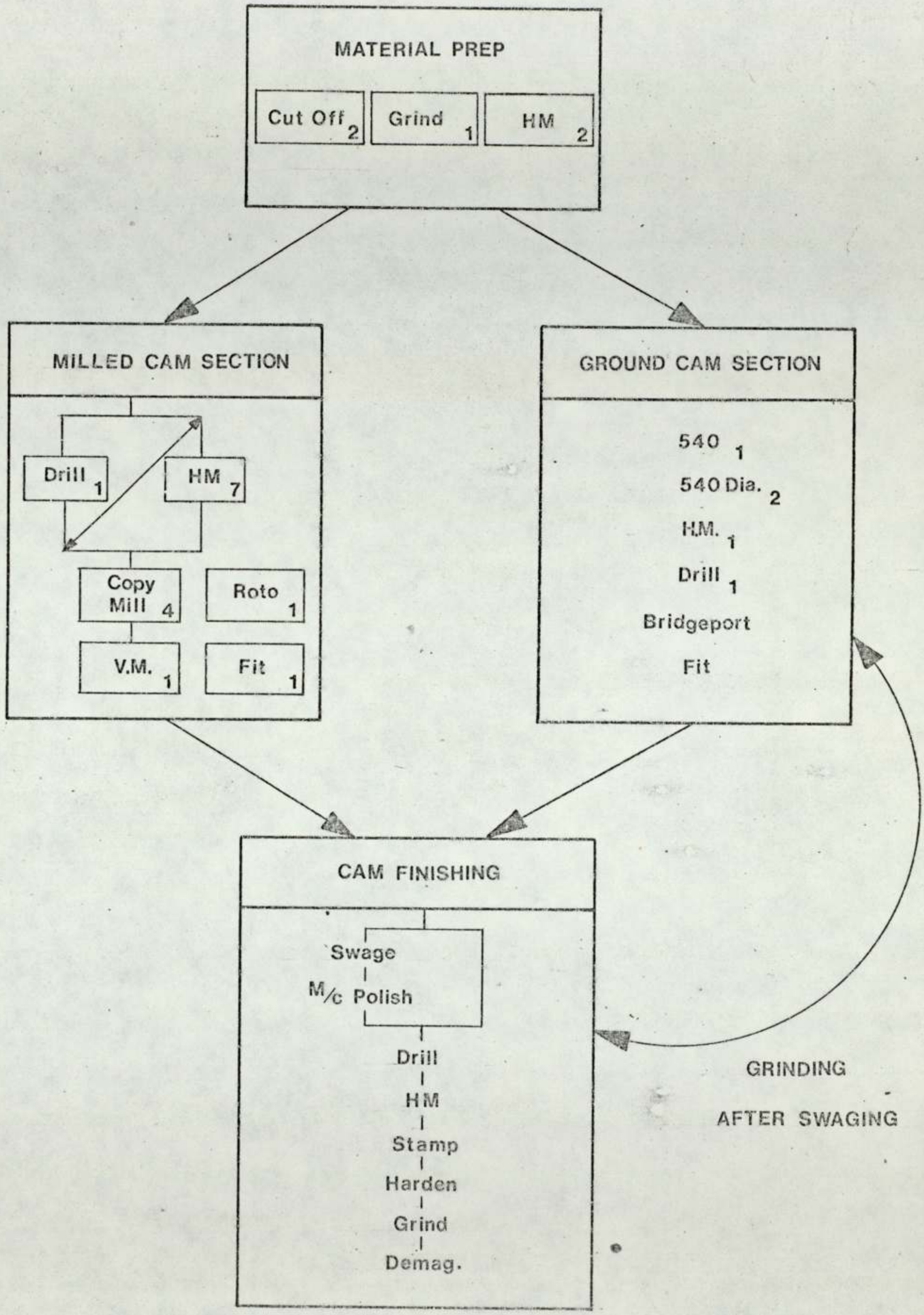
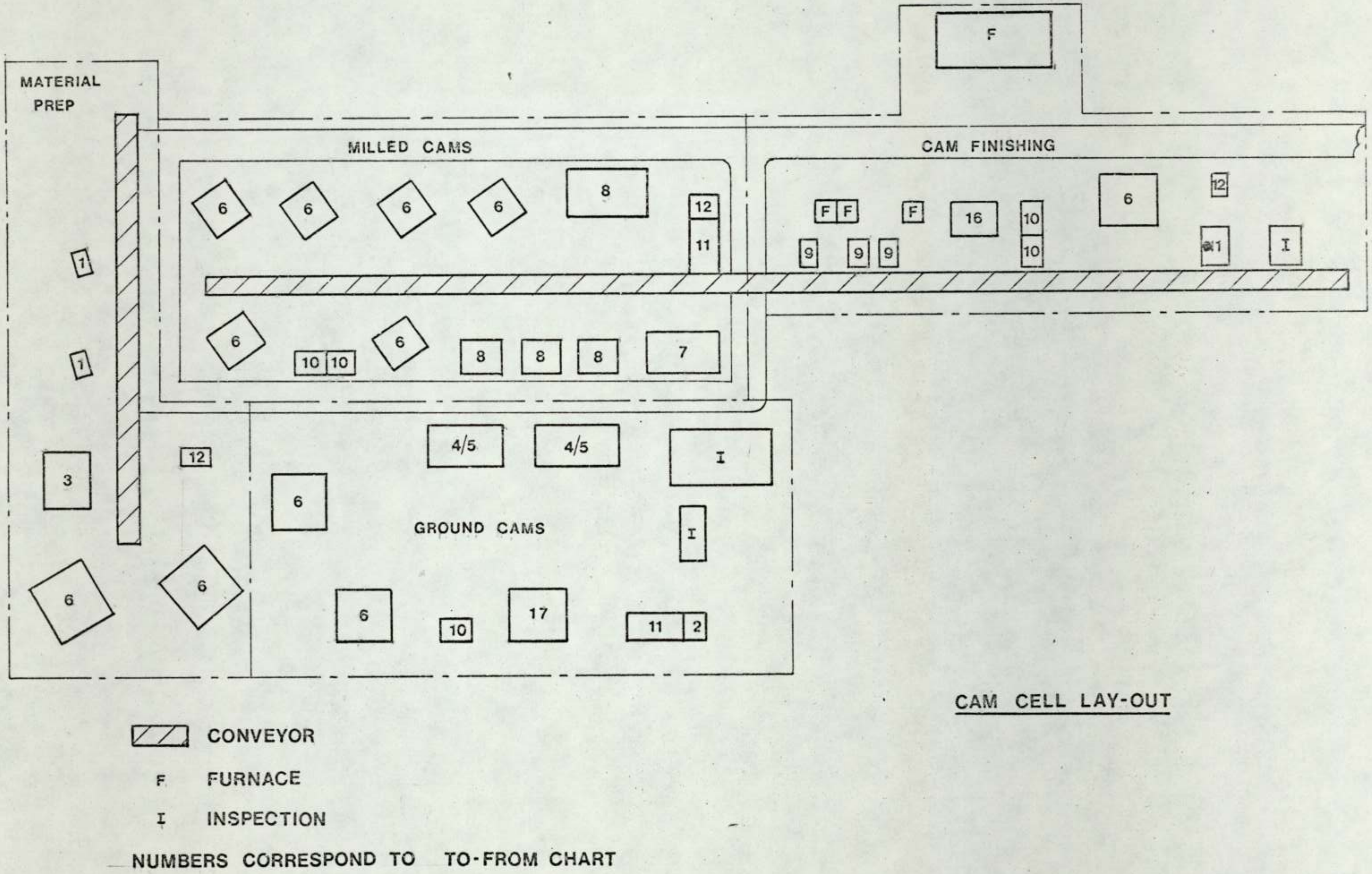
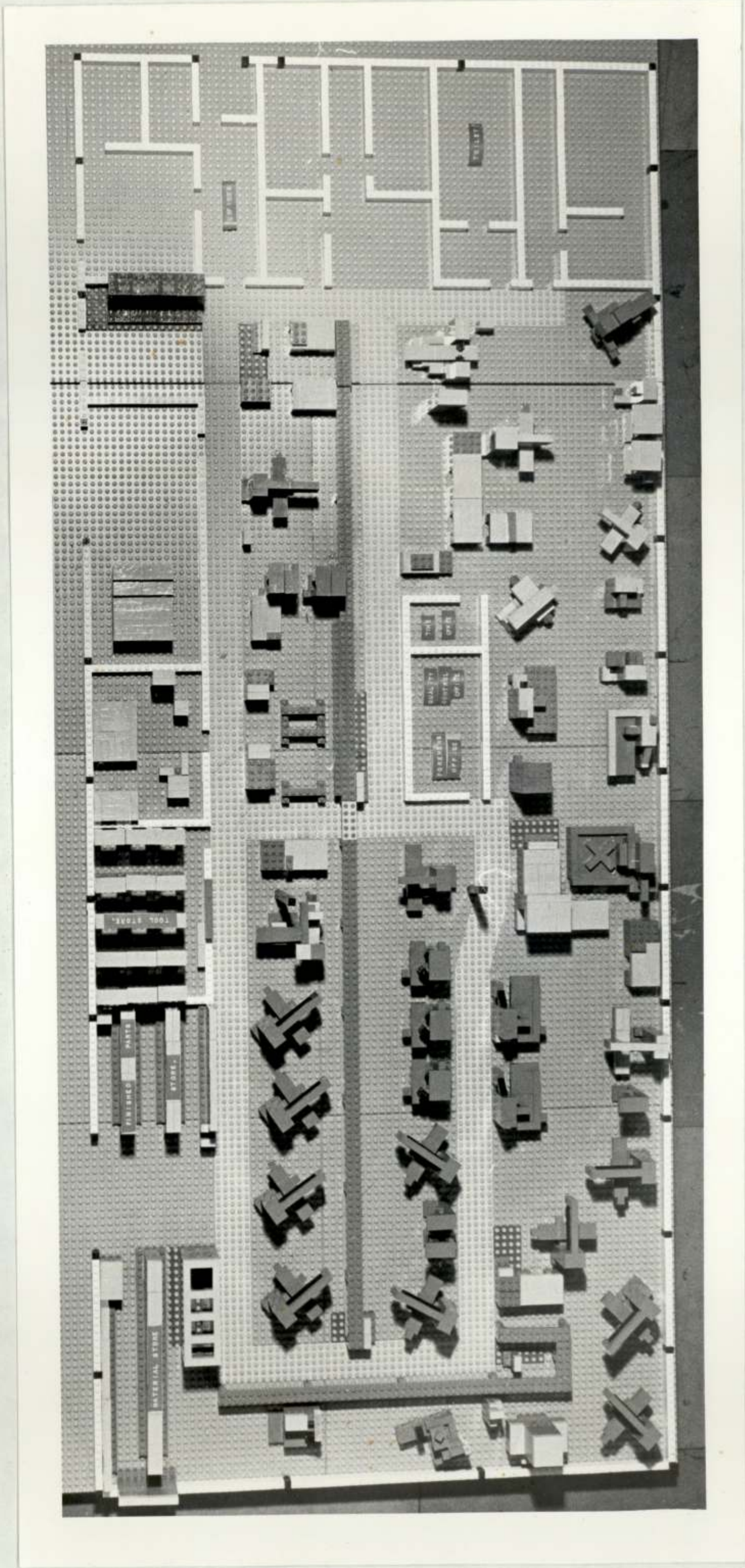


FIG 53



CAM CELL LAY-OUT

FIG 54



MODEL OF CAM CELL LAYOUT

FIG 55

WEST AVENUE SCHEDULING LIST

MILLED CAMS

000/001	RTR478
000/002	W2826
001/001	W2825
001/001	SP3877
005/001	C1655
005/002	C4693
005/003	C606
005/004	C604
005/005	C605
006/001	SP4472
006/002	SP4085
006/003	SP4084
007/001	SP4700
010/001	RS4608
010/002	RTR404
010/003	RS4592
010/004	RS4418
010/005	RS4414
010/006	RTR3559
010/007	RTR1618
010/008	W2786
010/009	W2772
010/010	W2218
010/011	
010/012	C1229
010/013	C7520
010/014	W2196
010/015	
010/016	RTR402
010/017	C2286
010/018	C2764
010/019	C2766
010/020	RTR3166

FIG 56

W.M.B. LTD. AYLESTONE ROAD NET REQUIREMENTS LOADING REPORT DATUM 73362

ITEM NUMBER				PRE-36	36-38	39-41	42-44	45-48	49-52	1- 4
95/756+	1.8 AUR	0 LT	GR	468	128	73	73	158	53	59
CLASS. A02	35 SSD		OO*	500						
ORD.GP. 10	500 OQ		ST	299	171	98	524	366	313	254
SUPP. 1000	FIXED		SO				500			
95/757	0.0 AUR	0 LT	GR	450	108	52	68	144	44	52
CLASS. A02	30 SSD		OO*	1000				500		
ORD.GP. 10	300 OQ		ST	376	268	216	148	504	460	408
SUPP. 1000	FIXED		SO							
95/939	0.3 AUR	0 LT	GR		11	1	3	9	5	5
CLASS. B03	2 SSD		OO							
ORD.GP. 40	0 OQ		ST	74	63	62	59	50	45	40
SUPP. 4400	DISCRETE		SO							
95/951	0.8 AUR	0 LT	GR	2435	82	36	80	107	35	27
CLASS. B05	25 SSD		OO*	900						
ORD.GP. 10	300 OQ		ST	92	310	273	193	86	50	323
SUPP. 1000	FIXED		SO	1500	300					300
95/952/1233	0.0 AUR	0 LT	GR	5	4	2	2		1	
CLASS. B02	1 SSD		OO*	20						
ORD.GP. 10	20 OQ		ST	20	16	14	12	12	11	11
SUPP. 1000	FIXED		SO							
95/990	0.0 AUR	0 LT	GR							
CLASS. B09	0 SSD		OO							
ORD.GP. 10	0 OQ		ST							
SUPP. 1000	DISCRETE		SO	3000						
95/1004/18	0.1 AUR	0 LT	GR	22		2	2		4	
CLASS. B09	0 SSD		OO							
ORD.GP. 70	0 OQ		ST	13	13	10	8	8	3	3
SUPP. 2316	DISCRETE		SO							
95/1004/20	0.0 AUR	0 LT	GR	44	2	2	5	2	4	2
CLASS. B09	1 SSD		OO							
ORD.GP. 70	100 OQ		ST	31	29	27	22	20	16	14
SUPP. 5700	FIXED		SO							

FIG 57

PART NUMBER	OPITZ CODE		PERIOD 9-13	14-17	18-21										TOTAL
SP 3784 /16	015/009		16	20	0										
SP 3784 /18	015/010		16	20	0										
SP 3786	006/021		20	15	30										
SP 3811 /16	030/003		0	0	10										
SP 3811 /17	030/004		0	5	0										
SP 3811 /18	030/005		5	5	5										
SP 3811 /20	030/006		0	1	1										
SP 3811 /22	030/007		64	32	64										
SP 4201	015/002		24	24	12										
SP 4202 /12	046/031		0	2	2										
SP 4202 /13	046/032		0	0	0										
SP 4202 /14	046/033		6	0	0										
SP 4202 /15	046/034		0	0	0										
SP 4202 /16	046/035		0	0	8										
SP 4202 /18	046/036		5	5	5										
SP 4202 /20	046/037		0	0	1										
SP 4202 /22	046/038		48	24	48										
SP 4612	020/001		12	48	0										
SP 4613	020/002		12	48	0										
SP 4711 /12	025/006		0	2	2										
SP 4711 /13	025/007		0	0	0										
SP 4711 /14	025/008		6	0	0										
SP 4711 /15	025/009		0	0	21										
SP 4711 /16	025/010		0	0	4										
SP 4711 /17	025/011		1	1	1										

FIG 58

CELL ORDER CHART

BUILD MONTH MARCH 1974

CELL MILLED CAMS	PLAN PERIOD JAN 74	MFG START DATE 2/1/74	MFG FINISH DATE 15/2/74	KEY MACHINE HORIZONTAL MILL No 2

BATCH NO.	PART NO.	DESCRIPTION	SCH CODE	GROSS REQU.	SCRAP SPARE	STOCK VAR'NCE	NET REQU.	QTY. INTO STORE	SCRAP SPARE SURPLUS	MATERIAL EACH	MAT'L PER BATCH	MATLS AV	TOOLS AV	SETTING HOURS	HOURS EACH	TOTAL BATCH HOURS	NO. OF M/C	TOTAL WEEKS	CUM. TOTAL	MFR. PERIOD	LOAD PREP.	LOAD M/C
0001	C1655	CUT-THROW CAM	005	20	3	2	25			K200×1 3/16×1 1/2"	3'-6"	✓	✓	2.00	.04	3.00	5	.015	.015	3/1/74		
0002	C4633	CUT-THROW GUARD CAM	005	16	2	1	19			K200×5/8×5/16×1 1/2"	2'-0"	✓	✓	0.10	.05	1.05	5	.005	.020			
0003	C606 /18	SELECTOR CUT-THROW CAM	005	4	1	(1)	4			K200×7/8×5/16×1"	0'-4"	✓	✓	0.10	.03	0.22	5	.001	.021			
0004	C606 /20	" " "	005	14	3	5	22			K200×7/8×5/16×7/8	1'-8"	✓	✓	0.10	.08	1.86	5	.009	.030			
0005	C604 /16	CUT-THROW GUARD CAM	005	2	1	(6)	—			K200×7/8×5/16×1 1/2	—	✓	✓	0.10	.06	—	5	—	.030			
0006	C604 /18	" " " "	005	8	2	3	13			K200×7/8×5/16×1 3/8	1'-6"	✓	✓	0.10	.07	1.01	5	.005	.035			
0007	C604 /20	" " " "	005	2	1	1	4			K200×7/8×5/16×1 3/8	0'-5"	✓	✓	0.10	.06	0.34	5	.002	.037			
0008	C605 /18	" " " "	005	24	4	(2)	26			K200×1"×5/16×1 3/8	3'-0"		✓	0.10	.09	2.44	5	.012	.049			
0009	SP4472 /20	SELECTOR CUT-THROW CAM	006	6	1	(1)	6			MVCS×1"×5/16×3 1/2	1'-9"	✓	✓	0.10	.09	.64	5	.003	.052			
0010	SP4472 /22	" " " "	006	36	6	0	42			MVCS×1"×5/16×3	10'-6"	✓	✓	0.10	.08	3.46	5	.017	.069			
0011	SP4472 /30	" " " "	006	18	3	2	23			MVCS×1×5/16×2 1/4	4'-4"	✓	✓	0.10	.02	.46	5	.002	.071			
0012	SP4085	CUT-THROW CAM	006	64	10	(4)	70			K200×1 1/4×1/4×4 1/2	26'-3"	✓	✓	0.10	.06	4.30	5	.022	.093			
0013	SP4084	CUT-THROW CAM	006	48	7	3	58			K200×1 1/2×1/4×4 1/4	20'-7"		✓	0.10	.07	4.16	5	.020	.113			
0014	SP4700 /22	RUN CAM	006	16	3	(10)	9			K200×5/8×1/4×3	2'-3"		✓	0.10	.05	.55	5	.003	.116			
0015	SP4700 /30	" "	006	8	2	2	12			K200×7/8×5/16×3 3/8	3'-2"		✓	0.10	.03	.46	5	.002	.118			
0016	RS4608 /18	GUARD CAM	010	30	5	5	40			K200×5/8×1/4×1 1/8	3'-9"	✓	✓	3.00	.06	5.40	5	.027	.145			
0017	RS4608 /20	" "	010	6	1	1	8			K200×5/8×1/4×1	0'-8"	✓	✓	0.15	.05	.55	5	.003	.148			
0018	RS4608 /22	" "	010	60	10	(1)	69			K200×5/8×1/4×7/8	5'-1"	✓	✓	0.15	.05	3.60	5	.018	.166			
0019	RTR404 /12	SHORT GUARD CAM	010	8	2	(1)	9			K200×3/4×1/4×1 1/2	1'-2"		✓	0.15	.05	.60	5	.003	.169			
0020	RTR404 /14	" " "	010	4	1	4	9			K200×3/4×1/4×1 1/4	1'-0"		✓	0.15	.06	.69	5	.003	.172			
0021	RTR404 /16	" " "	010	16	3	(5)	14			K200×3/4×1/4×1 1/2	1'-4"		✓	0.15	.07	1.13	5	.006	.178			
0022	RS4592 /18	GUARD CAM	010	8	2	2	12			K200×7/8×5/16×1 3/4	1'-9"		✓	0.15	.06	.87	5	.004	.182			
0023	RS4592 /20	" "	010	4	1	1	6			K200×7/8×5/16×1 1/2	0'-9"		✓	0.15	.08	.63	5	.003	.185			
0024	RS4592 /22	" "	010	32	5	3	40			K200×7/8×5/16×1 3/8	4'-7"		✓	0.15	.07	2.95	5	.015	.200	4/1/74		
0025	RS4418 /18	" "	010	8	2	6	16			K200×9/16×1/4×1 1/4	1'-8"	✓	✓	0.15	.08	1.43	5	.007	.207			
0026	RS4418 /20	" "	010	4	1	(2)	3			K200×9/16×1/4×1 1/8	0'-4"		✓	0.15	.06	.33	5	.002	.209			
0027	RS4418 /22	" "	010	32	6	5	43			K200×9/16×1/4×1 1/16	3'-10"		✓	0.15	.06	2.73	5	.014	.223			
0028	RS4414 /18	GUARD AFTER STITCH CAM	010	8	2	2	12			K200×5/8×1/4×1 3/4	1'-9"		✓	0.15	.05	.75	5	.004	.227			
0029	RS4414 /20	" " " "	010	4	2	(1)	5			K200×5/8×1/4×1 1/2	0'-8"		✓	0.15	.03	.30	5	.002	.229			
0030	RS4414 /22	" " " "	010	32	5	(10)	27			K200×5/8×1/4×1 1/4	2'-10"		✓	0.15	.04	1.23	5	.006	.235			
0031	RTR3559 /16	GUARD CAM	010	8	2	2	12			K200×7/8×5/16×1 1/2	1'-6"		✓	0.15	.09	1.23	5	.006	.241			
0032	RTR3559 /18	" "	010	14	4	3	21			K200×7/8×5/16×1 1/4	2'-3"			0.15	.10	2.25	5	.011	.252			
0033	W2786 /30	DEPRESS CAM	010	24	8	1	33			K200×7/8×1/4×3/4	2'-1"			0.15	.10	3.45	5	.017	.269			
0034	W2772 /30	JACK DEPRESS CAM	010	18	3	0	21			K200×3/4×5/16×5/8	1'-2"		✓	0.15	.11	2.46	5	.012	.281			
0035	W2218 /30	DEPRESS CAM	010	12	3	(2)	13			K200×1×5/16×7/8	1'-0"		✓	0.15	.13	1.84	5	.009	.290			
0036	C1229	GUARD CAM	010	72	11	(1)	82			K200×7/8×1/4×3/4	5'-2"		✓	0.15	.08	6.71	5	.033	.323			
0037	C7520 /30	OILING CAM	010	18	3	3	24			K200×1 1/8×5/16×7/8	1'-9"		✓	0.15	.10	2.55	5	.013	.336			

FIG 59

WMB/BW/WAC8

Family No.	010	Op. No.	3	M/c.	H.M. No.2	Cell No.	001
Start Date			Finish Date				

Batch No.	Part No.	Qty.	Time	Qty. Good	Cell No.	Operator
TOTAL TIME						

FAMILY JOB CARD

FIG 60

TYPICAL GANNT CHART

FOR ONE BATCH

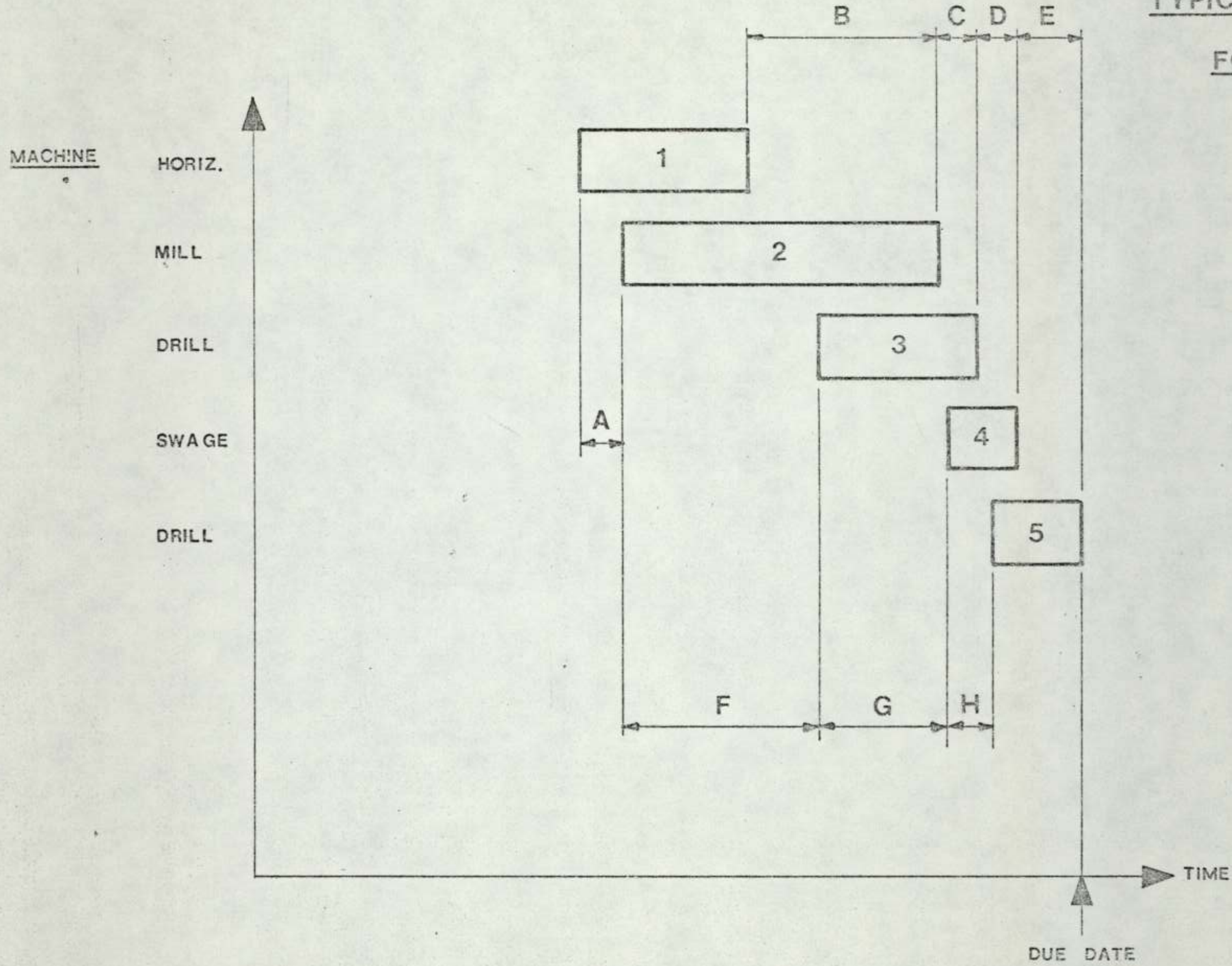


FIG 61

TYPICAL GANNT CHART

FOR SEVERAL BATCHES

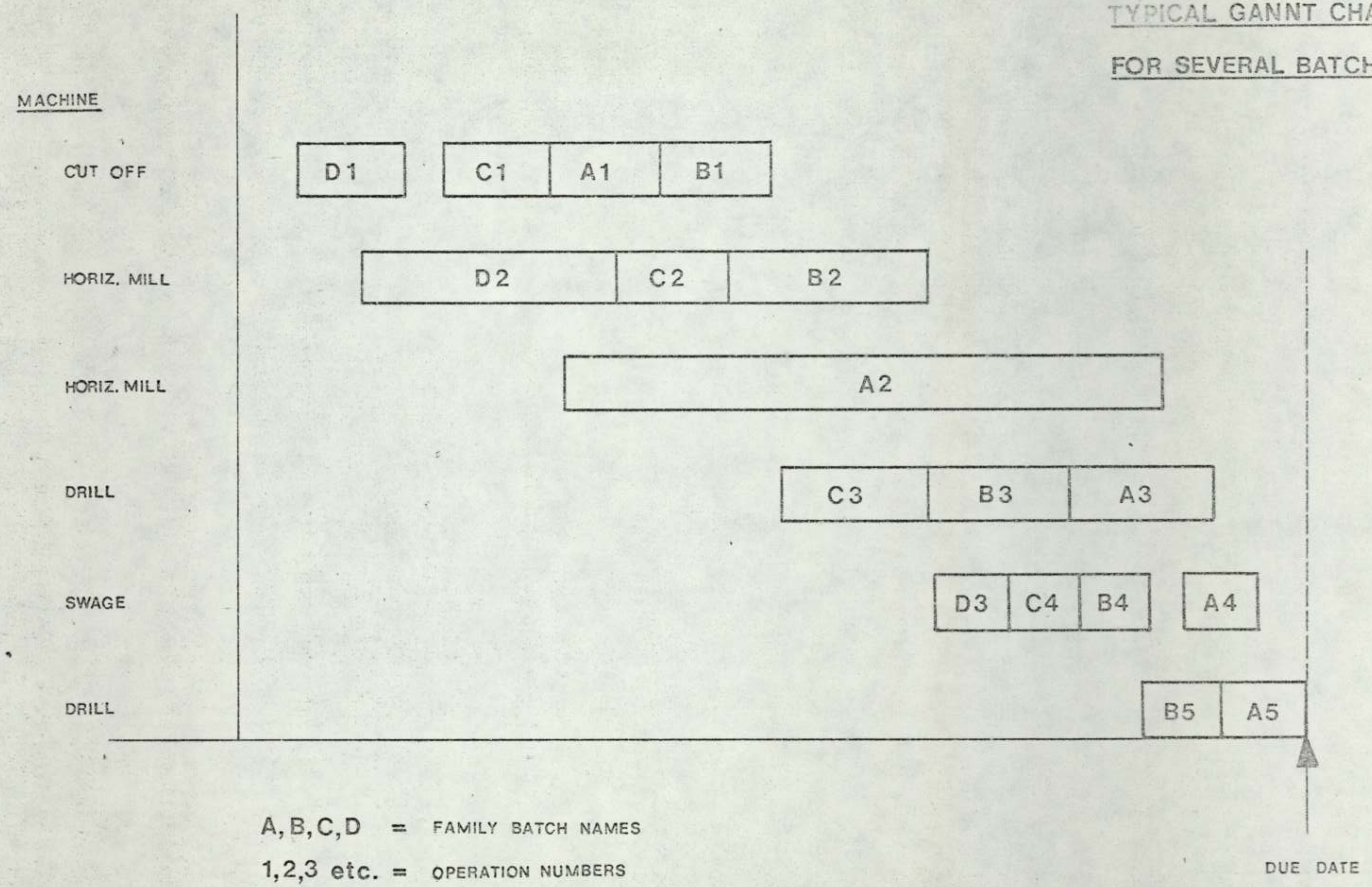
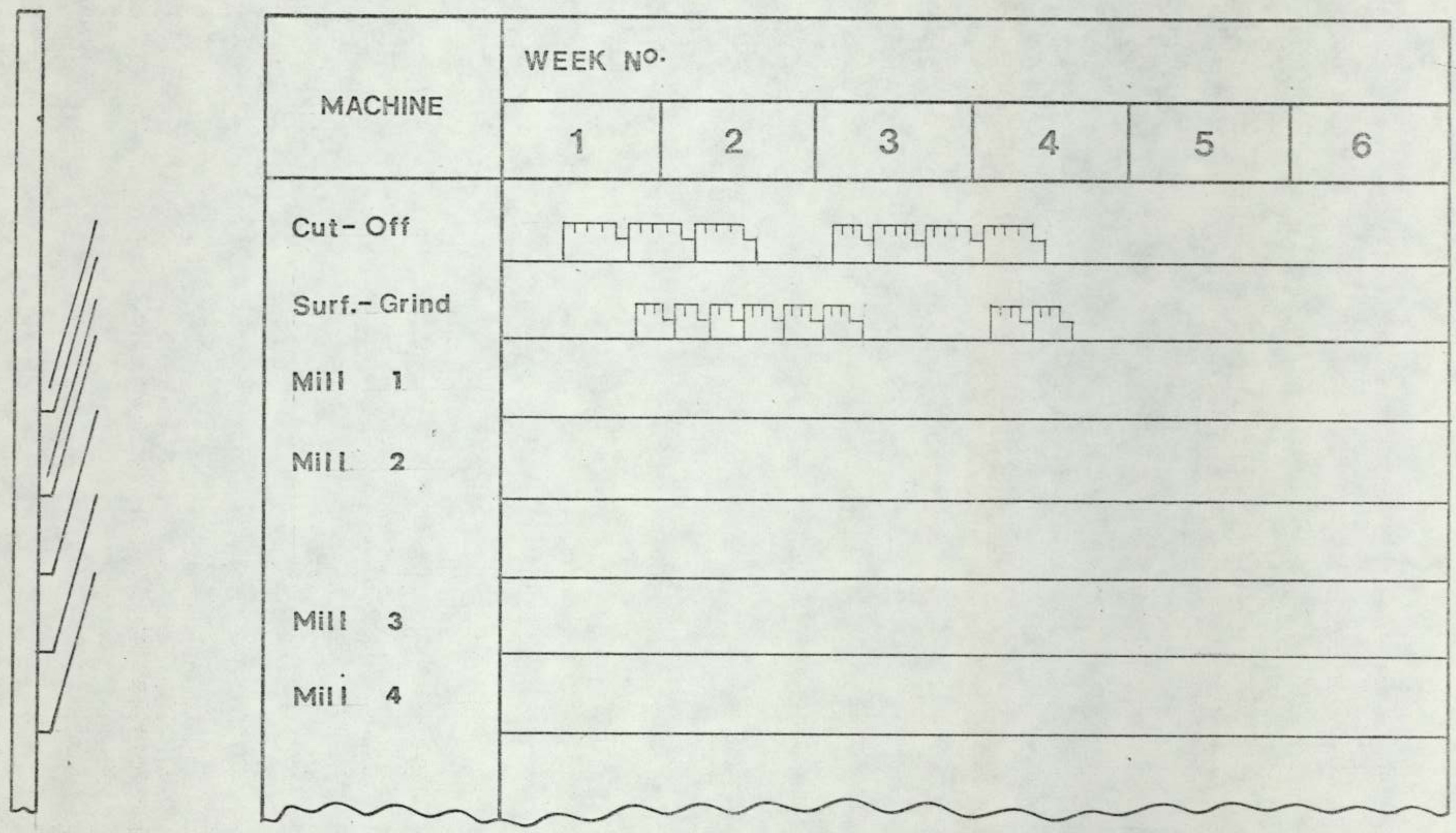


FIG 62



SCHEDULING BOARD

FIG 63

PRODUCTION PLANNING

FLOW CHART

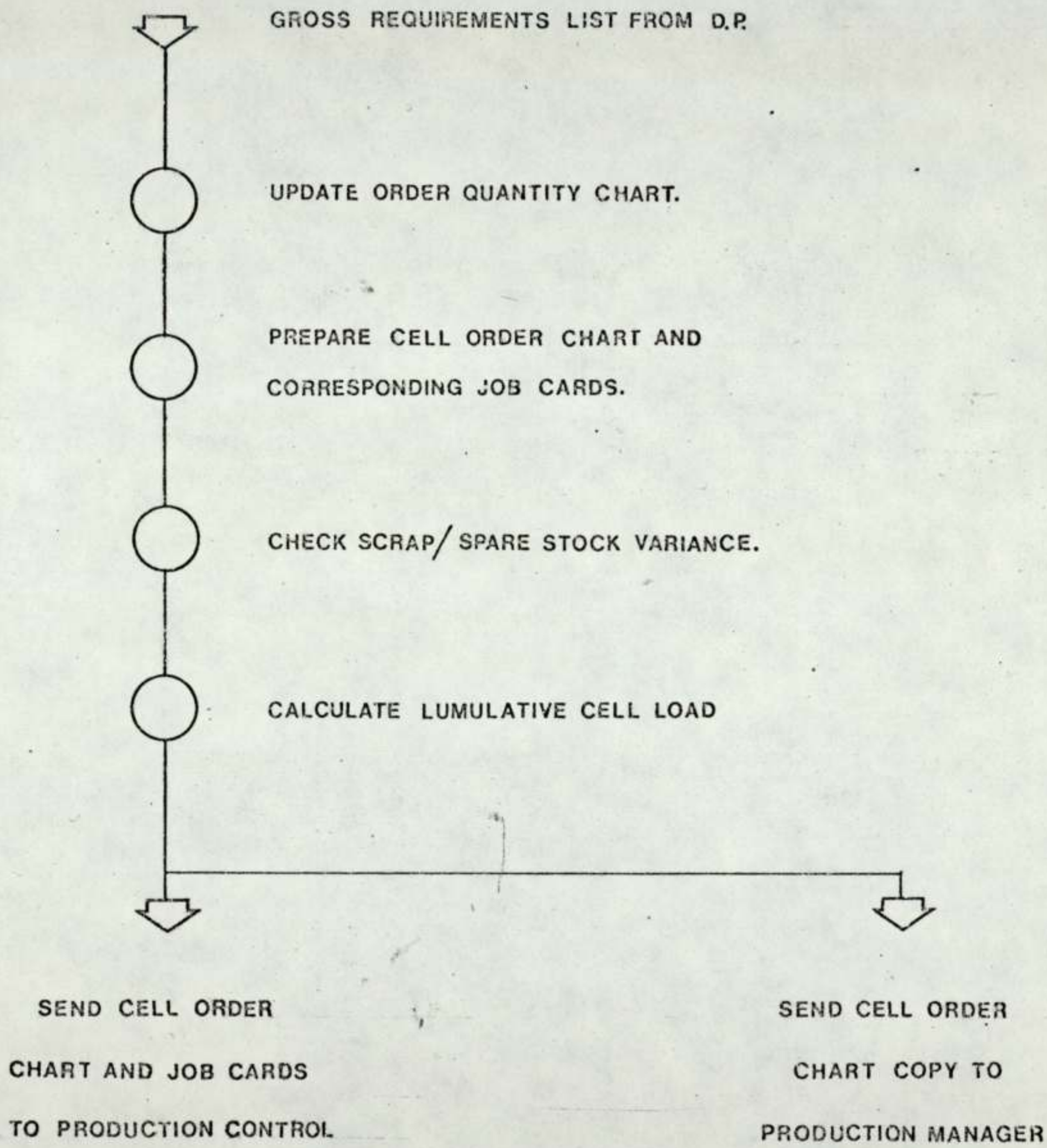
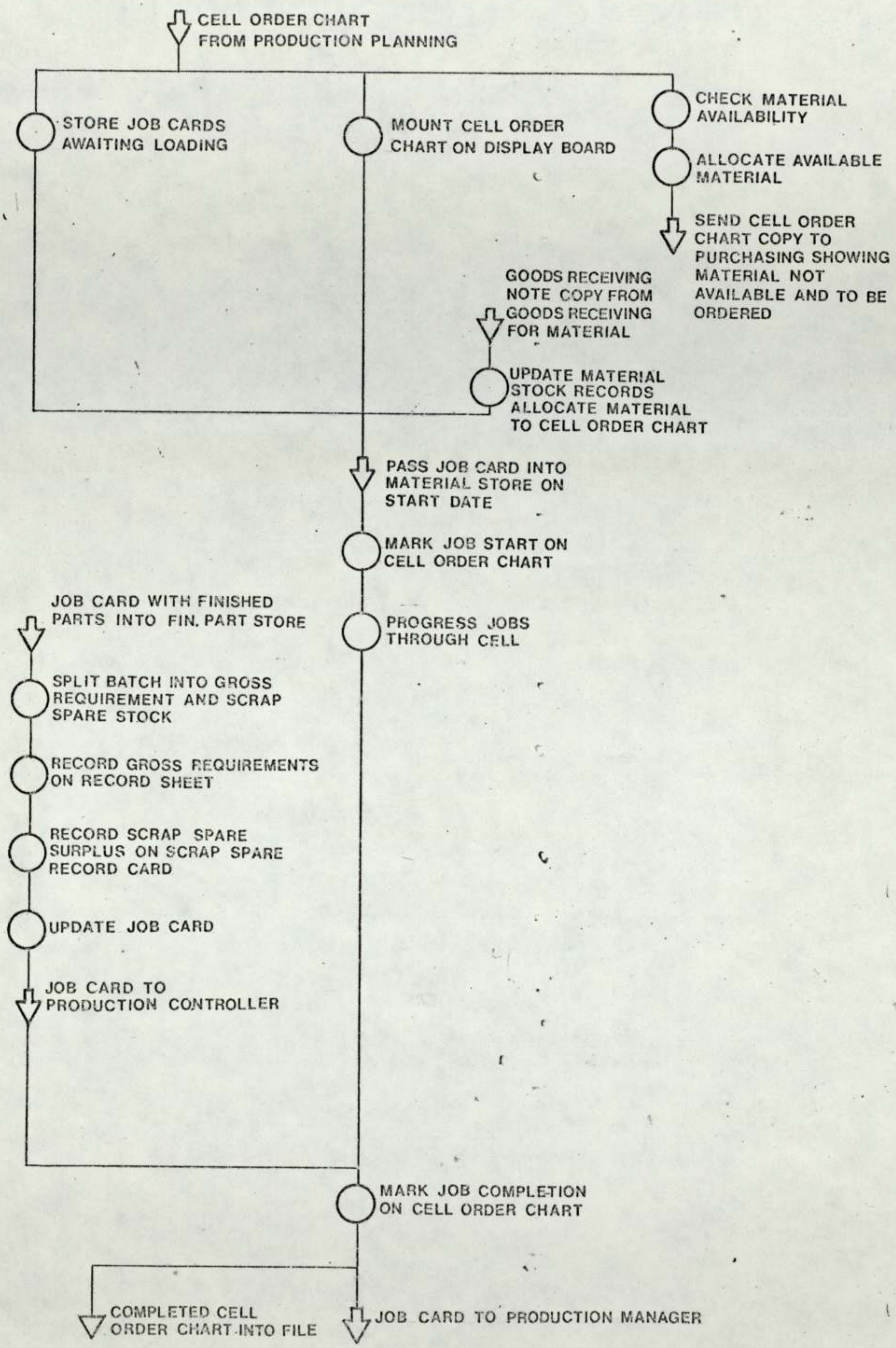


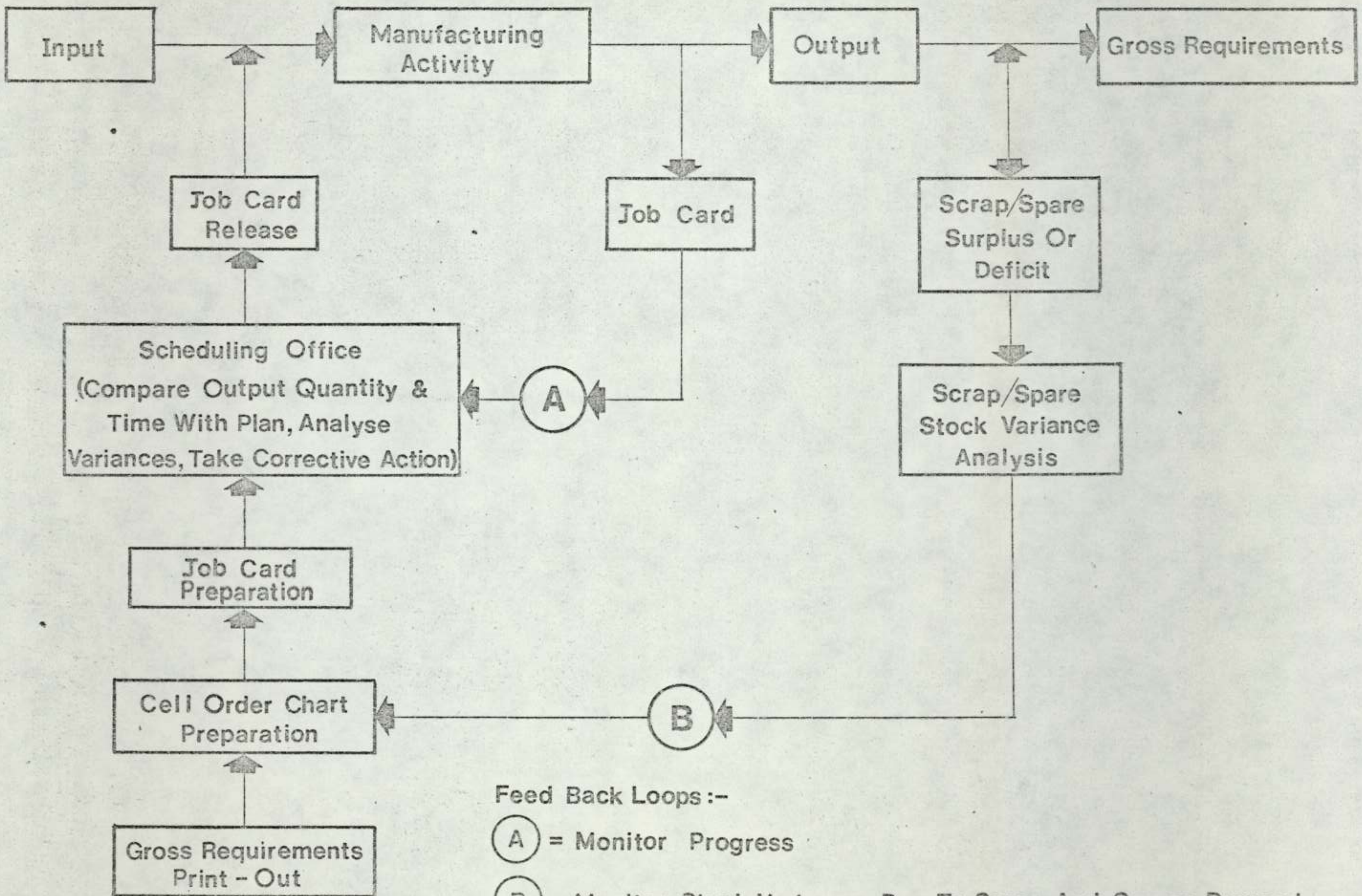
FIG 64



PRODUCTION CONTROL FLOW CHART

FIG 65

WEST AVENUE PRODUCTION CONTROL BLOCK DIAGRAM



Feed Back Loops :-

(A) = Monitor Progress

(B) = Monitor Stock Variances Due To Scrap And Spares Demand (Can Also Cope With Limited Program Changes)

FIG 66

FAMILY PLANNING SHEET

	001				SCEDULING CODE				
ES	000	001	002	005	006	007			
IPTION					DRG. Nº·				ISSUE
CODE		PLANNED BY			APPROVED BY			DATE	
IAL		CONDITION			INITIAL FORM		LENGTH EACH		

ALTERATIONS													
	B		C		D		E		F		G		H

SUB ELL	DESCRIPTION	M/C	FEED	SPEED	CUTTERS	FIXTURES	GAUGES
	CUT OFF TO LENGTH ....INCH						
	GRIND FACES TO ....INCH THICK						
	TOP TO........IN. WIDE END TO........IN. LONG						
	TOP TO.......IN. WIDE END TO........IN. LONG						
	MILL FEATURE						
	MILL FEATURE						
	SWAGE TO DRAWING						
	ANNEAL						
	POLISH TRACK						
	DRILL.....HOLE(S) TAP..................DIA. C'SINK...............DIA. REAM................DIA.						
						FIG 67	

UP FIXTURE
PING & ENDING
LING TOP EDGE
AND END)

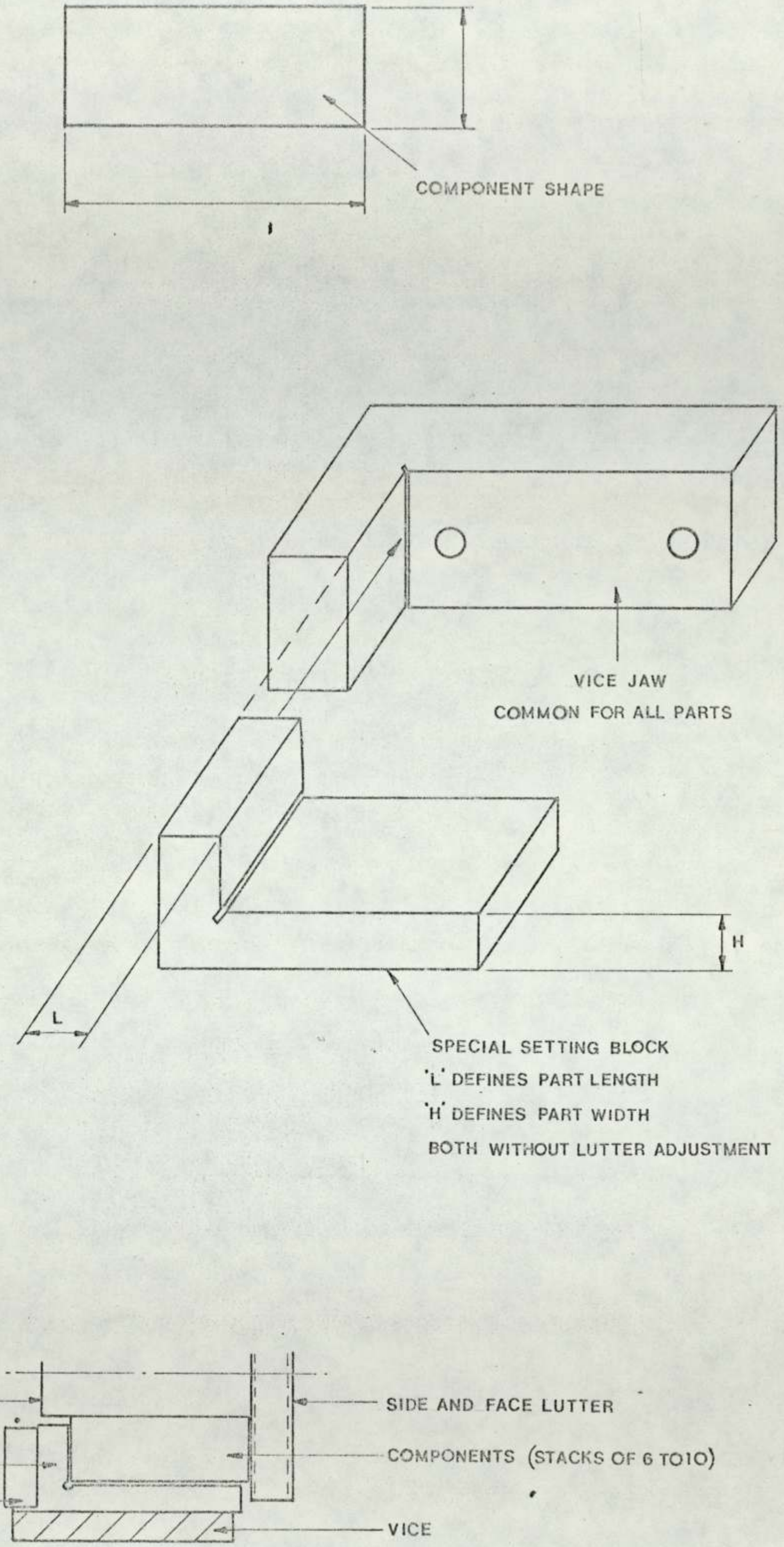
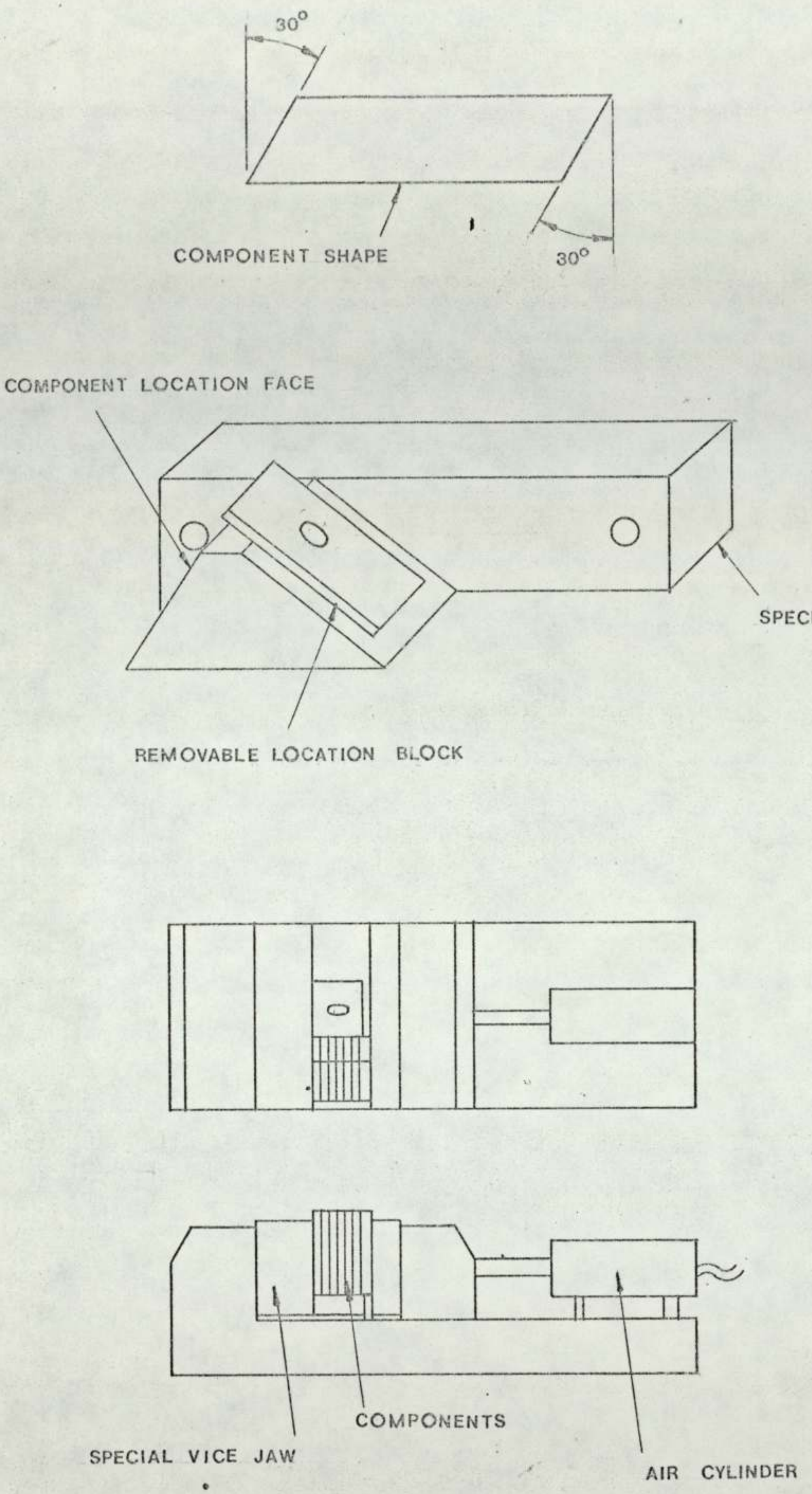
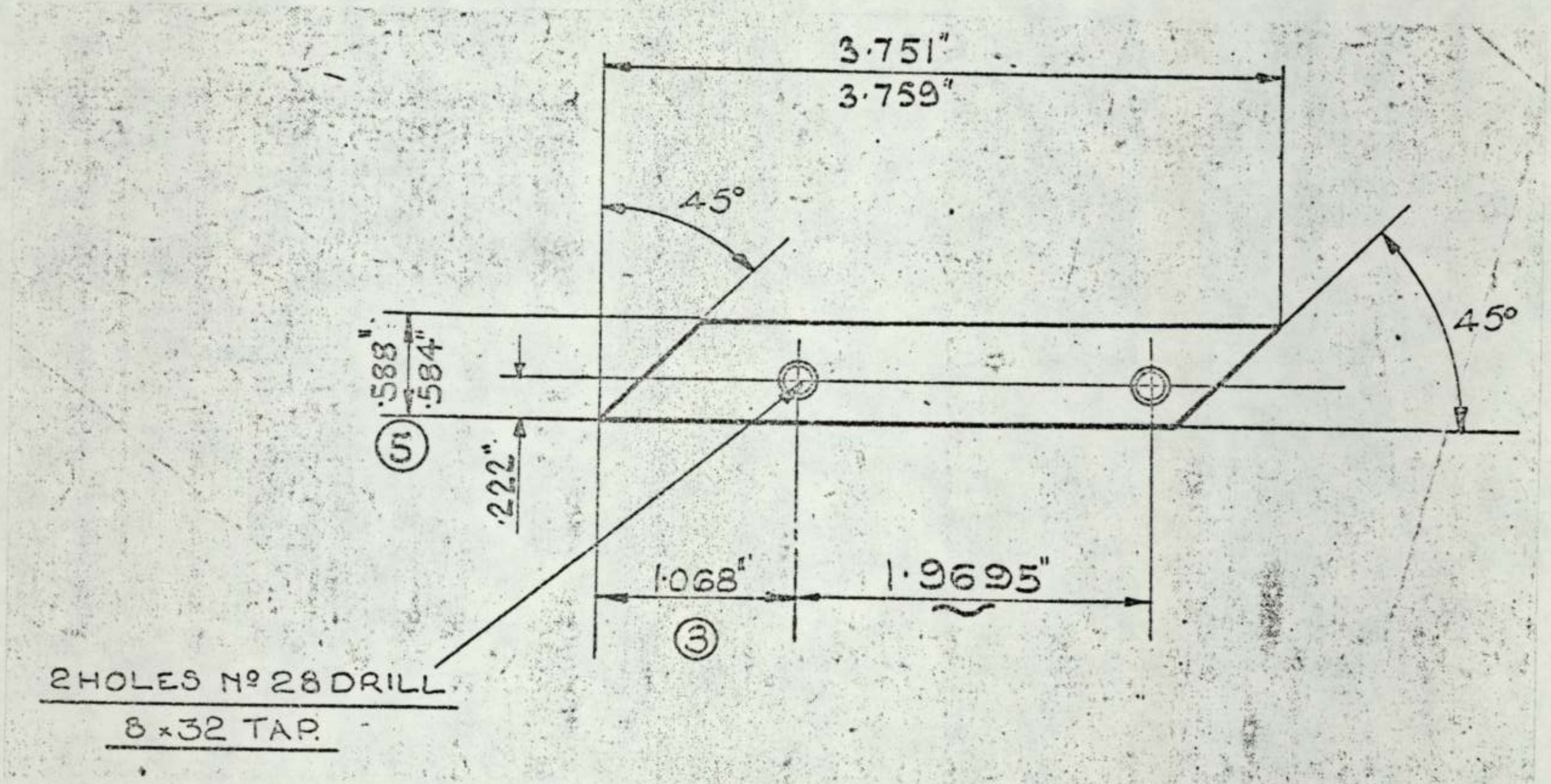


FIG 68



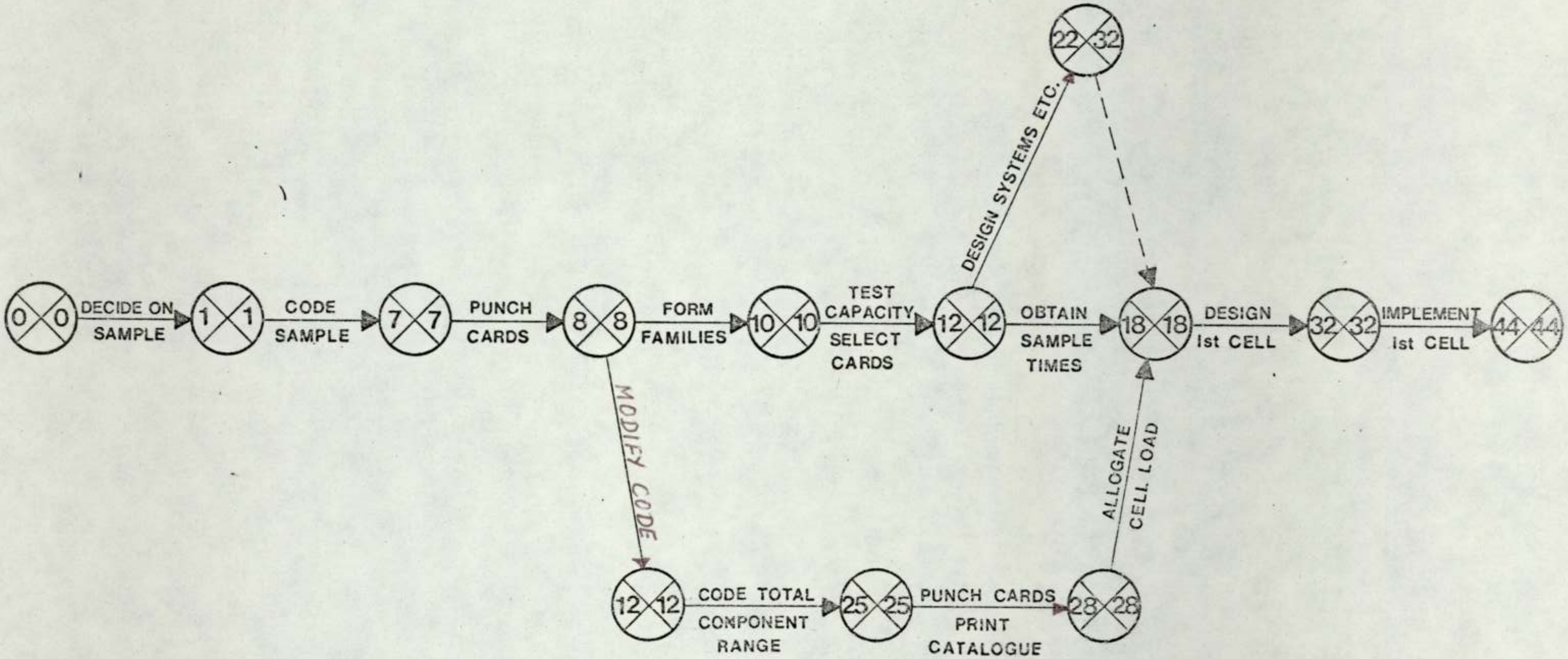
<u>GROUP FIXTURE FOR MILLING ANGLES</u>

FIG 69



TYPICAL CAM FOR GROUP TOOLING

FIG 70



SUGGESTED PROJECT PLAN TO ALLOW

CODE CHANGES FOR DESIGN RETRIEVAL CATALOGUE

FIG 71