DIVISION DE EDUCACION CONTINUA
FACULTAD DE INGENIERIA U.N.A.M.

APLICACION DE LA TECNOLOGIA DE GRUPOS

GROUP TECHNOLOGY APPLICATIONS FOR HIGHER MANUFACTURING PRODUCTIVITY

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Junio 1981

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FOR

HIGHER MANUFACTURING PRODUCTIVITY

BY

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** A PART OF THIS MANUAL WAS TAKEN FROM THE CHAPTER ON "GROUP TECHNOLOGY", AUTHORED BY I. HAM, OF THE INDUSTRIAL ENGINEERING HANDBOOK TO BE PUBLISHED BY JOHN WILEY & SONS, INC. PUBLISHERS, WITH THEIR PERMISSION.

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1. INTRODUCTION

1.1 Basic Concept:

More and more manufacturing industries involved with small lot size and a variety of products are becoming interested in Group Technology, which is particularly applicable in the area of batch-type manufacturing. It has also been recognized that Group Technology is an essential element of the foundation for the successful development and implementation of computer aided manufacturing (CAM) through the application of the part-family concept.

Group Technology is generally considered to be a manufacturing philosophy or concept which identifies and exploits the sameness or similarity of parts and operation processes in design and manufacture. In batch-type manufacturing, traditionally each part has been treated as being unique in design, process planning, production control, tooling, production, etc. However, by grouping similar parts into part families, based on either their geometrical shapes or operation processes, as exhibited in Figure 1, and also if possible forming machine groups or cells which process the designated part families, it is possible to reduce costs through: more effective design rationalization and design data retrieval; fewer stocks and purchases; simplified and improved process planning and production control; reduction of tooling; and set-up times; semi-flow line production by machine groups or cells; less in-process inventory; reduction of total throughput time; reduction of NC programming; and more efficient utilization of expensive NC machines and machining centers; etc.

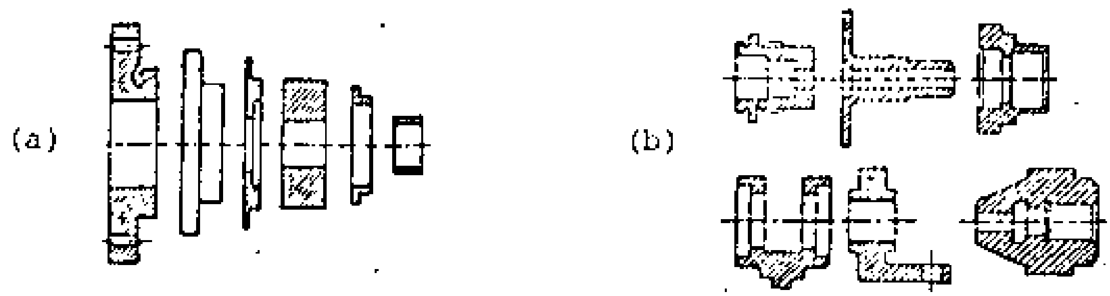


Fig. 1. Examples of part families: (a) similar in shape and geometry, and (b) similar in production operation processes.

1.2 Historical Background:

The basic concept of Group Technology has been practiced for many years as part of "Good Engineering Practice" or "Scientific Management". For example, a classification and coding system developed by F. W. Taylor(1) for formation of part families was used in manufacturing as early as the beginning of this century. Through the years many companies devised their own classification and coding systems and have been using them in various areas such as design, materials, tools, etc. There are numerous examples of machine groups or cells, group tooling devices, part family groupings and programming, etc., which have been in practice for many years in various sectors of industry. These practices and applications of Group Technology concepts were, in many cases, identified under different names and in various forms of engineering, manufacturing and management functions.

Around the world, Group Technology has been practiced in various forms and degrees for many years. Many countries took an interest in Group Technology in the 1950's and 1960's. At that time various classification and coding systems were developed, machine cell concepts were practiced, and many excellent group tooling practices have been reported. Until recently, Group Technology has not received formal recognition and has not been rigorously practiced as a systematic scientific technology. In the recent years, advanced manufacturing industry appears to be undergoing a revolution in the area of improving its manufacturing productivity. This has led to an intensified effort in integrated computer aided manufacturing. These current trends have stimulated a strong renewed interest in Group Technology since it provides the essential means for higher manufacturing productivity and for computer aided manufacturing, e.g. computer aided process planning.

1.3 Major Application Areas:

One of the most important reasons for increasing manufacturing productivity is economic. Manufacturing contributes a major part of the gross national product of modern industrialized countries. Yet in spite of that, manufacturing, although normally thought of as a highly productive and efficient activity, generally can still be improved significantly. This is especially true in a batch-type manufacturing environment. The potential for economic improvement of manufacturing by Group Technology is indeed not only tremendous now, but will grow with time.

Rationalization of various engineering activities, such as design data retrieval, process selection, process planning, etc. can be readily achieved by effective implementation of the Group Technology concept. It has been a recognized fact that, in batch-type manufacturing, major efforts should be made for continuous improvements in in-process inventory and efficient machine loading in order to achieve higher productivity. Again, Group Technology provides a key element toward this effort.

1.4 <u>Current Trend and Future Prospects</u>:

For various objectives in achieving higher productivity from design to manufacture, many manufacturing industries, which are primarily related to batch-type manufacturing have become increasingly interested in Group Technology implementation to meet their needs. Many industrial companies have been applying Group Technology principles in their own way, although in some cases it was not identified as Group Technology but simply as good engineering practice and effective scientific management. Group Technology implementation, in many instances, has been primarily limited to cellular manufacturing. However, recently more companies are interested in applying Group Technology concepts as a part of the total system of the overall company operations through design to manufacture.

A forecast of the future of production technology advancement, carried out by both the University of Michigan (2) and the International Institute for Production Engineering Research (CIRP)(3), predicted that approximately 50 to 75% of manufacturing industry will use Group Technology concepts in the period 1980-90. This forecast also predicts that the computer automated factory will be a full-blown reality in many industries well before the end of this century. It is evident that new technological innovations, such as DNC, CNC, machining centers, industrial robots, micro-processors, etc. will lead the way toward more automated computer-integrated manufacturing systems involving CAM, and thus assure more integrated applications of Group Technology for optimum manufacturing resulting in higher productivity. The effort related to the integrated computer aided manufacturing (ICAM) is a positive approach to achieve those objectives.(4)

A part classification system which is an integral part of and has been used as an essential tool of Group Technology applications, can also be evolved as a means of describing parts in a form that can be integrated readily into a computer data base structure, which will link design and production. Furthermore, as evolution of ICAM leads to generative design and to generative process planning, certain part classification and coding systems will become an integral part of the total generative system evolving with ICAM.

Group Technology is a dynamic and evolutionary development which continues to expand its influence on manufacturing systems. It is evident that the role of Group Technology will certainly be broadened with more innovative advancements in theory and application, not only for improving productivity in conventional batch-type manufacturing systems, but also for proper adaptation of CAM system.

2. PART FAMILY FORMATION AND MACHINE GROUPING

2.1 Methods and Procedure:

A part family may be defined as a group of related parts which have some specified sameness and similarities. They may have similar geometric shape or they may share similar processing requirements as shown in Figure 1. Parts may be dissimilar in shape but could be grouped as a part family because of some common production operations or visa versa. Parts are considered to be similar with respect to production operations when the same machines and processes are used and the type, sequence and tooling requirements are similar. In grouping part families, the number of parts and their frequency of manufacture should be taken into consideration. The greater the similarity of processing requirements and lot frequency, the more effective it is to form the part family for practical applications of the Group Technology concept, in forming machine groups or cells and in scheduling for optimum sequencing and machine loading.

The grouping of similar parts into part families is the key to Group Technology implementation. The problem which immediately presents itself is how are the parts to be efficiently grouped into these families? There are three basic methods used to form part families:

(a) Manual visual search
(b) Production flow analysis
(c) Classification and coding systems

The first method is obviously very simple, but limited in its effectiveness when dealing with a large number of parts. In general, the other two methods are more commonly used in forming part families and machine groups or cells.

2.2 Production Flow Analysis:

Production flow analysis(5) is a technique to analyze the operation sequence and the routing of the part through the machines and work-stations in the plant. Parts with common operations and routes are grouped and identified as a part family. Similarly, the machines and work stations used to produce the part families can be grouped to form the machine group or cell. An example of forming part families by using this method is shown in Figure 2. For successful use of this production flow analysis method, it should be assured that a company has a reliable data source of route sheets or operation sheets. One of the advantages of this method is to form part families with or without using a classification and coding system, since it forms part families using the data from operation or route sheets. There are a number of disadvantages in practice due to its reliance on existing production data and routing methods.

(a) Before grouping

Machine \ Part No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
L	✓	✓		✓	✓		✓	✓	✓		✓	✓		✓	✓		✓	✓	✓	✓
M_1	✓	✓	✓		✓	✓	✓		✓		✓		✓	✓		✓				✓
M_2			✓	✓				✓		✓		✓	✓		✓		✓	✓	✓	
D	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓		✓
G	✓	✓	✓	✓		✓			✓			✓	✓		✓			✓		✓

(b) After grouping

Machine \ Part No.	1	2	20	7	11	14	9	5	4	18	12	8	17	15	19	3	13	6	16	10
L	✓	✓	✓	✓	✓	✓	✓	✓												
M_1	✓	✓	✓	✓	✓	✓	✓	✓												
D	✓	✓	✓	✓	✓	✓														
G	✓	✓	✓				✓													
L									✓	✓	✓	✓	✓	✓	✓					
M_2									✓	✓	✓	✓	✓	✓	✓					
D									✓	✓	✓	✓	✓							
G									✓	✓	✓			✓						
M_1																✓	✓	✓	✓	
M_2																✓	✓			✓
D																✓	✓	✓	✓	✓
G																✓	✓	✓		

Fig. 2, Part family and machine grouping by production flow analysis.

2.3 Classification and Coding Systems:

A classification and coding system provides an effective means for sorting the coded parts, in forming part families based on the specific parameters of the system regardless of the origin or use of the parts. Especially for CAM applications, such a system becomes an essential requirement for effective implementation of Group Technology concepts.

"Classification" involves arranging items into groups according to some principle or system whereby like things are brought together by virtue of their similarities, and then separated by a specific difference. A "code" can be a system of symbols used in information processing in which numbers or letters or a combination of numbers and letters are given a certain meaning.

Many varieties of classification and coding systems are being developed and used around the world. An example of a coded part using a publicly-available system(6) is shown in Figure 3. Classification and coding for Group Technology applications is a very complex problem, and although many systems have been developed and countless efforts have been made to improve them, there is as yet, no universally acclaimed system. Since each company has its own specific needs and conditions, it is necessary to search for a suitable system that can be adapted to the specific needs and requirements of the company. It is essential that an adapted system be usable by all concerned departments in the company, including design/engineering, planning/control, manufacturing/tooling, as well as management.

For Group Technology applications, a well-designed classification and coding should be able to group part families as needed, based on specific parameters. An example of such part family grouping of the parts shown in Figure 1(a) (using a suitable coding system along with the related data need for the coding), is shown in Figure 4.

2.4 Cell Layout:

There are in general three basic types of plant layout, namely: (a) mass-production flow-line layout, (b) functional layout, and (c) group layout. In the practice of Group Technology, a group of machines for producing a part family, or more, may be formed such that it can perform all the operations required by the family or families of parts. The machines themselves are arranged in a semi-flow-line to minimize transportation distances and waiting problems. The result is very similar to a modern NC machining center. If conditions warrant, a machining center may be used instead of a group of single purpose machines. An example of a group layout of machine tools based on the Group Technology concept as compared with a conventional functional layout is shown in Figure 5. This illustrates the features of a group/cell layout.

PART NAME: PIN
MATERIAL: MILD STEEL (AISI-1020) FORGED ROUND BAR
TREATMENT: SURFACE HARDENING BY CARBORIZING/FINE FINISH
OPERATIONS: TURNING OF O.D. AND DRILLING HOLE

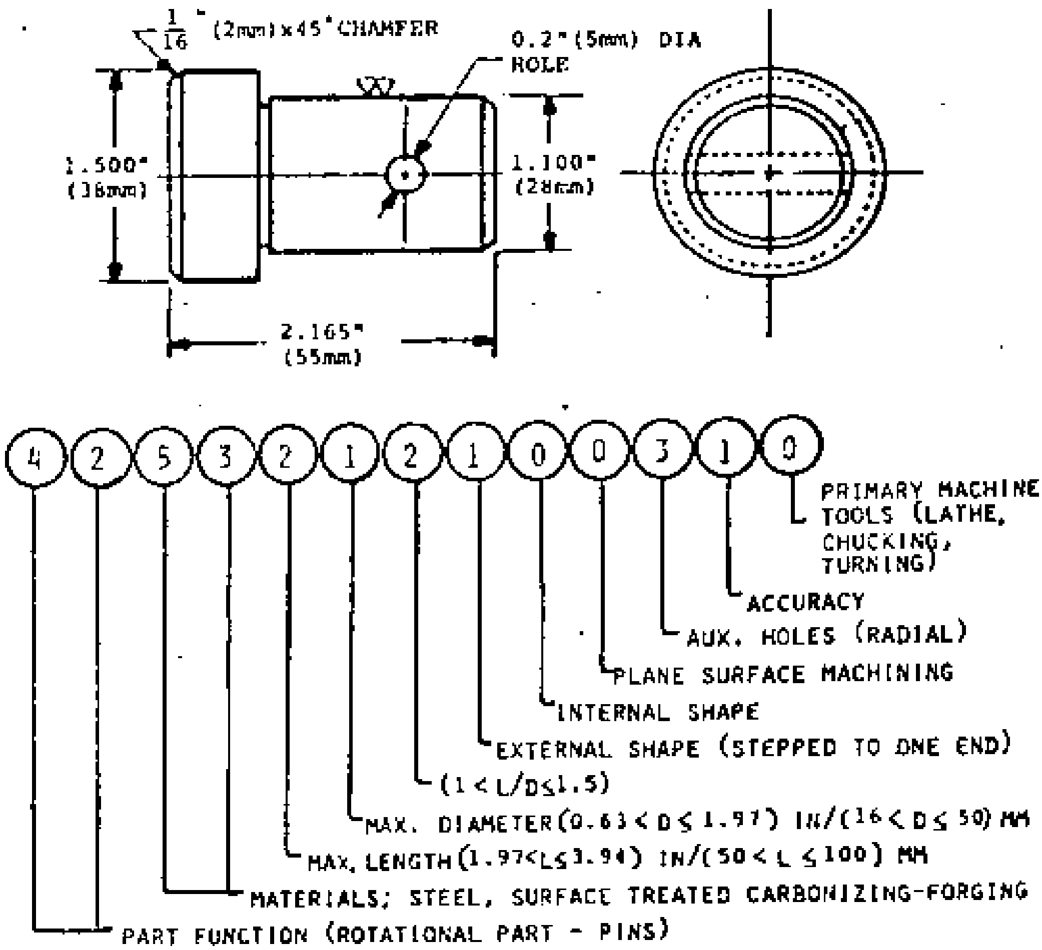
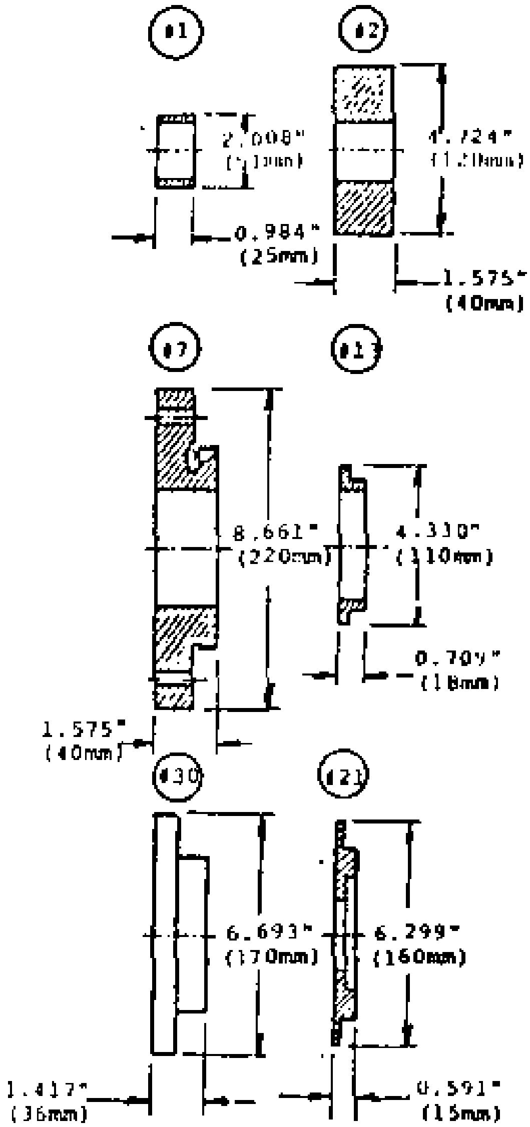


Fig. 3, Coded example using a classification and coding system (refer to Fig. 6-b).



Part No.	CODE NUMBER
#1	56 12 0000000 11 000008
#2	56 13 0000000 11 000008
#7	56 14 0110000 11 001005
#13	56 03 0100000 11 000006
#21	56 04 0100000 21 000005
#30	56 14 0100000 00 000006

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	✓		✓		✓	✓				✓	✓	✓		✓	✓	✓	✓		
1	✓		✓		✓	✓						✓			✓	✓			
2	✓			✓	✓							✓							
3	✓			✓	✓														
4	✓			✓	✓														
5	✓				✓														
6	✓	✓																	
7																			
8																			
9																			

PART FAMILY OPERATION SEQUENCE	
10	Cut Off
20	Turn
30	Radial Drill
40	Carburize
50	External Grind
60	Internal Grind

Fig. 4, Part family grouping using a classification and coding system.

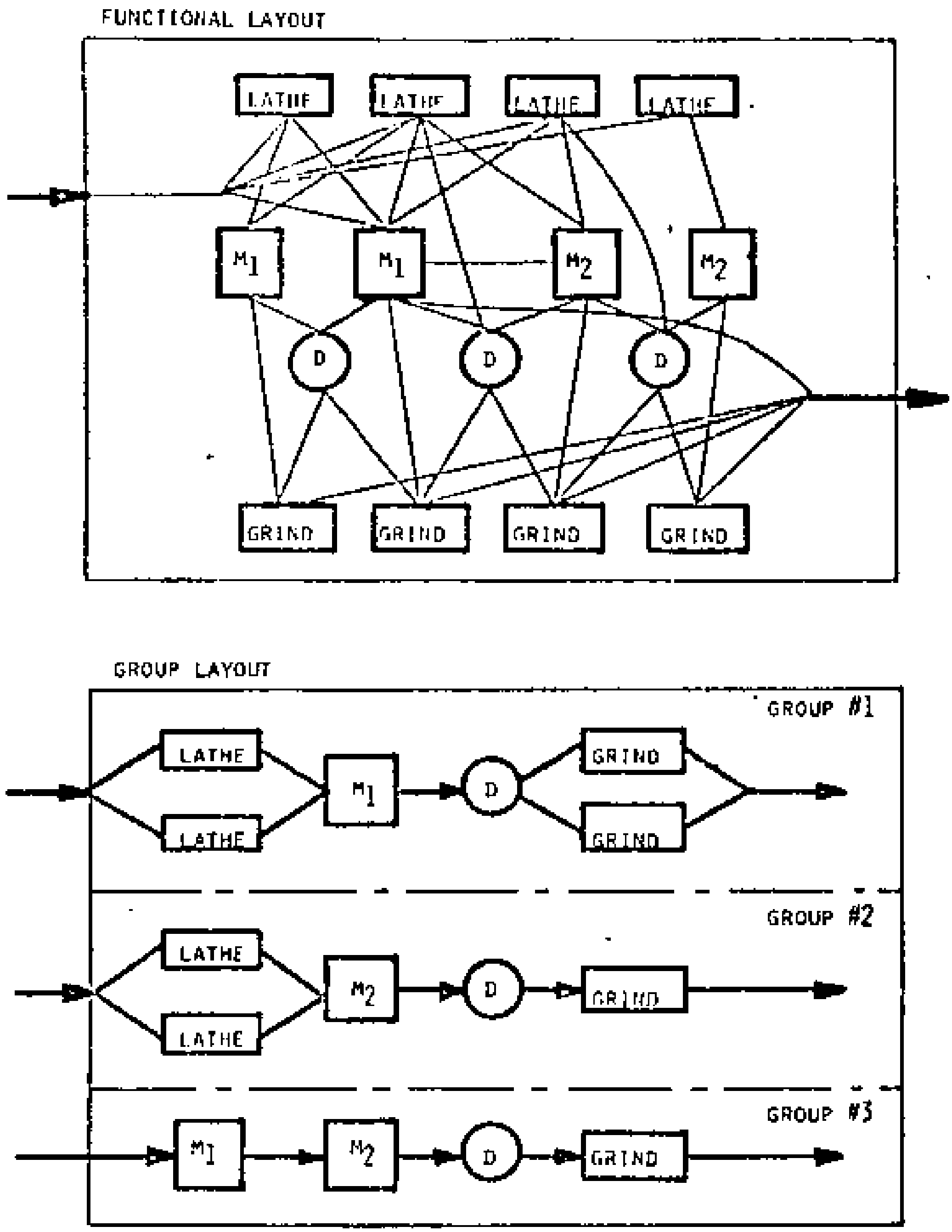


Fig. 5, Functional and group/cell layouts.

The formation of machine groups or cells to process part families is relatively easy if a well-designed classification and coding system has been introduced. It is also possible to form machine groups/cells or part families using the production flow analysis technique. Here the operation sequence and routing of the part through the machines in the plant is analyzed using the information obtained from the operation or routing sheets as illustrated in Figure 2. Each part family should have a certain group of operations associated with it. This group of operations indicates the type of machines and facilities needed to process each part within a family. The amount of time needed for each particular operation for each job in the family of parts can be determined if basic data such as lot sizes, set-up times, machining times, etc. is available. These times will be the basis of determining how much capacity is needed for each machine within the group or cell. The formation and grouping of part families permits the computation of the machine load in hours for each machine in the group cell.

The formation and grouping of part families permits the computation of the machine load in hours for each machine in the group. In the practice of Group Technology, an effort is made to maximize the utilization of machines in the group by:

(a) Extending basic part families by adding parts of a similar type or merging two or more sub-families;

(b) Machining two or more part families on the same machine group.

A simple example of machine loading computation for forming machine groups/cells for given part families is exhibited in Tables 1 and 2.

The machine loading analysis indicates that the part family #1 needs the total times of 2,783 hours for turning, 1,721 hours for milling, 1,085 hours for drilling and 3,367 hours for grinding, thus requiring 2 lathes, 1 milling machine, 1 drill press and 2 grinding machines respectively.

Although the group layout of machines for Group Technology applications has many advantageous features, it may also involve some problems. For example, it may be difficult to balance the labor and machine utilization. Also, there may be difficulty in finding suitable supervisory personnel.

Table 1, Basic data for machine loading analysis.

PT. NO.	CODE NO.	LOT SIZE	TURNING		MILLING(I)		MILLING(II)		DRILLING		GRINDING	
			S/T	M/T	S/T	M/T	S/T	M/T	S/T	M/T	S/T	M/T
1	010 120	115	20	9	13	5	-	-	15	3	6	20
2	010 124	30	15	12	15	7	-	-	23	6	7	15
3	002 123	55	-	-	13	5	16	8	23	12	6	10
4	111 121	105	33	14	-	-	15	6	25	8	8	9
5	010 120	25	23	10	10	8	-	-	-	-	-	-
6	002 123	10	-	-	15	8	-	-	18	10	8	23
7	011 123	5	15	9	11	9	-	-	15	15	-	-
8	110 124	12	15	15	-	-	10	9	24	11	-	-
9	011 124	18	23	12	10	8	-	-	-	-	5	23
10	002 120	35	-	-	-	-	13	6	30	11	-	-
11	011 123	10	23	14	12	6	-	-	24	7	-	-
12	112 122	10	30	8	-	-	12	10	18	10	7	15
13	001 122	21	-	-	11	7	10	9	25	11	6	15
14	011 123	61	15	8	10	5	-	-	24	4	-	-
15	111 121	4	15	17	-	-	12	9	-	-	5	18
16	002 120	5	-	-	10	6	-	-	20	13	-	-
17	110 120	24	23	10	-	-	10	8	20	11	-	-
18	111 121	46	30	11	-	-	11	17	30	7	5	10
19	111 124	61	20	9	-	-	13	5	-	-	-	-
20	012 124	10	15	10	11	9	-	-	20	5	5	18

Table 2(a), Machine loading analysis for turning operations of part family #1 (refer to Table 1 and Figures 2 and 5)

Part No.	Code No.	Lot Size (N_1)	Setup Time (S_t)	Machining Time (M_t)	$(M_t)\times(N_1)$	$(M_t)\times(N_1)+(S_t)$
1	010 120	115	20	9	1035	1055
2	010 124	30	15	12	360	375
20	012 124	10	15	10	100	115
7	011 123	5	15	9	45	60
11	011 123	10	23	14	140	163
14	011 123	61	15	8	488	503
9	011 124	18	23	12	216	239
5	010 120	25	23	10	250	273

Total Time = 2,783

Table 2(b), Machine loading analysis for milling operation (1) of part family #1 (refer to Table 1 and Figures 2 and 5)

Part No.	Code No.	Lot Size (N_1)	Setup Time (S_t)	Machining Time (M_t)	$(M_t)\times(N_1)$	$(M_t)\times(N_1)+(S_t)$
1	010 120	115	13	5	575	588
2	010 124	30	15	7	210	225
20	012 124	10	11	9	90	101
7	011 123	5	11	9	45	56
11	011 123	10	12	6	60	72
14	011 123	61	10	5	305	315
9	011 124	18	10	8	144	154
5	010 120	25	10	8	200	210

Total Time = 1,721

Table 2(c), Machine loading analysis for drilling operation of part family #1 (refer to Table 1 and Figures 2 and 5)

Part No.	Code No.	Lot Size (N_1)	Setup Time (S_t)	Machining Time (M_t)	$(M_t)\times(N_1)$	$(M_t)\times(N_1)+(S_t)$
1	010 120	115	15	3	345	360
2	010 124	30	23	6	180	203
20	012 124	10	20	5	50	70
7	011 121	5	15	15	75	90
11	011 123	10	24	7	70	94
14	011 123	61	24	4	244	268
9	011 124	-	-	-	-	-
5	010 120	-	-	-	-	-

Total Time = 1,085

Table 2(d), Machine loading analysis for grinding operation of part family #1 (refer to Table 1 and Figures 2 and 5)

Part No.	Code No.	Lot Size (N_1)	Setup Time (S_t)	Machining Time (M_t)	$(M_t)\times(N_1)$	$(M_t)\times(N_1)+(S_t)$
1	010 120	115	6	20	2300	2306
2	010 124	30	7	15	450	457
20	012 124	10	5	18	180	185
7	011 121	-	-	-	-	-
11	011 123	-	-	-	-	-
14	011 123	-	-	-	-	-
9	011 124	18	5	23	414	419
5	010 120	-	-	-	-	-

Total Time = 3,367

3. CLASSIFICATION AND CODING SYSTEMS

3.1 Types and Features:

Although there are many varieties of systems, basic types of classification and coding systems can be put into several categories, such as functional or descriptive, qualitative or quantitative criteria, design oriented or production oriented, hierarchic or chain-type (discrete) structure, monocodes vs. polycodes, separate codes vs. composite codes, long codes vs. short codes, etc. However, in most cases each system employs combinations of these features making it difficult to compare the systems strictly from these points of view. Regardless which system is selected, it should be adapted and modified to meet the specific needs and requirements of the company.

There are many types of classification and coding systems for general purposes. There are also other systems developed and used by many government agencies and professional societies, for such areas as libraries, museums, office supplies, commodities, insurance, credit cards, etc. However, these systems are not necessarily designed for Group Technology applications, though many systems have been used for industrial applications. It is not surprising to find some companies, which have been using their own coding systems for other purposes for many years, but did not realize the potential use of Group Technology applications.

There are three basic forms of classification and coding systems for the current Group Technology applications; namely:

(a) Hierarchical structure (monocode)
(b) Fixed-digit type structure (polycode)
(c) Combined structure (multicode)

A hierarchical code is constructed as a tree diagram where each digit amplifies the information of the previous digit, thus making each digit in the coding structure dependent on the digit prior to that particular digit. A hierarchical coding system provides an extensive analysis of the items classified since its code structure is very compact but can contain an enormous amount of information with a rather limited number of digits. This type of coding system is very effective for data retrieval based on geometrical shape, size/dimensions, etc., and has been adapted by design/engineering departments for many years. The hierarchical code is sometimes referred to as "monocode".(7)

A fixed-digit type, also called chain type, discrete type, or attribute type, has a code structure in which each position of a given digit represents independent information and is not directly related to the information given by other digits. A fixed-digit type of coding, also called polycode by some,(7) provides a system which is more adaptable for production oriented applications in classifying machine tools, tooling, process operations, etc. To construct a complete fixed digit type code structure, it is necessary to specify all items in the code. Therefore, usually this type of coding system requires a large number of digits. It is less compact than a hierarchical code. In practice, most classification and coding systems employ mixed (hybrid) codes which are combinations of both hierarchical (monocode) and fixed digit (polycode) types. The basic code structures of two publicly available classification and coding systems specifically developed for Group Technology applications in general metal-working discrete parts are exhibited in Figure 6.

A code is one or more symbols to which an arbitrary assigned meaning and/or arrangement has been given. When a code is deciphered, it communicates specific information or intelligence.

Coding may be made using:

(a) Hieroglyphical symbols

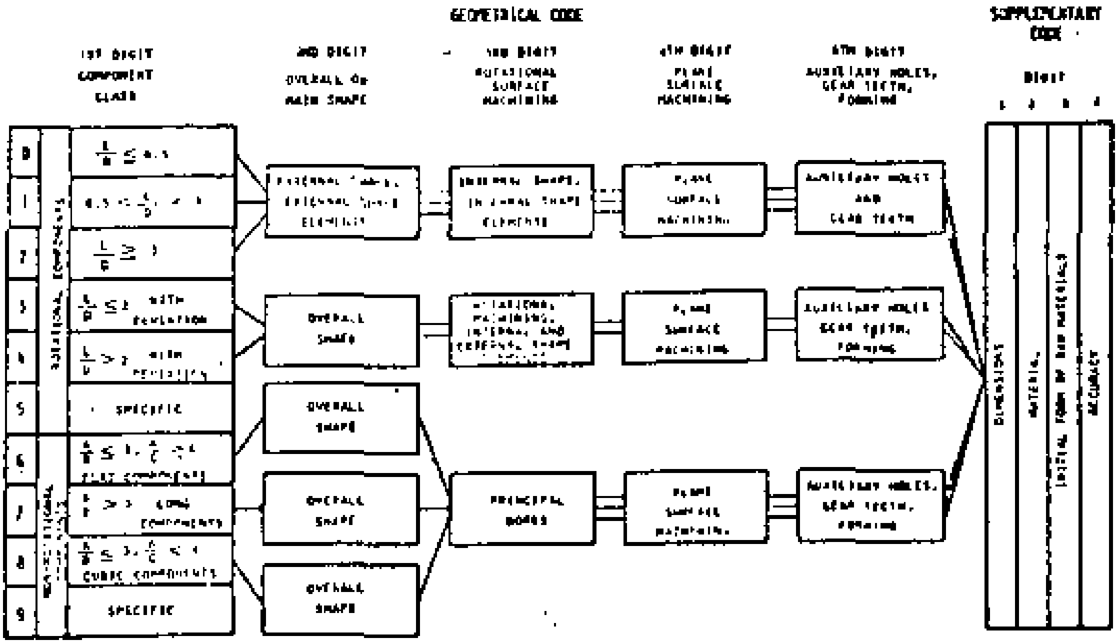
(b) Alpha-numeric and mnemonic

(1) All numeric - 10 values
(2) All alpha - 20 (except I,O,S,Z,&Q)
(3) Alpha-numeric - 30 (combined)
(4) Hexidecimal - 16 (0-9 & A-F)

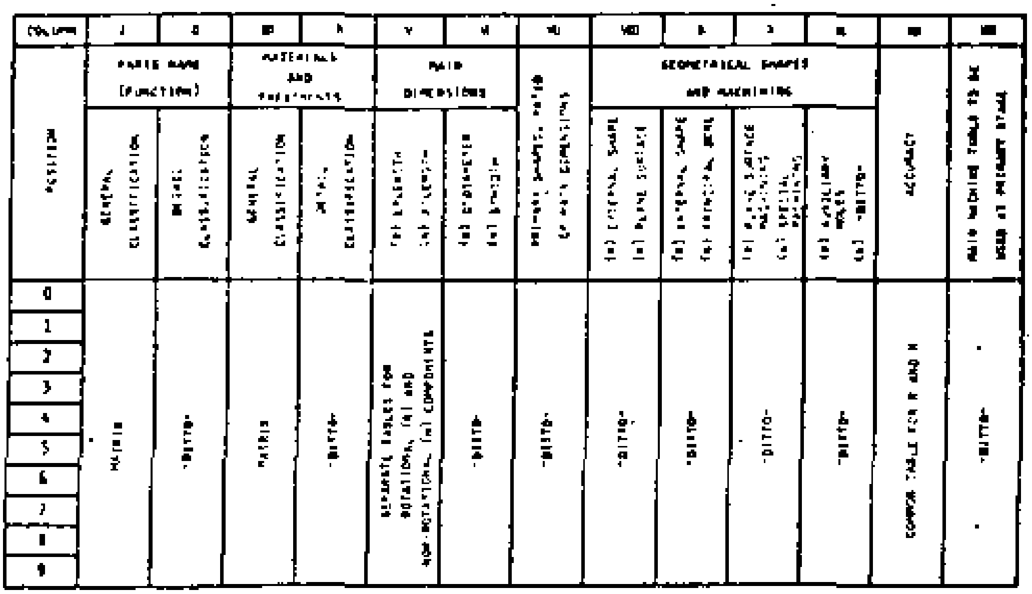
One of the important factors in selecting a classification and coding system is to maintain a balance between the amount of information needed and the number of digit columns required to provide this information. Each additional column generated increases the handling problem. Yet sufficient numbers of digits are needed to code all necessary features of the part or product. Classification is really the tool which enables the handling of vast quantities of data quickly. Thus, thousands of drawings and route sheets can be rapidly retrieved and compared for design, tooling, scheduling, etc., through effective use of classification codes.

A well-designed classification and coding system for Group Technology implementation should meet several basic requirements. It can provide many benefits and facilitate Group Technology applications in many areas of company operations. The major benefits of a well-designed classification and coding system for Group Technology applications can be summarized as follows:

(a) Formation of part families and machine groups (cells).
(b) Effective retrieval of designs/drawings and process plans/routings.
(c) Design rationalization and reduction of design costs.
(d) Standardization of product design.
(e) Secure reliable workpiece statistics.
(f) Accurate estimation of machine tool requirements, rationalized machine loading and optimized capital expenditure.



(a) Opitz System (West Germany)



(b) KK-1 System (Japan)

Fig. 6, Basic code structures of two publicly-available classification and coding systems (21 & 22)

(g) Rationalization of tooling set-up and reduction of set-up time and overall production time.
(h) Rationalization of tool design and reduction of time and cost for tool design and fabrication.
(i) Standardization of process routings/tooling.
(j) Rationalization of production planning and scheduling.
(k) Accurate cost accounting and cost estimation.
(l) Better utilization of machine tools, workholding devices, and manpower.
(m) Improvement of NC programming, and effective use of machine and machining centers.
(n) Establishment of a master data base.

It is important to identify the means of improving manufacturing productivity where a large variety of parts and small lot sizes are characteristic. The classification and coding systems should also be evaluated in relation to what they can contribute to the solution of manufacturing and control problems associated with job shop operation.

3.2 <u>Basic Requirements</u>:

For Group Technology applications, a classification and coding system should meet the following basic requirements:

(a) <u>All embracing</u>:

A classification and coding system must embrace all existing items being produced and/or purchased and be able to accept new items.

(b) <u>Mutally exclusive</u>:

A classification and coding system must be mutually exclusive, i.e., include like things while excluding unlike things, using clearly defined parameters.

(c) <u>Based on permanent characteristics</u>:

A classification and coding system must be based upon visible attributes or easily confirmed permanent and unchanging characteristics.

(d) <u>Specific to user needs</u>:

A classification and coding system should be developed to meet the needs of the user.

(e) <u>Adaptable to future changes</u>:

A classification and coding system should be adaptable to future expansion and technological changes.

(f) <u>Adaptable to computer processing</u>:

A classification and coding system can be functional without using a computer. However, it is often desirable to operate the system using a computer, and so should be adaptable to computer processing.

(g) Company-wide applications:

A classification and coding system should have application throughout all departments in the company.

There are several factors to be considered in selecting a suitable classification system. Some typical questions that should be answered are:

(a) Objective

What is the major objective (needs) of a classification and coding system?

(b) Scope of application

What departments are involved in using the system?

What are the specific needs and parameters to be coded?

How wide is the range of products and how complex are the part's shape, process operations, tooling, etc.?

(c) Costs and Time

How much expense will be involved in installation, training, and maintenance of the system?

What are the cost estimates for consultant fees, in-house design, training, etc.?

How long will it take to install and train the needed staff?

How long will it take to realize the effects of the system in all areas of application, ranging from design to production?

(d) Adaptability to other systems

Is the system easily adaptable to the computer and the data bases being used in the company?

Can the system be easily integrated to other systems such as process planning, NC programming, management information systems, etc.?

(e) Management problems

Are all management personnel involved in use of the system informed and supportive?

Is there any union problem?

Can good cooperation between the departments involved be obtained?

3.3 Comparative Evaluation:

Before selecting a classification and coding system, a company should make a thorough appraisal for Group Technology applications in the following four areas:

(a) Critical examination of the company functions.

(b) Defining the type or variety of Group Technology applications most suitable.
(c) Defining the most suitable approach to Group Technology implementation.
(d) Assessing the costs and potential savings of the proposed installation and implementation.

Since each company has different products, objectives, manufacturing facilities, needs and conditions, there is no universal system adaptable to all industries. A system should be adapted to meet the specific needs of the company. It is highly recommended that anyone planning to install a classification and coding system for Group Technology applications make a thorough comparative evaluation of a variety of the available systems before making a final decision.

In order to make comparative evaluations of the various classification and coding systems, some common basic parameters should be established in each specific area of the applications through design to manufacture.

First, a system should meet the needs of all concerned divisions/departments of the company. The specific needs and parameters required by each department should be checked for adaptability and applicability of the system. In general, most companies in the manufacturing industry should check the need for specific parameters and data in the following departments:

Departments		Parameters and data
Design/Engineering Purchasing Product Planning & Control Manufacturing/Production Engineering Workshop/Plants Inventory Control Sales Cost Accounting Management Information etc.	vs	function main shape shape element dimension tolerance material rough shape operations operation sequences machine tool workholding devices cutting tools lot size set-up time etc.

Although all departments may use a classification and coding system in one way or another, major users of the system are Design/Engineering, Process Planning and Control, and the Manufacturing area. A system should be tested to check whether it meets all the needs and represents the parameters needed in each of those three areas. Some representative parameters and data needed by these departments are:

(1) Design/Engineering Area

main shape
shape element
material
rough shape & size
major dimensions
minor dimensions
tolerances
functions
etc.

(2) Manufacturing Area

major operation
minor operation
major dimension and size ratio
rough shape and size
machine tool
workholding devices
cutting tools
lot size
set-up time
operation sequence
accuracy
special treatments
assembly, etc.

(3) A system should also be evaluated for its applicability in various major production processes such as:

casting	machining
forming	inspection
joining	assembly, etc.

A classification and coding system is essential for full exploitation of the benefits of Group Technology. One should understand, however, that installation of a classification and coding system is just the beginning, simply a prerequisite for Group Technology applications. Once a suitable system is installed, design and engineering work can then be rationalized and part families formed, followed by many Group Technology applications such as machine layout grouping, group scheduling, group tooling and set-up, inventory and purchasing requirements, etc.

The introduction of a classification and coding system requires a great deal of effort and time. It should be anticipated that there is likely to be some resistance to adaptation of the system and considerable differences in the degree of acceptance between departments. It is essential to check all possible difficulties and potential problems related to Group Technology applications in selecting a suitable classification and coding system. Problem areas should be resolved prior to introduction in order to maximize benefits.

4. DESIGN RATIONALIZATION:

4.1 Design Data Retrieval:

A classification and coding system facilitates a part reduction and standardization program which can be valuable to both the company and its customers. When a well-designed classification and coding system is efficiently implemented in the design area, the system provides a simple, systematic and efficient method for storing information in an organized manner. It will also use a computer data base if needed. The system provides for retrieving design data, e.g. drawings, specifications, geometric data, materials, etc. A code makes it possible to recall all stored data relative to a specified part family, grouped together based on their designated similarities. The design data retrieval system sorted by part family grouping provides the following important features which assist significantly for design rationalization:

(1) Part family grouping for design rationalization
(2) Retrieval of existing design information for new applications, modifications and references
(3) Standardization of design features, specifications and materials
(4) Improvement for better design
(5) Elimination of duplicate designs
(6) Simplified effective cost estimation

The retrieval system may be processed manually or by computer. An example of a flow diagram(8) for a design data retrieval system using the Group Technology concept is shown in Figure 7.

A successful classification and coding system application in design leads to substantial economic gains. The most significant and immediate savings results from design rationalization through effective design data retrieval. An industrial survey(9) reports that an average design engineering cost per new part is approximately $2,000. Approximately a 15 percent reduction of new design activity will take place when a suitable effective retrieval method is utilized. Therefore, if a company releases approximately 2,500 new parts annually, it can be estimated that the annual design cost of new parts released is approximately $5,000,000. The savings from an effective retrieval system would be estimated at $750,000 per annum.

In many cases, more intangible savings are realized by various indirect benefits resulting through design rationalization, e.g. design standardization, design improvement, productivity improvement in design activity in general, etc.

4.2 Standardization:

When all active parts are classified and coded using a suitable system, it is possible to analyze the part population and the frequency of the usages of specific parts in the part family. In practice, parts which belong to a specific part family can be sorted to identify standard designs which are most frequently used. It must be recognized that such standardization is only possible when a part family grouping is made to clearly identify the standard features. Usually, when parts are

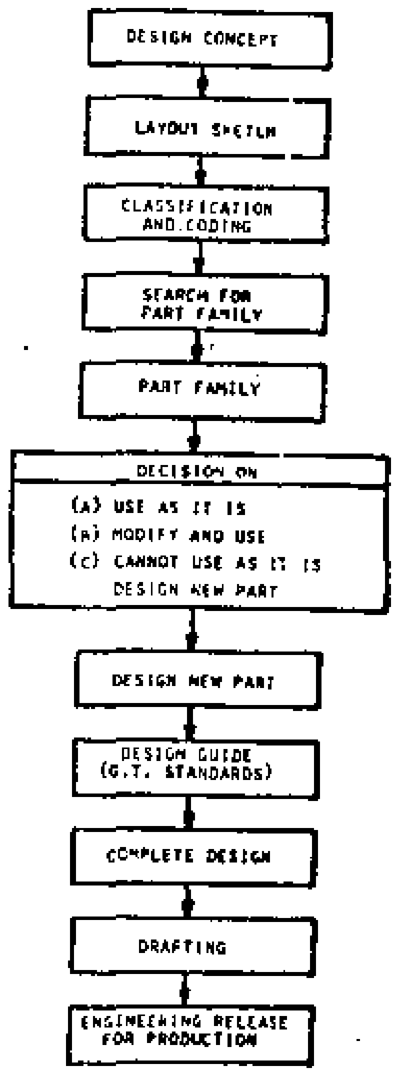


Fig. 7, Flow diagram for design rationalization.

designed independently at different times without any means of grouping into part families, it is difficult to identify the nature and degree of unnecessary duplications and obvious similarities among the parts of the company. Figure 8 shows a part family of washers. It immediately becomes obvious to recognize the standard parts based on the usage frequency of this part family. In many cases, many parts in the part family have a very minor variation in size, shape and features. In such cases, the part family grouping of a selected part assists not only identification of such similarities but also prevention of unnecessary variety through effective standardization. Although design personnel are knowledgeable as to the desirability of standardization and believe they have incorporated standard parts, they are not always aware that similar designs exist where standardization can be made. By part family groupings and design data retrieval, it is readily possible to incorporate a high level of standardization.

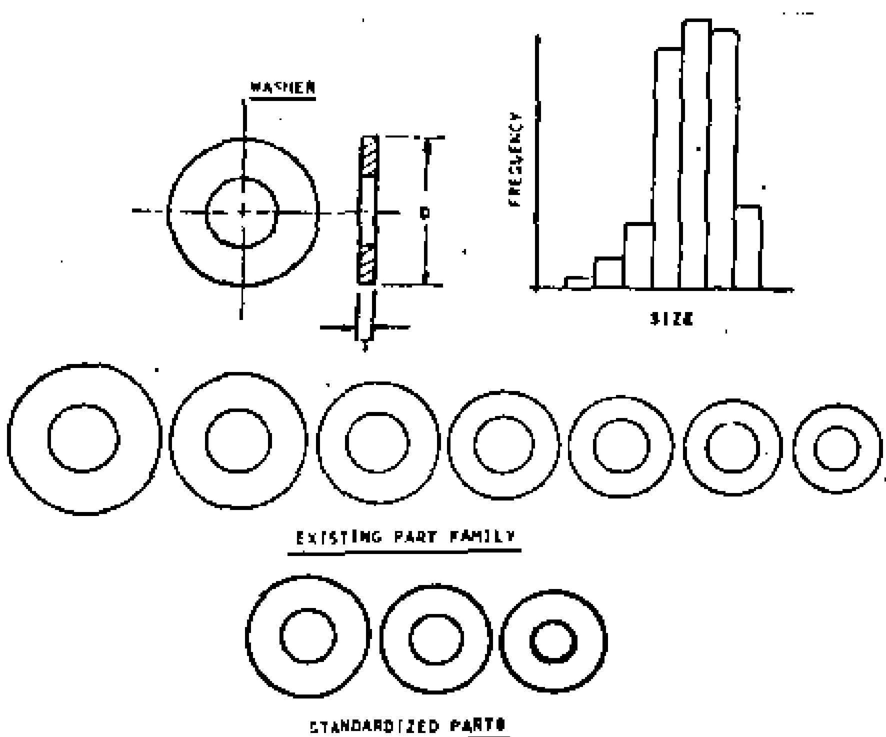


Fig. 8, Standardization of Parts

5. GROUP TOOLING

5.1 Composite Part:

The composite part provides an aid for the applications of Group Technology concept in the standardization of parts, standardization of process planning, machine grouping, design of group jigs and fixtures, the planning of group tooling set-ups, NC part family programming, etc. Figure 9 illustrates a group of parts represented by a composite part which possesses all the shape characteristics and processing features of a part family which is illustrated in Figure 1-a and Figure 4. If process planning or tooling is developed for the composite part, then any part in the family can be processed with the same operations and tooling.

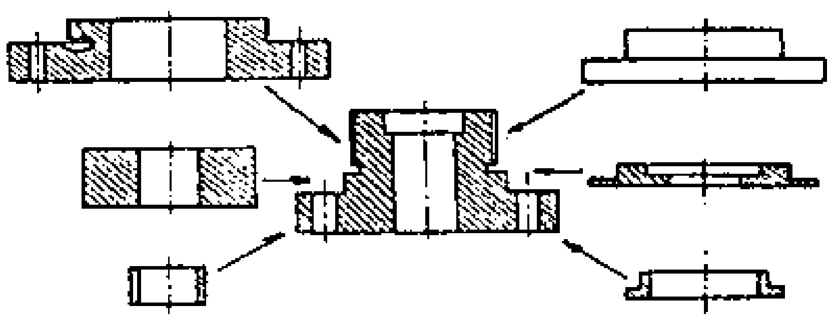
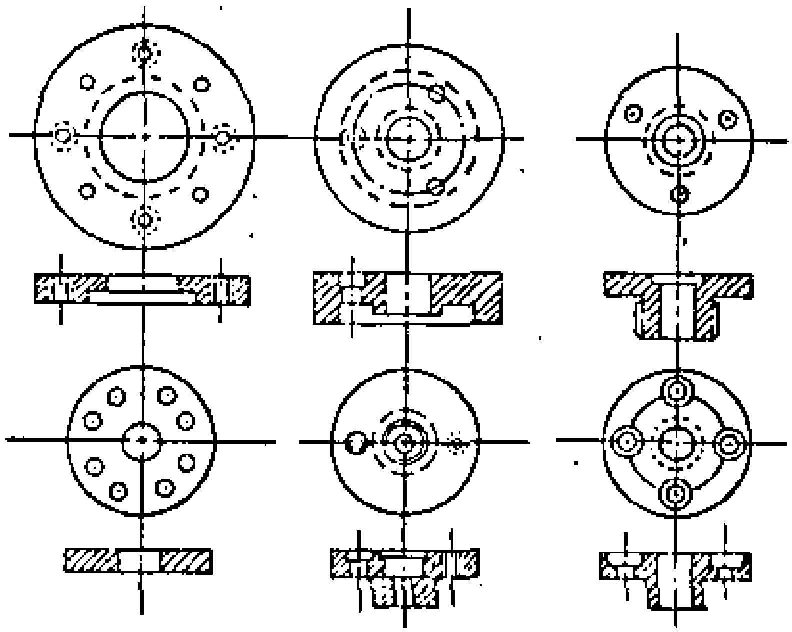


Fig. 9, Composite part.

5.2 Group Tooling Design and Set-Up:

To get the maximum utilization from tooling set-ups, tooling for the operations within a part family should be arranged so that all the parts, or as many as possible, in a part family can be processed with one group jig or fixture and set-up. Group jigs and fixtures are designed to accept every member of the part family, with adapters which accommodate some minor variations of parts. An example of such a group jig for drilling a part family is shown in Figure 10. To drill the holes of six (6) different parts in this part family, it requires only one group jig and six different auxiliary adapters to accommodate some minor differences in sizes, numbers and locations of the holes, and in size and shape of parts. Therefore, instead of designing, fabricating, and using six individual drill jigs as is done in a conventional production method, only one group jig and six adapters or bushing plates, which are essentially inexpensive, are required. Therefore, it becomes evident how much tooling costs can be reduced using Group Technology.

(a) Part family of round plates.



(b) Group jig for drilling.

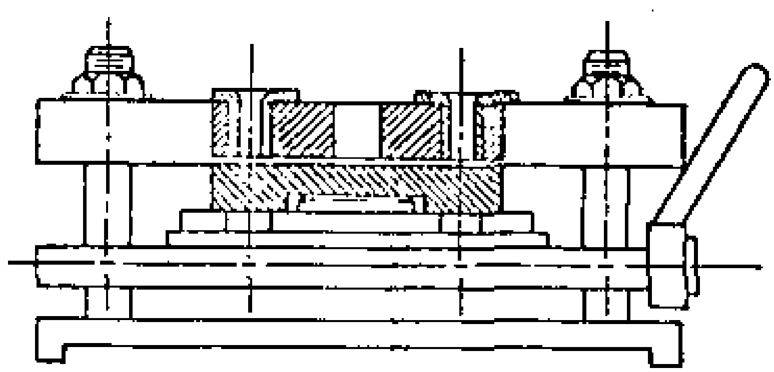


Fig. 10, Group tooling design for part family.

A group tooling set-up can also be applied to automatic machines. A set of tools for machining part families can be pre-set and given a code number that corresponds to the part family. The result is a situation in which the tooling set-up is simply a matter of selecting and installing the correct pre-set tooling and occasionally changing a tool. This reduces downtime between jobs.

6. GROUP SCHEDULING

6.1 Basic Concept:

A number of disciplined areas of concentration comprise the overall role of production scheduling. Line loading and balancing, determination of lead times for purchased items, the development of materials requirements planning and optimal sequencing of jobs through a facility are important aspects that must be coordinated in the proper manner. All play an important part in developing a manufacturing system that takes advantage of every opportunity to optimize efficiency. Optimal sequencing of jobs through a facility is probably the highest area of efficiency improvement. The group/cell layout and part family concepts ideally lend themselves to optimal sequencing efforts.

Production scheduling is greatly simplified by Group Technology. The scope of the problem is reduced from that of a large portion of the shop to a small group of machines. If the families of parts and groups of machines have been formed correctly, each job will indicate by its code number which group of machines will be used to process it. Within the group of machines, the scheduling problem is again reduced to simply scheduling the given jobs through the machines in the cell. Even though a machine group/cell is not formed, the production scheduling could be very much simplified, by use of part families in assigning jobs to the various machines in the shop. A computer program can be utilized to schedule jobs of a part family to a corresponding machine group/cell. The jobs can be properly sequenced in the family and the families properly sequenced through the machine group/cell.

Proper scheduling is an integral part of Group Technology. Good scheduling, combined with reduced set-up time and reduced transportation, will result in a significant cost reduction. The most obvious benefit is reduced total production time. With this reduction, production can more closely match demand so that inventories can be reduced and parts be produced on schedule. Thus, with more reliable scheduling, sales people can guarantee better delivery dates and have assurance of meeting them. Let us call production scheduling associated with

Group Technology "Group Scheduling". Proper application of Group Technology concept in production scheduling will:

(a) Reduce set-up times and costs.
(b) Permit optimal decision of group and job sequences.
(c) Permit flow-line production.
(d) Optimize group layout.
(e) Provide overall economic advantages.

The inherent nature of the group/cell layout and part family grouping lends itself to the sequencing problem. Classification and coding systems confine individual parts to part families. A plant layout is designed so that each part family is assigned to a specific group/cell. Since subsequent required work-stations are directly adjacent to preceding operations, transportation time is minimal and can, in all practical terms, be considered negligible in the sequencing problem. The queue, or waiting time for a part to be processed through a particular work-station, becomes very predictable and control of the manufacturing process is maintained. Considering the numerous advantages that the group/cell layout provides for optimal sequencing, it seems that the problem is solved for all intents and purposes. However, to find an optimum operation sequence for a given part family and a machine group/cell is not a simple task. All possible combinations of operation sequences for n jobs and m machines is $(n!)^m$. For example, if five different jobs are to be processed through nine different work stations, then $(5!)^9 = 5,160 \times 10^{15}$ different sequences are possible, assuming that operations can be performed in an arbitrary order.

When the work of jobs grouped into part families are processed as groups through either machine group/cell or conventional layout, it becomes simpler to solve the problems for optimum operations sequencing and machine loading compared to a general job-shop condition. When a part family is assigned to a given machine group/cell, the scope of the problem is reduced to $(n!)$ possible alternative sequencing. However, there still remains the extremely complex problem of resolving just how to schedule these jobs, since they are assigned to a particular machine group/cell for processing.

Machine loading and the product-mix decision are major problems in the field of production planning. An analysis for machine loading to optimally select parts to be manufactured in a given amount of time available by a given production facility under Group Technology environment is also very essential in production scheduling, and becomes simpler in comparison to the problems involved with a general job-shop condition. Many mathematical models and practical algorithms have been developed to handle idealized problems in the area of optimal sequencing and machine loading. These models are primarily addressed to general job-shop problems, and not to the sequencing and loading problems from the standpoint of Group Technology.

Group scheduling has some specific features that differ from conventional scheduling problems which are as follows:

(1) Optimization for group and job sequence and machine loading
(2) Possibility of flow-shop pattern
(3) Reduction of set-up times and cost
(4) Economic savings

6.2 Algorithms for Group Scheduling:

6.2.1 Optimal Sequencing for a Single Part Family:

Group scheduling can be analyzed in a multi-stage manufacturing system. In the case of manufacturing multiple parts (jobs) grouped into several part families, both optimal group and optimal job sequences can be determined such that the total flow time (makespan) is minimized, by means of various methods, e.g. branch-and-bound method, a heuristic method, etc.

To explain the optimum sequencing methods for group scheduling, a simple example is demonstrated using a heuristic algorithm developed by Petrov(10) and modified by Ham(11). Let us assume that the basic data given in Table 3 are to be used to find the optimum job sequence processing through four machines for a single part family group to minimize the total throughput time.

Table 3, Basic data for group scheduling of a single part family.

Job	Machines (hours)			
	M_1	M_2	M_3	M_4
J_1	17	13	15	10
J_2	8	16	21	7
J_3	16	14	15	4

Using the heuristic algorithm, it can be easily found that the optimum job sequence is J_2-J_1-J_3. The total throughput times for all possible combinations of this group is as follows:

J_1-J_2-J_3 ..... 95 hours
J_1-J_3-J_2 ..... 90 hours
J_2-J_1-J_3 ..... 74 hours
J_2-J_3-J_1 ..... 79 hours
J_3-J_1-J_2 ..... 89 hours
J_3-J_2-J_1 ..... 91 hours

It is obvious that the optimum job sequence (J_2-J_1-J_3) results in the shortest total throughput time compared to other possible sequences. The difference between the longest total time and the shortest time is 17 hours. The Gantt chart showing the optimum job sequencing is exhibited in Figure 11, which indicates the total throughput time is 74 hours.

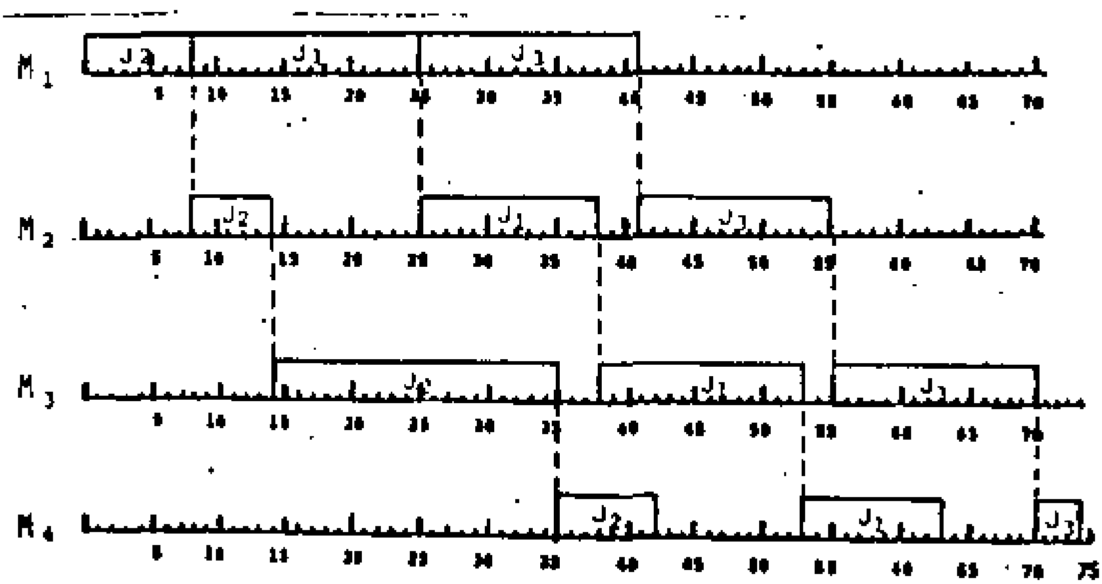


Fig. 11, Gantt chart for optimum job sequence of J_2-J_1-J_3 with uni-directional successive sequencing method.

However, the above sequencing method is based on the so-called uni-directional, successive sequencing method that a part family is processed as a group and transferred from one work-station to another as a batch. However, when a part family is processed through a designated machine group/cell where parts can be transferred from one work station to another as a part is completed, i.e. unidirectional parallel sequencing method, the total throughput time can be further reduced to 53 hours as indicated in Figure 12.

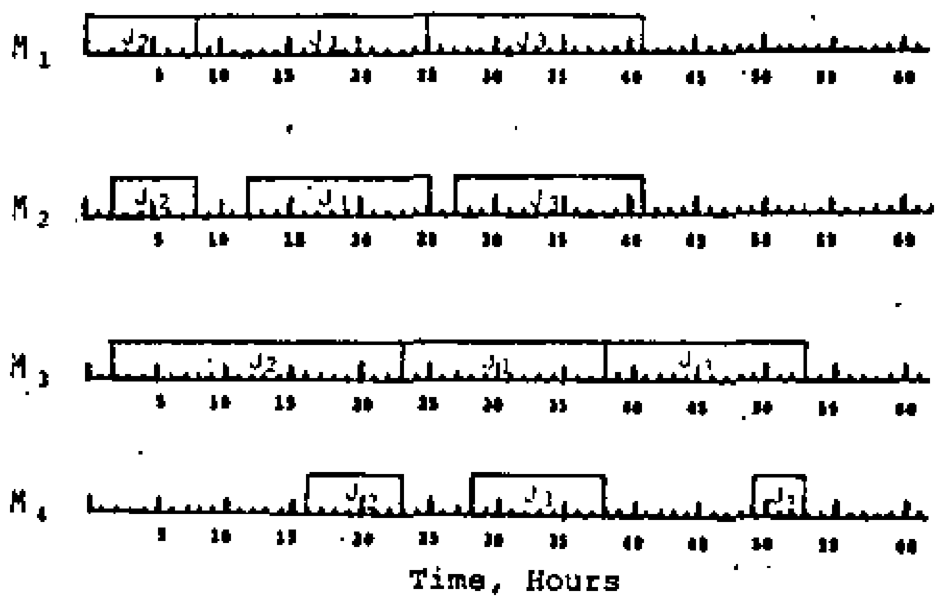


Fig. 12, Gantt chart for optimum job sequence of J_2-J_1-J_3 with uni-directional, parallel sequencing method.

In comparison to the other sequencing methods, this parallel sequencing method provides 21 hours reduction when compared to the optimum sequencing by successive sequencing, and 38 hours reduction when compared to the longest possible sequencing time.

This simple example illustrates that group scheduling is more effective and results in minimum total throughput time. This example also demonstrates that a machine group/cell provides for further reduction in the total throughput time by making parallel sequencing possible.

Related algorithms of this heuristic method are available for solving the problems for non-uniform, non-unidirectional scheduling where operations or work stations required for the selected part families are neither uniform nor the same order. The operations required for parts may be in different order, i.e., back and forth. In most cases, a real shop condition presents usually non-uniform and non-unidirectional problems.

6.2.2 Optimal Sequencing for a Set of Part Families:

Optimization analysis of Group Scheduling for multi-product and multi-stage manufacturing systems with more than one part family(12) is demonstrated with the basic data given in Table 4 and using both "branch and bound" method and the same heuristic method used in 6.2.1.

Table 4, Basic data for group scheduling in multi-product and multi-stage manufacturing system.

Group	G_1			G_2				G_3		
Job	-	J_{11}	J_{12}	-	J_{21}	J_{22}	J_{23}	-	J_{31}	J_{32}	J_{33}
Set-up/ Processing Time (hours)	S_1	P_{11}	P_{12}	S_2	P_{21}	P_{22}	P_{23}	S_3	P_{31}	P_{32}	P_{33}
M_1	5	5	7	3	2	4	3	7	2	1	9
M_2	5	5	1	6	3	2	8	3	2	8	2
M_3	4	3	8	4	1	6	5	1	7	4	5
Due-Date	-	d_{11} 46	d_{12} 37	-	d_{21} 28	d_{22} 35	d_{23} 80	-	d_{31} 18	d_{32} 24	d_{33} 52

The branch and bound method is based on the principle that the set of all possible schedules, partial and complete, can be represented by a tree structure with a root, branches and nodes. For modelling group scheduling for multi-product, multi-stage manufacturing systems, the following branching and bounding procedures are considered:

(1) Branching Procedure:

Group node (N_r) is a node at which r groups are chosen from among m groups and sequenced: $N_r = G_{<1>}, G_{<2>}, \ldots, G_{<r>}$.

Job node (N_{rs}) is a node at which s jobs at N_r are chosen from among n_r jobs belonging to $G_{<r>}$ and sequenced:

$N_{rs} = J_{<r><1>}, J_{<r><2>}, \ldots, J_{<r><s>}$.

(2) Bounding Procedure:

The lower bound (LB) of the total flow time at N_{rs} is estimated as follows:

$$LB(N_{rs}) = \max_{1<k<K} \left(F^{k'}_{N_{rs}} + F^{k''}_{N_{rs}}\right)$$

where $F^{k'}_{N_{rs}}$ and $F^{k''}_{N_{rs}}$ are total processing times for groups and jobs which are already sequenced and not yet sequenced, respectively, and k is number of machines.

The solution of this problem (Table 4) by branch and bound method is exhibited in Figure 13 and also in Table 5.

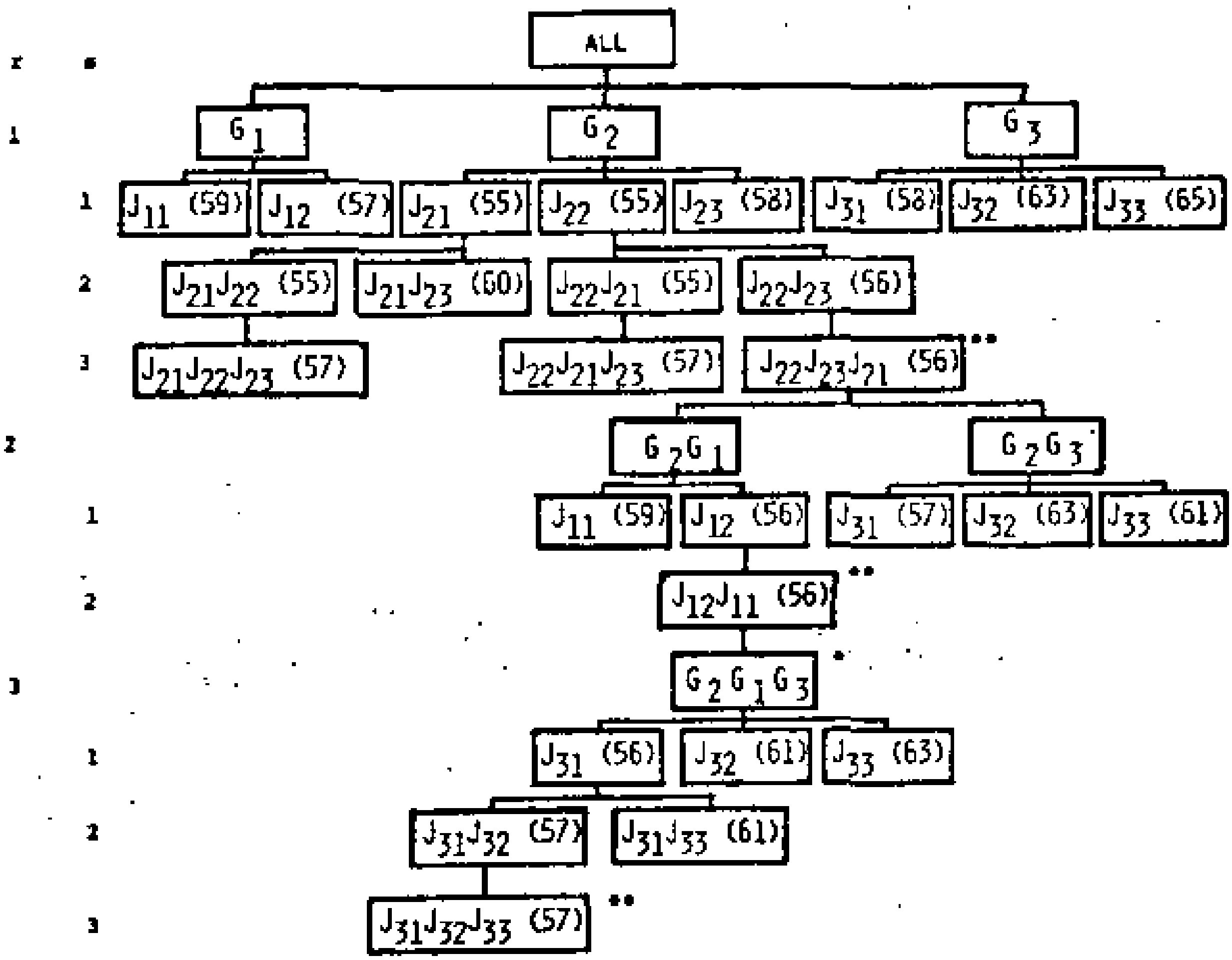


Fig. 13, Solution for optimum group and job sequences by branch-and-bound method (* mark indicates the optimal group sequence and ** mark indicates the optimal job sequences in each group).

Table 5, Optimal solution for minimizing the total throughput time (refer to Table 4, and Figure 13).

Group Sequence	G_2	G_1	G_3
Job Sequence	$J_{22}-J_{23}-J_{21}$	$J_{12}-J_{11}$	$J_{31}-J_{32}-J_{33}$

The optimizing algortihms for determining optimal group and job sequences to minimize the total tardiness are also available. The solution for optimum group and job sequences for minimizing the total tardiness is shown in Table 6.

Table 6, Optimal solution for minimizing the total Tardiness (refer to Table 4 and Figure 13).

Group Sequence	G_3	G_2	G_1
Job Sequence	$J_{31}-J_{32}-J_{33}$	$J_{21}-J_{22}-J_{23}$	$J_{11}-J_{12}$

The heuristic method for group scheduling, which is used for optimum sequencing for a single part family (see 6.2.2), can also be applied for a multi-products, multi-stage manufacturing problem. For this example (Table 4), the solutions for optimal group and job sequences are the same as the solutions by branch-and-bound method. Although it provides only near optimum solutions, the algorithm for this heuristic method is far simpler and easier to compute, compared to other similar heuristic algorithms and certainly in comparison to the branch and bound method.

6.2.3 Machine Loading Analysis:

Analysis for machine loading for group scheduling is a complex problem and it is not simple to develop an adequate algorithm for practical applications. However, some mathematical models for the machine loading and product-mix analysis problems (13) are available. An example of such model is given to demonstrate the machine loading analysis for group scheduling. The approach of this model is to maximize the total amount of parts to be produced in a limited time available, d. Hence, the objective function is to maximize:

$$Z = \sum_{i=1}^{M} \sum_{j=1}^{N_i} \ell_{ij} X_{ij}$$

with the following constraint:

$$\sum_{i=1}^{M} \left(\sum_{j=1}^{N_i} P_{ij} X_{ij} + S_i X_i \right) < d$$

where:

d : allowed time capacity (min)

ℓ_{ij}: lot size for J_{ij} (pcs)

M : number of groups

N_i : number of jobs in G_i

P_{ij}: total job production time for J_{ij} (min/lot)

S_i : group setup time for G_i (min/group)

X_{ij}= 0 or 1 $(i=1,2,\ldots,M,\ J=1,2,\ldots,N_i)$

$$X_i = \begin{cases} 0, & \text{if } \sum_{j=1}^{N_i} X_{ij} = 0 \\ 1, & \text{if } \sum_{j=1}^{N_i} X_{ij} > 1 \end{cases}$$

Using the algorithm (14), a numerical example for determining the optimal parts to be made as well as optimal machining speeds to be utilized for producing the parts are presented in Tables 7 and 8.

Table 7, Basic data for machine loading analysis (1)

GROUP	PART	LOT SIZE	GROUP SETUP TIME	JOB SETUP TIME	UNIT PRODUCTION TIME
i	j	l_{ij}	S_i	s_{ij}	p_{ij}
No.	No.	pcs	min	min/lot	min/pc
1	1	30	40	19	6
	2	10		8	2
2	1	20	35	10	17
	2	50		9	9
	3	30		15	7
3	1	20	20	5	12
	2	60		13	6
4	1	20	45	6	16
	2	10		10	13
	3	40		20	15

ALLOWABLE TIME d = 40 (h)

Table 8, Optimal solution for machine loading (1)

GROUP	No.	1		2			3		4		
PART	No.	1	2	1	2	3	1	2	1	2	3
LOT SIZE DEMANDED	pcs	30	10	20	50	30	20	60	20	10	40
ACCEPT(A) OR REJECT(R)		A	A	R	A	A	A	A	R	A	A
PRODUCTION AMOUNT	pcs	30	10	-	50	30	20	60	-	7	40
PRODUCTION TIME	min/lot	199	28		459	225	245	373		101	62-
GROUP PROD. TIME	min	267		719			638		766		
TOTAL PROD. AMT	pcs	247	TOTAL PROD. TIME	min	2390	REMAIN. TIME	min	10			

6.3 Integrated Applications with MRP:

The typical multi-stage manufacturing operation with multiple products presents a problem for which it has been found difficult to find means for effective production control. Such a problem is typically characterized by:

(a) Vast numbers of individual components
(b) A high variability between parts in terms of part geometry
(c) A high variability between parts in terms of manufacturing operations, and their sequence
(d) Variability in the demand for the final assembled product as both a function of the final product and time

To provide a viable system for production control, such a system must answer the following questions:

(a) What specific parts should be produced during a given period?
(b) How many of these parts should we produce during that period?
(c) What is the specific time-line (or schedule) for production within each period?
(d) Are there any "similar" parts that may be produced at the same time so as to provide for more economic lot sizes and also decrease the total amount of set-up time required?

Group Technology takes all of the component parts and attempts to classify them into a workable set of part families and/or assign them to machine groups/cells. Ideally, each part family has enough inter-part similarity that the individual parts may be processed via a particular subset of the total production processes.

Material Requirements Planning (MRP) is yet another tool for the alleviation of problems within the multistage, multiproduct plant. In its simplest form, MRP reduces each final product into its elementary parts and, using a forecast of the requirements for the final product, assigns the required quantities of each elementary part to a specific time period.

When introduced separately, both Group Technology and MRP are subject to several inherent limitations. The group scheduling algorithms, for example, do not consider the very practical, and important time-phase aspects of part production, nor the machine capacity limitations of the machine groups/cells assigned to each part family. That is, a typical group scheduling algorithm assumes that all parts (for the job under consideration) are available at the beginning of the time period.

MRP, while considering the time-phase aspects of the problem, simply assigns various quantities of parts to specific time periods without consideration of either the schedule necessary within that period or the advantages of processing by part family groupings.

It should be obvious, however, that MRP develops the set of data necessary for a group scheduling algorithm that does consider the time-phase aspects of the problem. Consequently, by suitably combining group scheduling and MRP, it is possible to construct an integrated system that possesses the advantages of both concepts while alleviating their individual limitations. Such a system then can answer the set of questions listed earlier and thus provide a viable means for effective production control.

A procedure for integrated applications of group scheduling and MRP may be broken down into a series of steps as listed below:

Step 1: Gather the data normally required of both the Group Technology and MRP concepts (i.e., parts and their description, machine capabilities, a breakdown of each final product into its individual components, a forecast of final product demand, and so forth).

Step 2: Use Group Technology so as to determine part families. Designate each family as G_i $(i=1,2,\ldots,m)$.

Step 3: Use MRP to assign each component part to a specific time period.

Step 4: Arrange the component part/time period assignments of Step 3 according to the part family groups of Step 2.

Step 5: Use a suitable group scheduling algorithm to determine the optimal schedule for all those parts, within a given group, for each time period.

A simplified illustration (15) to explain the procedure is given in Tables 9, 10 and 11. Let us assume that five parts are being produced within a jobshop. These parts, designated as A, B, C, D, and E respectively, are used to form certain final products and it would be impractical to further subdivide them. Using Group Technology, we are able to divide the five parts into two part families, designated simply as G_1 and G_2. Also, a specific part code number is assigned to each part using a classification and coding system.

The number of units required for each part, for a certain month, have been determined to be: A=60, B=60, C=60, D=30 and E=50. This information has been summarized in Table 9. However, if a group scheduling algorithm alone is used on the data given in Table 9, such a schedule could well violate specific due date constraints. For example, one might schedule 60 units of part A for production in week 4, whereas it may be that 15 of these are actually needed in week 1.

Using MRP, the precise number of each part on a short term (e.g., weekly) basis, may be determined. Table 10 illustrates such an MRP output for this example. This table gives the number of units of each part as needed in each week of the month under consideration, but does nothing to answer the question as to what is the optimal schedule within each week.

Thus, to take full advantage of the integrated Group Technology/MRP system, Tables 9 and 10 are combined into the integrated form of Table 11. Next, by applying an appropriate scheduling algorithm to those sets of parts within a common group and week, we may obtain an optimal schedule for each week of the entire month, and one that does take advantage of the Group Technology induced flowshop as well as the MRP derived due date considerations.

Table 9, Part family examples.

Group	Part Code Number	Part Name	Units Required During Month
G_1	6212-023	A	60
	6212-015	B	60
	6212-083	D	30
G_2	5333-125	C	60
	5333-186	E	50

Table 10, Weekly part assignments by MRP

Part Code No.	Part Name	Planned Order Release			
		Week			
		1	2	3	4
6212-023	A	30	30	0	0
6212-015	B	15	15	15	15
5333-123	C	20	20	10	10
6212-083	D	10	10	5	5
5333-186	E	15	15	10	10

Table 11, Combined GT/MRP data.

Group	Part Code No.	Part Name	Planned Order Release			
			Week			
			1	2	3	4
G_1	6212-023	A	30	30	0	0
	6212-015	B	15	15	15	15
	6212-083	D	10	10	5	5
G_2	5333-125	C	20	20	10	10
	5333-186	E	15	15	10	10

7. COMPUTER AIDED MANUFACTURING AND GROUP TECHNOLOGY

7.1 Computer Aided Manufacturing:

Development and implementation of computer aided manufacturing (CAM) in the manufacturing industry lead to more integrated applications of Group Technology for higher productivity. It has been recognized that Group Technology is an essential element of the foundation of successful development and implementation of CAM, through applications of the part-family concept based on geometrical and processing similarities between parts. This approach creates a compatible, economic basis for evolution of computer automation in batch type manufacturing, through increased use of hierarchical computer control and multi-station NC manufacturing systems.

A part classification system which is an integral part of, and has been used as an essential tool of, Group Technology applications can also be evolved as a means of describing parts in a form that can be integrated readily into a computer data base structure; which links design and production. These data bases should be developed so that they correspond to groupings of tooling set-ups, machines or machine stations using Group Technology concepts, and also to provide a basis for computer automated process planning. Also an evolution of CAM leads to generative design and to generative process planning, part classification and coding systems will become an integral part of the total generative system evolving with CAM.

An approach for integrated computer aided manufacturing (ICAM) emphasizes the need of Group Technology implementation for its successful realization, as shown in Figure 14.(16)

As future development of CAM oriented manufacturing technology progresses, more generative and evolutionary systems of Group Technology should be studied and implemented in all areas of manufacturing, e.g., design, planning, control, scheduling, inventory, tooling, production, testing, assembly, etc. The ultimate successful implementation of CAM is certainly based on the balanced development of hardware and software for Group Technology implementation which provides the essential basis for the further development of CAM technology.

Group Technology is a dynamic and revolutionary development which continues to expand its influence on manufacturing systems. It is evident that the role of Group Technology certainly is broadened with more innnovative advancements in theory and application, not only for improving productivity in conventional batch-type manufacturing systems, but also for proper adaptation of CAM systems.

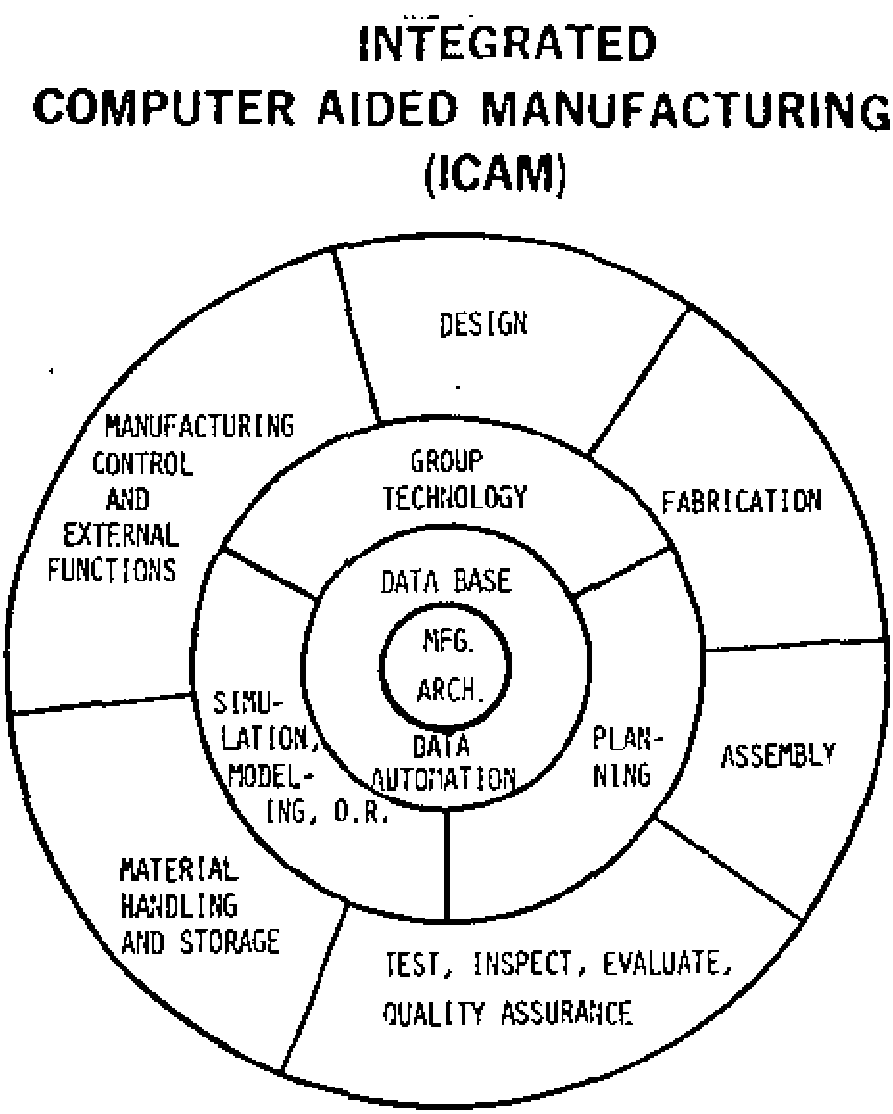


Fig. 14, Integrated computer aided manufacturing (ICAM) and Group Technology (16).

7.2 Computer Aided Process Planning:

For successful implementation of CAM systems, one of the essential requirements is computer aided process planning. The use of automated process planning techniques, as a basis for a rational and logical approach to the design of components for manufacture in the most economic manner, is a key to achieving optimum manufacturing productivity in CAM systems. An essential requirement is to develop a framework of decision-making based on a number of algorithms or logic flow diagrams at each particular decision-making stage; and in particular to develop procedures for the retrieval of information on part design specifications, tooling requirements, machining conditions and capabilities, and other pertinent data stored in computer data banks.

Computer aided process planning can be made either by the retrieval of available data or the generative process. Most of the current process planning systems employ the retrieval techmique which is based on part families and given data bases of standard tooling and processes. The generative technique creates a new unique process plan for a particular part. Efforts have been made to develop a generative type process planning by various interest groups.

It has been recognized that Group Technology is an essential element for successful execution of computer automated process planning. As indicated in the flow diagram (Figure 15) proposed by the CAM-I (Computer Aided Manufacturing - International),(17) the logical approach to successful automated process planning is a system based on the part family concept. The development of part families, using suitable classification and coding systems will make it possible to develop standards of shape and process within the part families. Thus it is possible for the initiation of automatically generated process planning.

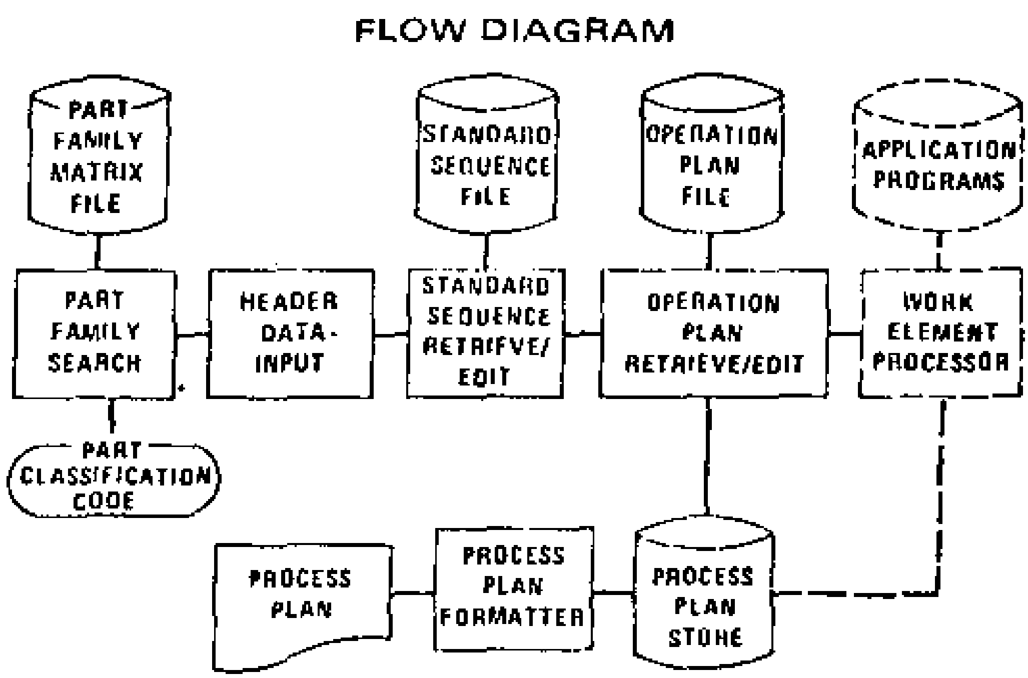


Fig. 15, Flow diagram for computer aided process planning (CAPP) proposed by CAM-I (17).

7.3 NC-GT Programming:

Group Technology can make economically feasible the use of sophisticated automatic equipment such as NC machines and/or special tooling which may have been too costly for batch type production. The advantages of NC type automatic equipment are usually outweighed by the problems and costs of production planning and tooling, low utilization, long set-up times, etc. With proper Group Technology applications, these problems can be reduced to such an extent that it becomes advantageous to use NC equipment which otherwise might be uneconomical. This is particularly true of current sophisticated, expensive machining center type NC machines. NC machine tool costs can also be reduced by selecting smaller and/or less flexible NC machines through Group Technology applications by proper machine grouping and efficient machine loading.

Many advantages claimed for NC machine tools are also of greater importance in a Group Technology environment. While numerical control of machine tools offers the ability to machine small batches of components economically by reducing set-up time, Group Technology offers the same. In many cases, NC and Group Technology will not only be mutually viable, but together they can be self-improving and self-sustaining. Therefore, combined utilization of special features of NC and Group Technology make it possible to realize maximum benefits of both.

One of the important applications of Group Technology is a software development of NC machining called "Part-family Programming". Part-family programming is a NC program system that groups common or similar program elements into a single, master computer program. The master computer program, or preprocessor, is a permanent base from which a NC tape can be prepared, for any part in the part family. Therefore, part-family programming increases the production of costly NC operations by saving programming time, manpower, and tape prove-out time. It also reduces lead time, tool inventory, simplifies maintenance and requires fewer computer reruns.

Part family programming (18) slashes one of the big cost elements in NC operations. One master program for a part family stored in the computer, plus a small amount of variable input, delivers a tape for any part in the family. Some of the typical advantages and disadvantages of part-family programming are as follows:

Advantages:

Higher NC productivity
Minimum-error first tapes
Less risk of machine collision
Minimum program debugging
Higher operator productivity
Fewer computer reruns
Same-day new tapes
Low risk of first-part scrap
Programmer manpower savings
Clerk-level part programming
Standardized cutting tools
Standardized job processing
"Wholesale" optimization
Uniform documentation
"Wholesale" program maintenance
Aid to design standardization
Transferable program logic

Disadvantages:

Higher initial investment
More complex program logic
More software storage
Longer computer run

7.4 Machining Centers and Multistation Manufacturing Systems:

NC machining centers, by virtue of their characteristics, are capable of doing the work of several conventional machine tools. They consolidate a number of set-ups into one, thus having an effect of group layout (cellular layout) of machines. Therefore, machining centers can be considered as machine groups or cells, with the capability of reducing lead time and in-process inventory. Such machining centers are expensive. Their use should be optimized through Group Technology.

Where the installation of a machining center is being considered, the maximum benefits will be obtained by paying attention to the whole machining complex, which supports and loads the machining center. In other words, NC machining center will generally be operated efficiently under a Group Technology environment.

With Group Technology applications in the layout and organization of a factory, its manpower and equipment on a part-family basis rather than a functional basis, a successful CAM program can be achieved. Evolution of CNC and DNC is also related to Group Technology through the computer hierarchy. As CNC type mini-computer control of the individual machines in a Group Technology cell is brought together, in due time it will provide a more economic basis for overall DNC of the cell. Eventually, it will become profitable to link all the cells in the factory with a large computer, providing an initial basis for overall on-line optimization and automation of the factory.

One of the future trends of CAM is "Multi-station Manufacturing Systems", which also involves evolution of the Group Technology cells. As the number of NC work-stations under CNC/DNC in a cell increases, more economic operations become possible through complete automation and integration of tool and work handling and transfer within the cell.

The final step in the evolution of CAM is, of course, the computer-integrated automatic factory operating under Group Technology cells. The overall concept for the total system is based on the use of Group Technology cells, each devoted to the production of given parts families. Each cell is controlled by a built-in micro-computer. The overall computer system for the plant is hierarchical in nature. Middle-level computers control and coordinate the operation and work scheduling of one or more cells, while the overall system is being controlled by a central computer.

8. ECONOMICS OF GROUP TECHNOLOGY

8.1 Economic Benefit and Justification:

Appropriate and successful implementation of Group Technology will lead to improvements which include more effective design, less stock and fewer purchases, simplified production planning and control, optimum sequencing and loading, reduced tooling and set-up times, reduced in-process inventories, shorter throughput time, more efficient utilization of expensive machines, etc. Significant economic benefits will be achieved as shown in Figure 16.

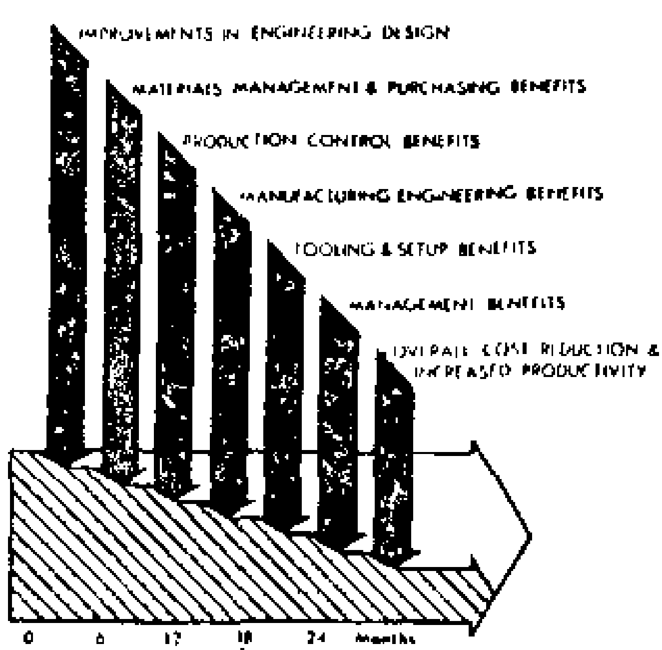


Fig. 16, Reduction of manufacturing costs through Group Technology application.

It is desirable to analyze these economic gains through cost analysis of specific applications by comparing the economic benefits of both the present conventional method and the proposed Group Technology method. Economic justification is a key for implementation of Group Technology. Various formulae and procedures have been developed for economic analysis and some examples of such methods are presented in section 8.2, "Comparative Cost Analysis".

The economic gains through successful Group Technology applications are great. However, it requires a period of time to gain new savings since a considerable cost is involved in maintaining the system as indicated in the case history shown in Figure 17.

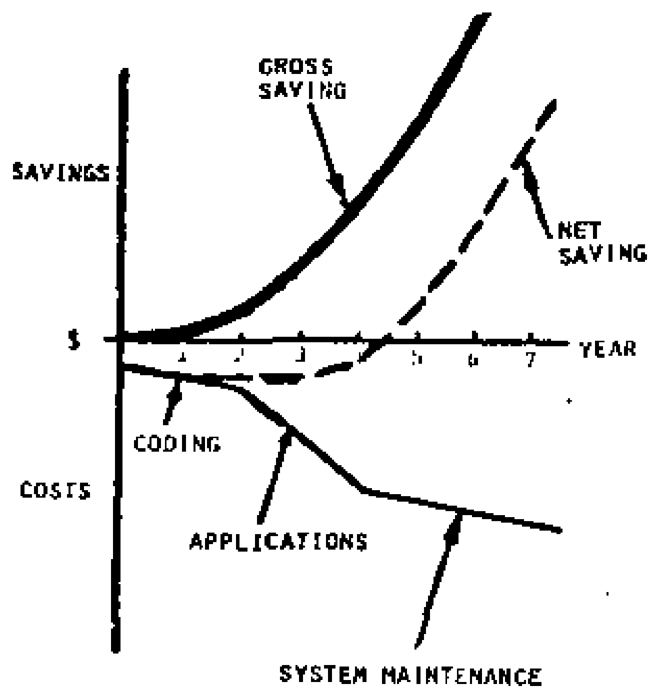


Fig. 17, Examples of cost savings, expenditure and time-period for Group Technology implementation.

8.2 Comparative Cost Analysis:

8.2.1 Group Tooling Costs:

One of the advantages of Group Technology applications is the rationalization of tool designs and the reduction of tooling set-ups, which lead to reduction of tooling costs and production costs as a whole. The cost analysis of group tooling (group jigs and fixtures) in comparison with the tooling costs of conventional tooling methods becomes essential for the justification of Group Technology applications in tooling.(19)

(a) Conventional tooling method:

$$C_{tw1} = \sum_{i=1}^{p} C_{w1}(i)$$

where:

C_{w1} : cost of a jig or fixture of conventional tooling method, \$

C_{tw1}: total tooling costs of conventional methods using "p" different jigs or fixtures, \$

p : number of different jigs or fixtures used (also possibly number of different parts to be produced)

(b) Group tooling method:

$$C_{tw2} = \sum_{i=1}^{q} C_{a}(i) + C_{w2}$$

where:

C_{w2} : cost of a group jig or fixture, \$

C_{tw2}: total costs for the group tooling using a group jig or fixture with "q" different adapters, \$

C_a : cost of an adapter, \$

q : number of adapters used for the production of a family of parts

(c) Unit tooling cost:

(i) Conventional tooling method:

$$C_{u1} = \frac{C_{tw1}}{N} = \frac{\sum_{i=1}^{p} C_{w1(i)}}{N}$$

where:

C_{u1}: unit tooling cost for conventional tooling method, \$/piece

N : number of parts produced

(ii) Group Tooling method:

$$C_{u2} = \frac{C_{tw2}}{N} = \frac{\sum_{i=1}^{q} C_{a(i)} + C_{w2}}{N}$$

where:

C_{u2}: unit tooling cost for group tooling method, \$/piece

The following data shown in Tables 12 and 13 are given for comparison of a conventional tooling method using conventional milling fixtures and a new group tooling method using a master group fixture and adapters.

The total tooling costs (C_{tw}) and the unit tooling costs (C_u) of the conventional tooling method and the group tooling method, in relation to the number of different parts in the part family or the group are computed, and listed in Table 13. The total tooling costs (C_{tw}) and the unit tooling costs (C_u) as a function of the number of parts in the part family or group are plotted in Figure 18 and Figure 19, respectively.

As shown in these graphs, the rate of increase in the total tooling costs for the conventional tooling method is exceedingly larger than that of the group tooling method. From the standpoint of the unit tooling costs, as the number of parts in the part family increases, the unit tooling costs for the group tooling methods become far more economical compared to the conventional tooling method which is not affected by the number of parts in the part family. However, the sharp decrease in the unit tooling costs levels off after a certain number of parts in the group. This indicates that there is a limit up to which reduction of the unit tooling costs is effective. Also, both graphs of the total tooling costs and the unit tooling costs indicate the break-even points at which the decision for selection of appropriate tooling method can be made.

In comparison of conventional and group tooling methods, it becomes necessary, not only to analyze the total tooling costs and the unit tooling costs, but also the number of parts in the part family where break-even takes place. A break-even point in the tooling costs of both methods can be obtained as follows:

Table 12, Cost data for comparative analysis.

Item	Conventional Tooling Method	Group Tooling Method
Cost of the Drill Jig	$815	$2208
Number of jigs required	6	1
Cost of an adapter	-	$450
Number of adapters required	-	5
Number of pieces to be prod.	240	240

Table 13, Computed example of tooling costs for Comparison.

No. of parts in part family	Conventional Method		Group Tooling Method	
	C_{tw1}	C_{u1}	C_{tw2}	C_{u2}
1	$ 815	$3.40	$ 2,658	$11.08
2	1,630	3.40	3,108	6.48
3	2,445	3.40	3,558	4.94
4	3,260	3.40	4,008	4.18
5	4,075	3.40	4,458	3.72
6	4,890	3.40	4,908	3.41
7	5,705	3.40	5,358	3.19
8	6,520	3.40	5,808	3.03
9	7,335	3.40	6,258	2.90
10	8,150	3.40	6,708	2.80
11	8,965	3.40	7,158	2.71
12	9,780	3.40	7,608	2.64
13	12,225	3.40	8,958	2.49
14	10,595	3.40	9,058	2.58
15	12,225	3.40	8,956	2.49
20	$16,360	$3.40	$11,208	$2.34

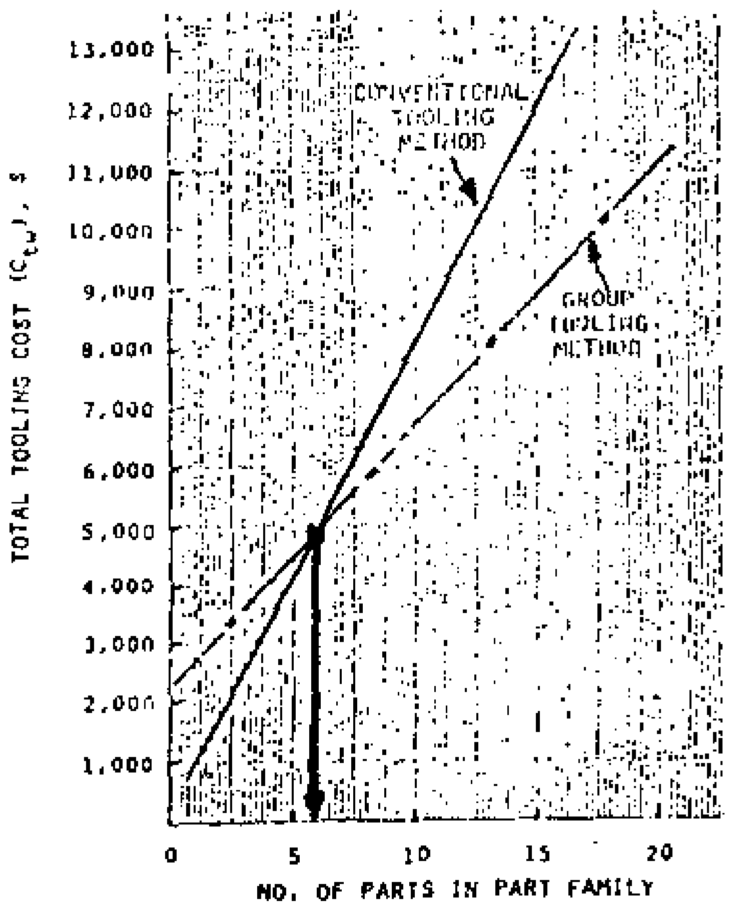


Fig. 18, Total tooling costs of conventional and group tooling methods (refer to Tables 12 and 13).

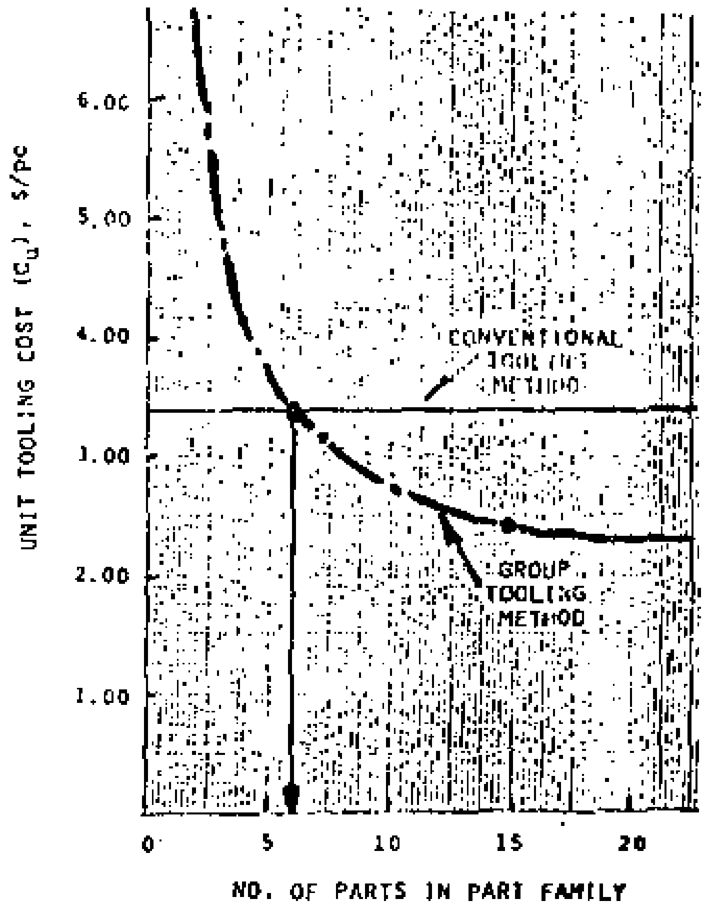


Fig. 19, Unit tooling costs of conventional and group tooling methods (refer to Tables 12 and 13).

when $n = n_b$ $\quad C_{tw1} = C_{tw2}$

$$\sum_{i=1}^{p \text{ at } n_b} C_{w1(i)} = C_{w2} + \sum_{i=1}^{q \text{ at } n_b} C_{a(i)}$$

where:

n : number of parts in the part family

n_b: number of parts in the part family at the break-even point

For simplicity, let us assume that the break-even point may be analyzed using the average tooling costs which are expressed as:

Average tooling cost: $\bar{C}_w = \dfrac{\sum_{i=1}^{p} C_{w1(i)}}{p}$

Average adapter cost: $\bar{C}_a = \dfrac{\sum_{i=1}^{q} C_{a(i)}}{q}$

The break-even number of parts in the part family (n_b) can be formed as follows:

$$n_b = \frac{C_{w2}}{\bar{C}_{w1} - \bar{C}_a}$$

However, the number of fixtures or adapters needed at the break-even point may or may not be equal to the number of parts in the part family or group. For example, if an adapter can be used for two different parts, the number of adapters needed will be one less than the number of parts in the part family. This concept applies also to the number of fixtures "p". In a conventional tooling method, the number of fixtures is usually equal to the number of different parts produced. However, in some cases, the number of fixtures needed might be less than the number of different parts to be produced.

Let us assume that "p" fixtures for conventional tooling methods, and one group fixture with "q" adapters for group tooling method are required for production of "n" different parts in the part family. Then (n - p) of (n - q) represents the number of parts which does not require their own fixture or adapter, since these parts can be produced by using the fixtures or adapters designed for other parts. It is also natural to assume that these (n - p) or (n - q) parts are included in the break-even number (n_b). Therefore, the actual number of fixtures or adapters required at the break-even point are: n_b - (n-p) or n_b - (n-q) respectively. Therefore, the break-even number of parts in the part family for these cases when $n \neq p$ and/or $n \neq q$ may be expressed.

$$n_b = \left\{ \frac{C_{w2} + (n-p)\ \bar{C}_{w1} - (n-q)\ \bar{C}_a}{(\bar{C}_{w1} - \bar{C}_a)} \right\}$$

8.2.2 <u>Group Machining Costs</u>:

Group machining is one of the most important features of Group Technology applications. Although group machining is advantageous from various technical points of view, it is still desirable to confirm the advantages of the group machining method over the conventional machining method.

(a) The total machining cost for a single lot of a part with a special individual tooling may be expressed as:

$$C_{tm} = C_o\ (T_c N_\ell + T_s) + D_t$$

where:

C_{tm}: total machining cost, $

C_o : labor rate, $/min

T_c : unit machining time per piece, min/pc

n_ℓ : lot size, no. of pc/lot

T_s : set-up time per a lot, min/lot

D_t : depreciation of tooling per a lot, $/lot

(b) The total machining costs for machining of "n" lots or "n" different parts in the part family for both conventional and group machining can be expressed as follows:

(i) Conventional (individual) machining:

$$C_{tm1} = C_o \sum_{i=1}^{n} T_{c1(i)} N_{\ell 1(i)} + \sum_{i=1}^{n} T_{s1(i)} + \sum_{i=1}^{n} D_{t1(i)}$$

where:

C_{tm1}: total machining cost for conventional machining, $

n : number of lots or number of different parts to be produced

T_{c1} : unit machining time per piece by conventional machining, min/pc

T_{s1} : set-up time per lot for conventional machining, min/lot or part

D_{t1} : average depreciation of tooling per lot for conventional machining, \$/lot or part

(ii) Group machining:

$$C_{tm2}=C_o \sum_{i=1}^{n} T_{c2(i)} N_{\ell 2(i)} + T_{s2} + \sum_{i=1}^{n-1} T_{sa(i)} + D_{t2} + \sum_{i=1}^{n-1} D_{ta(i)}$$

where:

C_{tm2}: total machining cost for group machining, \$

n : number of parts in the part family

T_{c2} : average unit machining time per piece by group machining, \$/pc

T_{s2} : set-up time per lot (per a part family) for group machining, min/lot or part family

T_{sa} : set-up time per adapter for group machining, min/adapter

D_{t2} : depreciation of tooling per lot or part family for group machining, \$/lot or part family

The total production time necessary to process "n" different parts by conventional method can be defined by the processing time of the parts and the time spent on setting the fixtures necessary for each part.

$$T_{m1} = \sum_{i=1}^{n_1} T_{c1(i)} N_{\ell 1(i)} + \sum_{i=1}^{p} T_{s1(i)}$$

where:

T_{m1}: total production time for producing a group of parts by conventional method, min.

n_1 : number of different parts produced

T_{c1}: processing time per piece, min/pc

$N_{\ell 1}$: lot size

p : number of fixtures used. Usually, p=n, however, if $p \neq n$, this means that (n-p) parts are processed consecutively using the same fixture

T_{s1}: set-up time per a lot, min

In the group machining method, the necessary total production time to produce n different parts in a part family can be computed by the processing time of the parts, the set-up time of the group fixture and the set-up time of the adapters used for the processing of each part.

$$T_{m2}=\sum_{i=1}^{n_2} T_{c2(i)}N_{\ell 2(i)}+T_{s2}+\sum_{i=1}^{q} T_{a(i)}$$

where:

- T_{m2}: production time for producing a part family by group technology, min
- n_2 : number of different parts in the part family
- T_{c2}: unit processing time per piece, min
- $N_{\ell 2}$: lot size
- T_{s2}: set-up time for group fixture, min
- q : number of adapters used
- T_a : set-up time per adapter, min

8.2.3 Group Set-up Costs:

One of the main advantages of the group production method over the conventional production method is reduction of set-up costs through the use of group jigs or fixtures for specific part families. Set-up costs may be expressed as follows:

(a) Conventional tooling method:

$$C_{s1} = C_o \sum_{i=1}^{q} \sum_{j=1}^{ni} T_{sij}$$

(b) Group tooling method:

$$C_{s2} = C_o \sum_{i=1}^{q} (T_{si} + \sum_{j=1}^{ni} T_{saij})$$

where:

- C_o : labor rate, \$/min
- g : number of part families
- n : number of jobs (parts) in group i (G_i)
- T_s : Set-up time per a lot, min/lot
- T_{sa}: set-up time per an adapter, min/adapter

9. MANAGEMENT PROBLEMS:

9.1 Personal Problems:

Implementation of a new concept or system calls for a high degree of cooperation between a number of groups or departments in the company. Personnel in design engineering, process planning, production control, inventory control, purchasing, tooling, and the production shops must realize how dependent each group is on the others. This type of communication and cooperation is often lacking, but is absolutely essential if Group Technology is to be implemented successfully. It is a common phenomenon that a great deal of suspicion follows any form of change to an existing pattern of life, whether this change is within an industrial environment or entirely outside of it. Group Technology will not only change the pattern of work environment for many of the employees in a company, but it will also demand a new form of thinking.

As Group Technology has become more accepted, it has also become apparent that efficiencies obtained through Group Technology applications are not determined entirely by its technical characteristics. Additional factors of a social nature are making an important contribution, and these are among the major appeals which Group Technology is making to the behavioral scientist.(20) It offers some solutions to job satisfaction such as worker participation in decision-making as a group, personalized work relationships, variety in tasks, freedom to determine methods, group production methods, etc.

In group production methods when a job is assigned to a machine group/cell, it is processed under given production operations by that one group of workers in the shop. Since all the jobs in a group are confined to a cell of the shop and a small group of workers, the supervisor of the cell can have better control of the job processing. It has been found that Group Technology applications contribute significantly to increase the group morale of workers thus leading to higher productivity and better quality. Because all the parts produced by the group belong to specific part families with common similarities, the workers in the group become very familiar with the work and the operations required. As a result, the efficiency and quality of production are improved when compared to those employees under conventional functional job-shop conditions. Furthermore, in comparison to the conventional job-shop production method where each worker is only aware of his own job, not knowing the related prior or preceding operations, the workers in a group/cell have a closer awareness of and identification with the jobs. There develops a certain group responsibility in quality maintenance, which assist both the product and the attitudes of the workers through higher group morale.

9.2 Appraisal for Implementation:

It is essential to check all possible questions and potential problems before any major undertaking is made for Group Technology implementation. Some major advantages and disadvantages of Group Technology applications are summarized below.

(I) Potential Advantages of Group Technology Applications

A. Design Engineering

1. A well-designed classification and coding system provices an engineering design file for effective product design data and for an efficient retrieval system.

2. A classification scheme enhances the standardization of functional designs and consequently avoids unnecessary design duplication and design variety.

3. An effective design retrieval system brings about design rationalization which results in significant design cost savings, in particular for the design of new parts.

4. Savings resulting from an effective design data retrieval system and design rationalization are immediately achievable.

5. A well-designed classification and coding system provides complete and accurate information needed to form part families having a reasonable and practical number of parts in a particular part family.

6. With the formation of part families a composite part file will be developed for assistance in the design and development of composite components.

7. In the utilization of a classification and coding system, data will be provided for the evlauation of manufacturing capability, producibility tips, value analysis and methods engineering.

8. Part family groupings assist to identify parts that would be advantageously purchased, fabricated, or assembled.

9. Engineering changes may be more easily incorporated into the system.

10. Advanced classification and coding systems can easily become an integral part of a generative computer aided design scheme.

B. Planning and Control of Production

1. A well-designed classification and coding system will provide for the fast and reliable retrieval of process

plans for all types of parts and assemblies, and standard routings for part families.

2. Standard routings for part families lead to effective design of group toolings for family groups, for NC part family programmings, and group set-ups for part families.

3. Part family files provide basic information required for computerized process planning.

4. Production control can be simplified and effectively executed under Group Technology environment.

5. Production scheduling is greatly simplified by scheduling to groups/cells for the processing of part families.

6. In-process inventory can be reduced due to shorter inter-process transportation and less queueing time using group scheduling methods.

7. Correct application of Group scheduling methods results in reduction of total production time.

8. Appropriate scheduling for groups of part families assures the meeting of delivery dates, thus improving the competitive position of the company, ensuring fast delivery and better customer relations.

9. With the use of group scheduling integrated with material requirments planning (MRP), more effective control of production scheduling and inventory for a better stock balance is assured.

10. Reduction of investment in work in progress through diminished in-process inventory is realized.

11. More efficient machine loading through part family grouping and machine group/cell provides a base for the economic justification for expensive machine tools such as NC machine centers and special purpose facilities.

12. Man/machine utilization is usually improved under Group Technology environment.

C. <u>Manufacturing</u>

1. A classification and coding system and/or production flow analysis will provide meaningful data for forming machine groups/cells for part families with resulting opportunities for better manufacturing engineering methods.

2. Part family groupings by manufacturing features provide data for improving the plant layout.

3. Cellular layout of machine groups/cells can improve the floor space utilization.

4. Machine grouping or cell formation for processing part families provides a flow-line, resulting in reduced transportation and in-process waiting time.

5. The composite component concept for part families provides the basis for designing group toolings and set-ups, grouping of machine cells, and programming for NC part families.

6. Utilizing group tooling for processing part families will greatly reduce the total set-up for a part family.

7. The actual production time may be reduced through the effective use of group tooling methods.

8. Tool engineering can be accomplished on a rational basis through the use of effective coded data related to product parts, manufacturing processes, and existing tooling.

9. Tooling costs may be significantly reduced by designing for group toolings and set-ups.

10. Part family grouping and proper group scheduling can make economically feasible the use of sophisticated automatic equipment, NC machines, and machining centers through improved machine-loading efficiency.

11. Parts adaptable for NC machine centers, and multi-station machining centers can be identified from the part family data file.

12. Part family programming for NC machines reduces one of the major cost elements in NC operations.

13. Group Technology applications enables more efficient operation of multi-station manufacturing systems with NC machining centers and industrial robots.

14. Fully- or semi-automatic computer-integrated factories can more successfully operate under Group Technology environment.

D. <u>Management</u>

1. Successful integrated systems brought about by Group Technology applications stimulate more effective cooperation between the departments in a company.

2. Group morale of workers in a group cell is high, resulting in higher productivity.

3. Supervision of a group cell may be more effective since the supervisor has immediate knowledge of the state of jobs in the group.

4. Workers in a group cell tend to be more conscious of and have a better understanding of the operations required, work flow and in-process status. This knowledge leads to higher work quality and efficiency compared to the conventional batch-type operation.

5. Improved industrial relations is brought about by a group production system which can offer more job satisfaction.

6. There can be an overall cost reduction when group technology is effectively applied.

7. Overhead costs will be reduced as a result of better utilization of employees, facilities, and space.

8. Appropriate implementation of Group Technology concept provides economic justification for new capital investment.

9. Reduction in the variety of raw materials and purchased items can result through reduction of the variety of purchased parts and materials by effective part family groupings.

10. A well-designed classification and coding system constitutes a form of universal data which is usable in a variety of departments and can be easily integrated into a master data base.

11. Group Technology provides means for the proper work flow and the establishment of cost centers providing efficient man and machine loading.

12. Group Technology can have a long range favorable impact on all production employees by providing an environment of higher job satisfaction, greater worker involvement in decision making, job enlargement, and job enrichment.

(II) Possible Disadvantages of Group Technology Applications

1. A great deal of expenditure and time may be involved in installing and maintaining a classification and coding system.

2. Additional personnel may be needed to operate and maintain a classification and coding system.

3. The cost of rearranging drawings and files to conform to a new classification and coding system may be expensive and time consuming.

4. The currently available classification and coding systems might not satisfy the various needs for all aspects of the company operations. Therefore, it might be necessary to supplement a present system with additional codes or to develop a new coding system.

5. When cooperation and coordination between the design department and the manufacturing department is poor, Group Technology implementation is usually difficult and not fully successful.

6. Because of different definitions and interpretation of Group Technology concepts, there is no common understanding or approach to Group Technology applications that is currently accepted.

7. When design changes are made, it may be necessary to change existing codes; this could cause difficulty by inadvertently affecting other code-related activities.

8. Balancing the machine loading of all machines and facilities within a group/cell is difficult.

9. There may be a reduction in overall efficiency because of unbalanced machine loading.

10. If one machine breaks down, the whole flow line of the group/cell might stop. That is, a group/cell has less flexibility in responding to unexpected changes.

11. Whenever changes in production methods and production quantity of parts occur, rearrangement of the group/cell might be necessary, and it could be very costly.

12. Large costs may be incurred when reorganizing the plant layout to introduce new cellular layouts.

13. Contrary to the general claims, there may be many difficulties in production planning and control with groups/cells, and it could be difficult to meet the due date in practice.

14. Optimum man/machine utilization for all machines in groups/cells is not always possible.

15. Part family grouping without constraint of a defined time period is not adaptable to effective group scheduling.

16. Reliance on existing production data and routing for part family grouping and for the formation of machine groups/cells by production flow analysis has a definite limitation.

17. Unless well-defined and reliable operation/route sheet information is available, grouping part families, and organizing machine cells by production flow analysis will be ineffective and inaccurate.

18. The optimum results with respect to the total throughput time, product due-date, and the effective utilization of man/machine will not be achieved without suitable analytical techniques for group scheduling.

19. Selecting qualified personnel to be put in charge of Group Technology implementation programs is essential and is difficult at the present time due to lack of qualified personnel.

20. Training supervisory personnel for group/cell with a variety of skills and management capability is costly.

21. Negotiations with workers and their union may be required for Group Technology implementation.

22. There will be some difficulties to adjust to new changes and to resolve various resentments and objections from some personnel and departments in the company.

23. When strong support from top management is lacking, the implementation of Group Technology will be difficult.

24. Because of the long period of pay-off for the successful implementation of Group Technology, top management might become impatient and terminate the project prematurely.

25. For successful implementation of Group Technology, the full cooperation of all departments and personnel concerned is essential. However, it is not always easy to achieve this cooperation.

26. When the Group Technology concept is implemented on a piece-meal basis, the full benefits of Group Technology are not realized. Therefore, whenever possible, it is desirable to implement the Group Technology concept as an integral part of the total system of the company's operation.

REFERENCES

1. Hathaway, H.D., "The Mnemonic Systems of Classification; as Used in the Taylor System of Management", Industrial Management, Vol. LX, No. 3, September 1920, pp. 173-183.

2. Evans, L., "Production Technology Advancements: A Forecast to 1988", Industrial Development Division, Institute of Science & Technology, University of Michigan, 1973.

3. Merchant, M.E., "Delphi-type Forecast of the Future of Production Engineering", CIRP Annals, Vol. 20, September 1971,

4. Wisnosky, D.E., Harris, W.A., & Shunk, O.L., "An Overview of the Air Force Program for Integrated Computer Aided Manufacturing (ICAM)", Technical Paper #MS77-254, Society of Manufacturing Engineers, 1977.

5. Burbidge, J.L., Production Planning, Heinemann, London, 1971.

6. Japan Society for Promotion of Machine Industry, Guide Book for Group Technology Implementation, (Japanese), Tokyo, Japan, 1979.

7. Gombinski, J., "Fundamental Aspects of Component Classification", CIRP Annals, Vol. 17, 1969, pp. 367-75.

8. Thompson, A.R., "Establishing a Classification and Coding System", Technical Paper No. MS76-276, Society of Manufacturing Engineers, 1976.

9. Ham, I. and Reed, W., "Preliminary Survey Results on Group Technology Applications in Metal-Working", Machine Tool Blue Book, May, 1977, pp. 100-108; also Technical Paper No. MS77-328, Society of Manufacturing Engineers, 1977.

10. Petrov, V.A., Flowline Group Production Planning, Business Publications Ltd., London, 1968.

11. Ham, I., Dutkosky, R.J., and Hitomi, K., "Production Scheduling in Group Technology Applications", Technical Paper No. MS76-275, Society of Manufacturing Engineers, 1976, and also the lecture manual by Ham (not published).

12. Hitomi, K. and Ham, I., "Group Scheduling Techniques for Multi-Production Multistage Manufacturing Systems", ASME Transactions, Aug. 1977, pp. 419-422.

13. Ham, I. and Hitomi, K., "Machine Loading and Product-Mix Analysis for Group Technology", ASME Transactions, Vol. 100, Aug. 1978, pp. 370-374.

References (continued):

14. Ham, I. and Hitomi, K., "Machine Loading for Group Technology Applications", CIRP Annals, Vol. 25, August 1977, Hallaway Ltd., Switzerland, pp. 279-281.

15. Ham, I., Ignizio, J. and Sato, N., "Integrated Applications of Group Scheduling and Materials Requirements Planning (MRP)", CIRP Annals, Vol. 27, August 1978, Hallaway Ltd., Switzerland, pp. 471-473.

16. Wisnosky, D.E., Harris, W.A. and Shunk, D.L., "An Overview of the Air Force Program for Integrated Computer Aided Manufacturing (ICAM)", Technical Paper No. MS77-254, Society of Manufacturing Engineers, 1977.

17. CAM-I Training Manual for CAPP, Computer Aided Manufacturing International, TM-77-AMP-01, Arlington, Texas, 1977.

18. Hayner, C., "New Route to NC Productivity: Family Programming", Metalworking Economics, Nov. 1969, pp. 2-10.

19. Mitrafanov, S.P., Scientific Principles of Group Technology, (English Translation), National Lending Library for Science & Technology, United Kingdom, 1966.

20. Burbidge, J.L., Report on a Study of the Effects of Group Production Methods on the Humanization of Work, ILO Report, International Labor Organization, Switzerland, 1974.

21. Opitz, H., "Werkstuckbesch-reibendes Klassitizierung System", W. Girardet, Essen, West Germany 1967, English Translation by Pergaman Press, 1970.

22. Japan Society for Promtion of Machinery Industry, "Group Technology Implementation Guide Book", (Japanese), Tokyo, Japan, 1973 & 1979.

SELECTED REFERENCES (BOOKS AND REPORTS)

(1) Mitrafanov, S.P., "Scientific Principles of Group Technology", (English Translation) edited by J. Grayson, National Lending Library for Science and Technology, U.K., 1966.

Mitrafanov, S.P., Scientific Principles of Group Technology, (Russian), Moscow, 1970.

Mitrafanov, S.P., Scientific Principles of Machine Building Production, (Russian), Moscow, 1976.

(2) Gallagher, C.C. and Knight, W.A., Group Technology, Butterworths, London, 1973.

(3) Burbidge, J.L., The Introduction of Group Technology, John Wiley & Sons, New York, 1975.

(4) Edwards, G.A.B., Readings in Group Technology, Machinery Pub. Co., London, 1971.

(5) DeVries, M.F., Harvey, S.M. and Tipnis, V.A., Group Technology: An Overview and Bibliography, Machinability Data Center, (MDC 76-601), Cincinnati, 1976.

(6) Petrov, V.A., Flowline Group Production Planning, (English translation), Business Publications, Ltd., London, 1968.

(7) Burbidge, J.L., Production Planning, Heineman, London, 1971.

(8) Opitz, H., A Classification System to Describe Workpieces (Parts I & II), Pergaman Press, London, & New York, 1970.

(9) Japanese Society for Promotion of Machine Industry, Guide Book for Group Technology Implementation, (Japanese), April, 1979.

(10) Burbidge, J.L., Proceedings of International Seminar on Group Technology, International Centre for Advanced Technical & Vocational Training, Turin, Italy, 1969.

(11) Ham, I. and Ross, D.T., Integrated Computer-Aided Manufacturing (ICAM) Task-II Final Report, Vol. 1, Group Technology Classification and Coding, USAF Technical Report AFML-TR-77-218, December, 1977.

(12) Burbidge, J.L., Final Report on "A Study of the Effects of Group Production Methods on the Humanization of Work", International Labor Office (ILO), June 1975.

APLICACION DE LA TECNOLOGIA DE GRUPOS

WORK-SHOP MANUAL
FOR
GROUP TECHNOLOGY SEMINAR

Dr. Inyong Ham

Junio 1981

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WORK-SHOP MANUAL

FOR

GROUP TECHNOLOGY SEMINAR

BY

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DEPT. OF INDUSTRIAL & MANAGEMENT SYSTEMS ENGINEERING

PENNSYLVANIA STATE UNIVERSITY

UNIVERSITY PARK, PA 16802

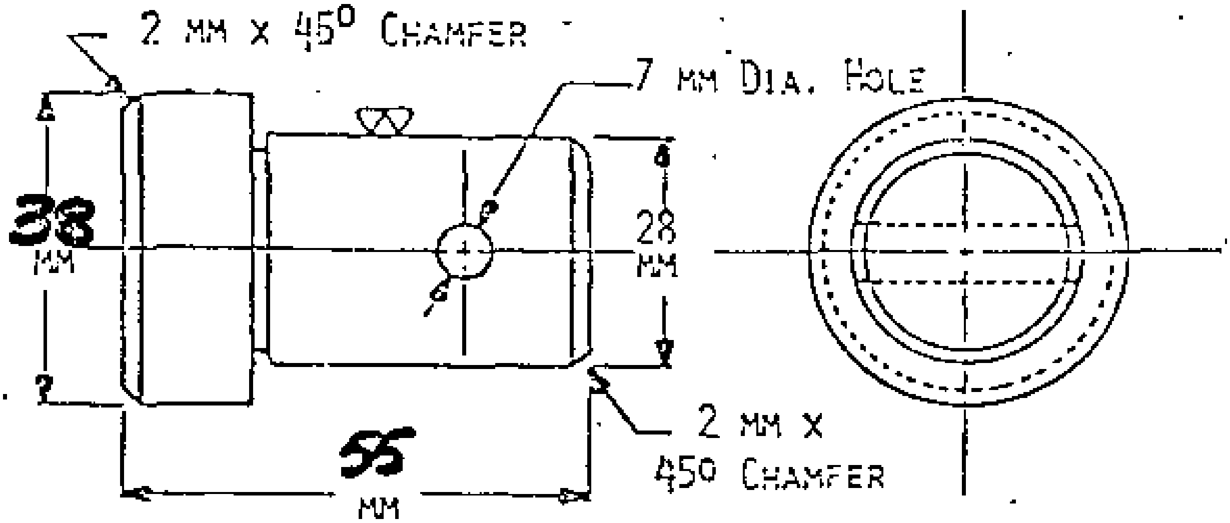
U.S.A.

WORKSHEET FOR CLASSIFICATION AND CODING PRACTICE:

PART NAME .... PIN

MATERIAL .... MILD STEEL, FORGED ROUND BAR

TREATMENT .... SURFACE HARDENING BY CARBORIZING



L = ☐ , D = ☐ , L/D = ☐

OPITZ SYSTEM: ○○○○○ — ○○○○

KC-1 SYSTEM: ○○○○○

KK-1 SYSTEM: ○○○○○○○○○○○○○

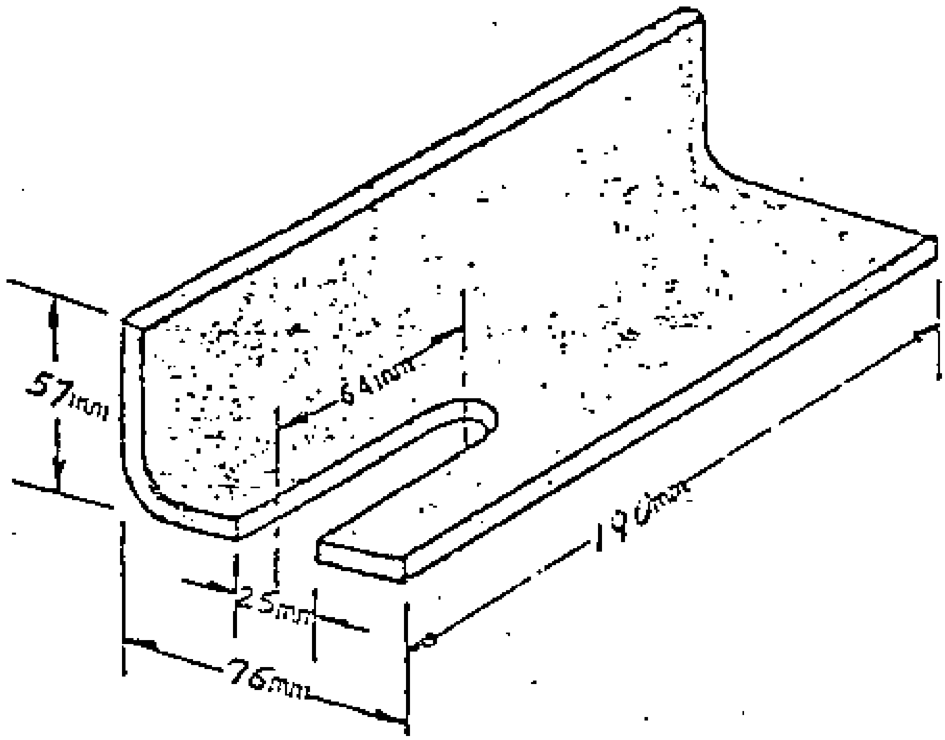
WORKSHEET FOR CLASSIFICATION AND CODING PRACTICE:

PART NAME: BRACKET

MATERIAL: ALUMINUM SHEET (A-2024-0, CLAD), 5MM THICK

TREATMENT: HEAT TREATMENT

OPERATIONS: SHEAR, BREAKFORM, TRIM, DEBURR

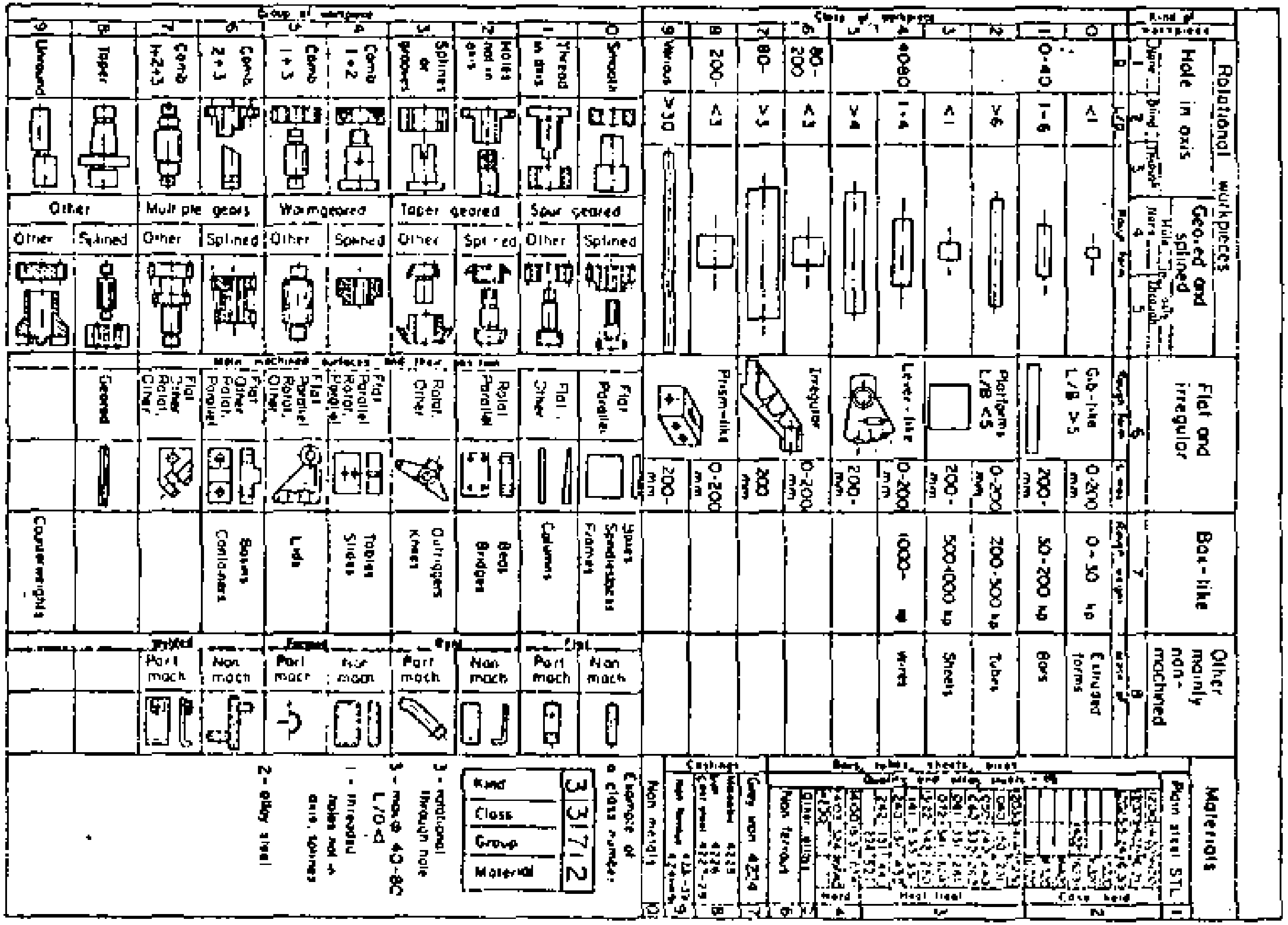


OPITZ ---- ○○○○○ – ○○○○

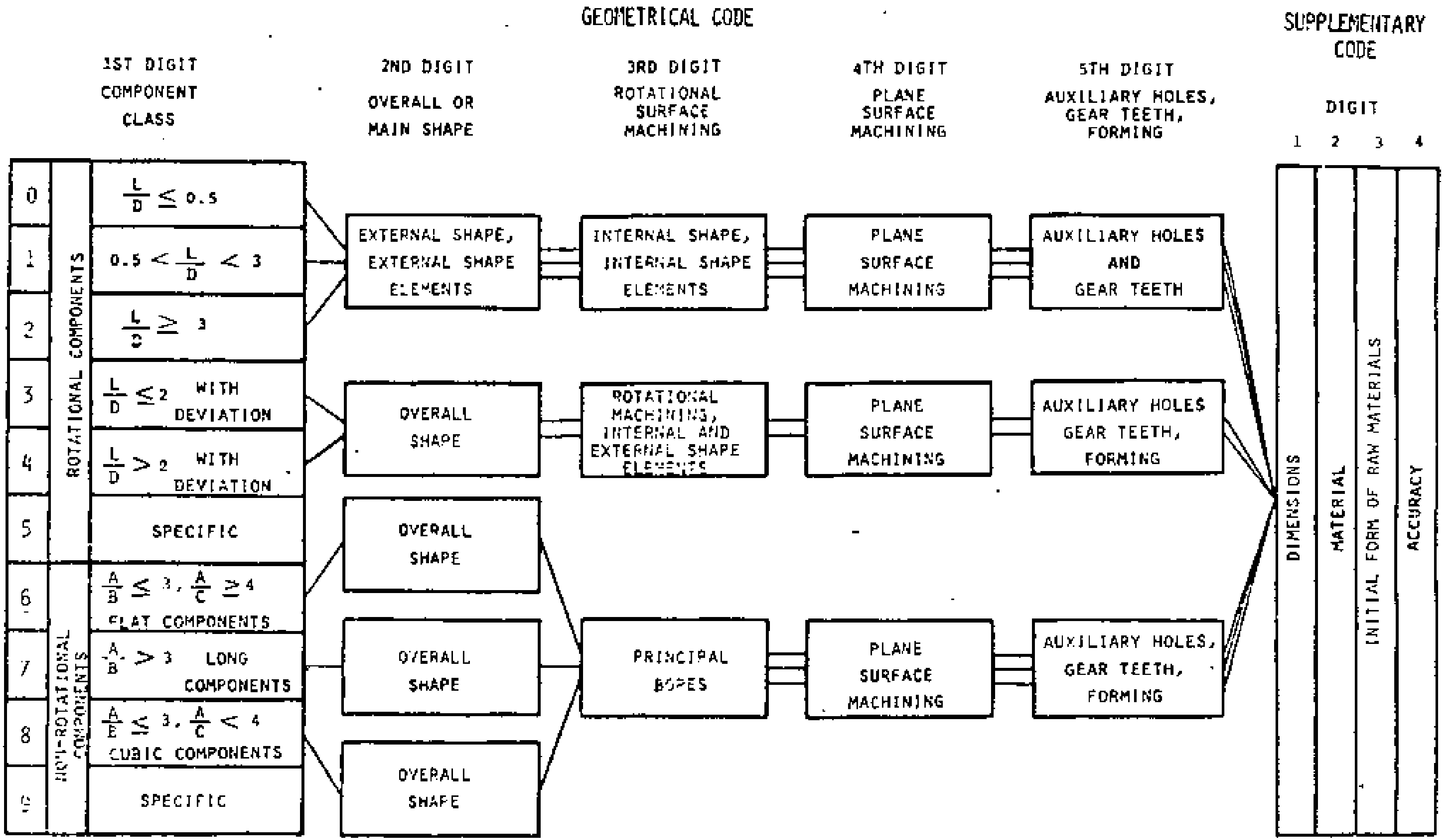
KC-1 ----- ○○○○○

KK-1 ----- ○○○○○○○○○○○○○

VUSO CLASSIFICATION & CODING SYSTEM



OPITZ CLASSIFICATION & CODING SYSTEM (1)



OPITZ CLASSIFICATION & CODING SYSTEM (2)

GEOMETRICAL CODE

	1ST DIGIT	2ND DIGIT	3RD DIGIT	4TH DIGIT	5TH DIGIT
	COMPONENT CLASS	EXTERNAL SHAPE, EXTERNAL SHAPE ELEMENTS	INTERNAL SHAPE, INTERNAL SHAPE ELEMENTS	PLANE SURFACE MACHINING	AUXILIARY HOLE(S) AND GEAR TEETH
0	ROTATIONAL COMPONENTS: $\frac{L}{D} \leq 0.5$	SMOOTH, NO SHAPE ELEMENTS	WITHOUT THROUGH BORE BLIND HOLE	NO SURFACE MACHINING	NO GEAR TEETH: NO AUXILIARY HOLE(S)
1	$0.5 < \frac{L}{D} < 3$	STEPPED TO ONE END: NO SHAPE ELEMENTS	SMOOTH OR STEPPED TO ONE END: NO SHAPE ELEMENTS	EXTERNAL PLANE SURFACE AND/OR SURFACE CURVED IN ONE DIRECTION	AXIAL HOLE(S) NOT RELATED BY A DRILLING PATTERN
2	$\frac{L}{D} \geq 3$	STEPPED TO ONE END OR SMOOTH: WITH SCREWTHREAD	WITH SCREWTHREAD	EXTERNAL PLANE SURFACES RELATED TO ONE ANOTHER BY GRADUATION AROUND A CIRCLE	AXIAL HOLES RELATED BY A DRILLING PATTERN
3		WITH FUNCTIONAL GROOVE	WITH FUNCTIONAL GROOVE	EXTERNAL GROOVE AND/OR SLOT	RADIAL HOLE(S) NOT RELATED BY A DRILLLING PATTERN
4		STEPPED TO BOTH ENDS (MULTIPLE INCREASES): NO SHAPE ELEMENTS	STEPPED TO BOTH ENDS (MULTIPLE INCREASES): NO SHAPE ELEMENTS	EXTERNAL SPLINE AND/OR POLYGON	HOLES AXIAL AND/OR RADIAL AND/OR IN OTHER DIRECTIONS, NOT RELATED
5		WITH SCREWTHREAD	WITH SCREWTHREAD	EXTERNAL PLANE SURFACE AND/OR SLOT AND/OR GROOVE, SPLINE	HOLES AXIAL AND/OR RADIAL AND IN OTHER DIRECTIONS RELATED BY DRILLING PATTERN
6		WITH FUNCTIONAL GROOVE	WITH FUNCTIONAL GROOVE	INTERNAL PLANE SURFACE AND/OR GROOVE	WITH GEAR TEETH: SPUR GEAR TEETH
7		FUNCTIONAL TAPER	FUNCTIONAL TAPER	INTERNAL SPLINE AND/OR POLYGON	BEVEL GEAR TEETH
8		OPERATING THREAD	OPERATING THREAD	EXTERNAL AND INTERNAL SPLINES AND/OR SLOT AND/OR GROOVE	OTHER GEAR TEETH
9		OTHERS (>10 FUNCTIONAL DIAMETERS)	OTHERS (>10 FUNCTIONAL DIAMETERS)	OTHERS	OTHERS

OPITZ CLASSIFICATION & CODING SYSTEM (3)

OPITZ GEOMETRICAL CODING SYSTEM . SUPPLEMENTARY CODE

1st Digit

	DIAMETER "D" or EDGE LENGTH "A"	
	MM's	Inches
0	≤20	≤0.8
1	>20≤50	>0.8≤2.0
2	>60≤100	>2.0≤4.0
3	>100≤180	>4.0≤3.5
4	>100≤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 26.5tonf/in^2 Not heat treated
3	
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

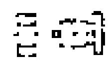
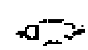
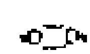
4th Digit

	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)

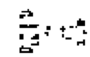
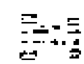
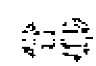
KC-1 CLASSIFICATION & CODING SYSTEM (JAPAN) - (1)

1st Digit				2nd Digit			3rd Digit		
Part Kind Principal Shape of Part				**Part Class** Dimensional Range of Part			**Part Group** Shape Feature		
0	Rotational parts	Concentric hole	None	0	(mm) D≦20		0	Smooth or stepped to one end	Basis
1	Rotational parts	Concentric hole	Blind hole	1	20<D≦50	L/D≦2.5	1	Smooth or stepped to one end	(a) Inconcentric hole
2	Rotational parts	Concentric hole	Through hole	2	20<D≦50	L/D>2.5	2	Smooth or stepped to one end	(1) (b) Straight groove
				3	50<D≦100	L/D≦0.5	3	Smooth or stepped to one end	(a) + (b)
				4	50<D≦100	0.5<L/D≦2	4	Stepped to both ends	Basis
				5	50<D≦100	L/D>2	5	Stepped to both ends	(a) Inconcentric hole
				6	100<D≦200	L/D≦1.5	6	Stepped to both ends	(1) (b) Straight groove
				7	100<D≦200	L/D>1.5	7	Stepped to both ends	(a) + (b)
				8	200<D≦500		8	With shape element (2) such as taper or spherical surface	
				9	D>500		9	Special shape (3)	

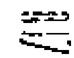
KC-1 CLASSIFICATION & CODING SYSTEM (JAPAN) - (2)

1st Digit			2nd Digit			3rd Digit			
Part Kind Principal Shape of Part			Part Class Dimensional Range of Part			Part Group Shape Feature			
	Rotational Parts		0	(mm) D≤20		0	Smooth or stepped to one end	Basis	
			1	20<D≤50	L/D≤2.5	1		(a) Inconcentric hole	
			2		L/D>2.5	2		(1) (b) Straight groove	
3	Concentric hole with screw thread / Concentric hole with axle	None	3		L/D≤0.5	3		(a) + (b)	
4		Blind hole	4	50<D≤100	0.5<L/D≤2	4	Stepped to both ends	Basis	
			5		L/D>2	5		(a) Inconcentric hole	
			6	100<D≤200	L/D≤1.5	6		(1) (b) Straight groove	
			7		L/D>1.5	7		(a) + (b)	
			8	200<D≤500		8	With shape element (2) such as taper or spherical surface		
			9	D>500		9	Special shape		

KC-1 CLASSIFICATION & CODING SYSTEM (JAPAN) - (3)

1st Digit		2nd Digit			3rd Digit				
Part Kind Principal Shape of Part		Part Class Dimensional Range of Part			Part Group Shape Feature				
	Rotational Part	0	(mm) D≤20		0	Spur & helical gear	Smooth or stepped to one end	Without spline	
	Rotational Part	1	20<D≤50	L/D≤2.5	1	Spur & helical gear	Smooth or stepped to one end	With spline	
	Rotational Part	2	20<D≤50	L/D>2.5	2	Spur & helical gear	Stepped to both ends	Without spline	
	Rotational Part	3	50<D≤100	L/D≤0.5	3	Spur & helical gear	Stepped to both ends	With spline	
	Rotational Part	4	50<D≤100	0.5<L/D≤2	4	Worm gear		Worm	
5	Rotational Part – Gear (4) – Concentric hole with axle – None, Blind hole	5	50<D≤100	L/D>2	5	Worm gear		Worm wheel	
6	Rotational Part – Gear (4) – Concentric hole with axle – Through hole	6	100<D≤200	L/D≤1.5	6	Bevel gear, Hypoid gear		Without spline	
		7	100<D≤200	L/D>1.5	7	Bevel gear, Hypoid gear		With spline	
		8	200<D≤500		8	Special gear		Without spline	
		9	D>500		9	Special gear		With spline	

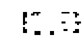
KC-1 CLASSIFICATION & CODING SYSTEM (JAPAN) - (4)

1st Digit		2nd Digit				3rd Digit		
Part Kind Principal Shape of Part		Part Class Dimensional Range of Part				Part Group Shape Feature		
		0	A/B≤3	(6) (mm) A≤200	Lump 	0	Plane (parallel, non-parallel)	
		1	A/C≤4	A>200		1	Parallel hole	
		2	A/B≤3	A≤200	Sheet 	2	Non-parallel hole	
		3	A/C>4	A>200		3	Plane, Parallel hole	
		4	A/B>3	A≤200	Bar (flat square) 	4	Plane, Non-parallel hole	
		5		A>200		5	With turned surface	
		6	A/B≤3	A≤200	Combined of round & square 	6	Concentric screw with axle	
7	Lump, sheet, bar and combined shape	7		A>200		7	With teeth	
		8	A/B>3	A≤200		8	With specially curved surface	
		9		A>200		9	Others	

KC-1 CLASSIFICATION & CODING SYSTEM (JAPAN) - (5)

1st Digit		2nd Digit			3rd Digit	
Part Kind Principal Shape of Part		Part Class Dimensional Range of Part			Part Group Shape Feature	
		0	W≤20 (kg) (7)		0	Main axle head
		1	20<W≤70		1	Main body
		2	70<W≤200	A/B≤3	2	Column Housing
		3		A/B>3	3	Bed Base
		4	200<W≤500	A/B≤3	4	Cross rail Arm Bracket
		5		A/B>3	5	Table Cross slide
		6	500<W≤1000	A/B≤3	6	Cover
		7		A/B>3	7	Pan Tub Tank
8	Box shaped hollow	8	1000<W≤2000		8	Plummet
		9	W>2000		9	others

KC-1 CLASSIFICATION & CODING SYSTEM (JAPAN) - (6)

1st Digit		2nd Digit			3rd Digit			
Part Kind Principal Shape of Part		Part Class Dimensional Range of Part			Part Group Shape Feature			
		0		Rolled material	0	Straight parts	Without machining	
		1		Round bar material	1	Straight parts	Partially machined	
		2		Square bar material	2	Parts to be bent	Without machining	
		3		Tubing material	3	Parts to be bent	Partially machined	
		4		Thin sheet	4	Parts to be squeezed	Without machining	
		5		Wire	5	Parts to be squeezed	Partially machined	
		6	Precisely formed	Casting	6	Parts to be welded	Without machining	
		7	Precisely formed	Forging	7	Parts to be welded	Partially machined	
		8	Precisely formed	Sintering	8	Parts to be formed precisely	Without machining	
9	Other parts almost raw material without machining	9		Wing shaped (specially ordered), Others	9	Parts to be formed precisely	Partially machined	

KC-1 CLASSIFICATION & CODING SYSTEM (JAPAN) - (7)

4th Digit	Material Raw Material				5th Digit	Portion to be Machined (11) with High Accuracy	
0	Ferrous			Ordinary Cast Iron	0	Shaving	Without High Accuracy (12)
1	Ferrous			Special Cast Iron, Cast Steel, Sintered Alloy Steel	1	Shaving	Turned Surface (a) (internal, external & end surface)
2	Ferrous	Steel	Non-Forged	Non-Refined (10)	2	Shaving	Plane (b) (13)
3	Ferrous	Steel	Non-Forged	Refined	3	Shaving	Non-concentric hole (c)
4	Ferrous	Steel	Forged	Non-Refined	4	Shaving	(a) + (b)
5	Ferrous	Steel	Forged	Refined	5	Shaving	(a) + (c)
6	Non-Ferrous			Copper & its Alloys	6	Shaving	(b) + (c)
7	Non-Ferrous			Light Alloys	7	Shaving	(a) + (b) + (c)
8	Non-Ferrous			Others	8	Grinding (14)	
9	Non-Metals				9	Special Processing (Electric discharge, etc.)	

JAPANESE KK-1 CLASSIFICATION AND CODING SYSTEM

(Table 1...to...Table 6)

Table 1

Fundamental Construction

Column	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
	Parts Name (function) in form of Matrix		Materials in form of Matrix		Main Dimentions			Geometrical shapes and machining					
Position	General Classification	Detail Classification	General Classification	Detail Classification	(R) L=Length (N) A=Length	(R) D=Diameter (N) B=Width	Primary Shapes, Ratio of Main Dimensions	(R) External Shape (N) Plane Surface machining	(R) Internal Shape (N) Principal bore, rotational surf. machining	(R) Plane Surf. machining (N) Special machining	(R) Aux. holes, other machining (N) -ditto-	Accuracy	Main Machine Tool to be used at primary stage of machining
0	As per attached Table 2 (Matrix)	-ditto-	As per attached Table 3 (Matrix)	-ditto-	separate table for R or N for R Table 4 (R) for N Table 4 (N)	-ditto-	-ditto-	separate table for R or N for R Table 5 (R) for N Table 5 (N)	-ditto-	-ditto-	-ditto-	common table for R and N Table 6	-ditto-
1													
2													
3													
4													
5													
6													
7													
8													
9													

R=rotational components

N=non-rotational components

Table 2 (Matrix)

Classification of Parts Name (Function)

I \ II			0	1	2	3	4	5	6	7	8	9	II / I
0	Rotational Components (R)	Gears	Spur Gears Helical Gears	Internal Gears	Bevel Gears	Hypoid Gears	Worm Gears	Screw Gears	Sprocket Wheels	Combination Gears, Special Gears	Round Vessels	Others	Vessels, Containers or Others
1		Shafts, Spindles	Spindles, Arbors, Main Spindles	Counter Shaft	Lead Screws	Screwed Shaft	Round Rods	Eccentric Shafts, Crank Shafts	Spline Shaft	Cross Shafts or Joints, Others	Round Columns	Round Covers, & Others	Bodies
2		Main Driving or Moving Parts	Pulleys	Clutches	Brakes	Impellers	Pistons	Round Tables	Others	Flanges	Chucks	Labyrinth Seals, & Others	Supporting Parts
3		Guiding Parts	Sleeves, Bushes	Bearing Metals	Bearings	Rollers	Cylinders	Others	Dial Plates	Index Plates	Cams	Others	Controlling Parts
4		Fixing Parts	Collars	Sockets Spacers	Pins	Fastening Screws	Others	Handles	Spools	Sound Links	Screws	Others	Aux. Driving or Moving Parts
5	Non-Rotational Components (N)	Fixing Parts	Covers	Jibs, Wedges	Plates	Fastening Screws	Others	Arms Levers	Square Links	Cross head	Screws	Others	Aux. Driving or Moving Parts
6		Guiding Parts	Adjusting Wedges for Guide Surface	Rails	Bearing Metals for Straight Movement	Others	Dogs	Stoppers	Nuts	Gauges	Cams	Others	Controlling Parts
7		Main Driving or moving Parts	Saddles	Square Tables	Others	Brackets	Holders	Blocks	Stays	Trunnions		Others	Supporting Parts
8		Shafts, Rods	Square or Rectangular Shafts	Square Rods, & Others	Cases	Housings	Chassis	Columns	Beds	Bases		Others	Bodies
9		Gears	Racks	Non-circular Gears, & Others	Vessels, Containers	Oil Tank	Traps, Conduits	Pipings	Valves	Counter Weight & Other Weights		Others	Vessels, Containers & Others

Table 5 (Matrix)

Classification of Materials

III \ IV		0	1	2	3	4	5	6	7	8	9
0	Cast Iron	Gray Cast Iron ≤ FC25	Gray Cast Iron ≥ FC30	Nodular Graphite C. I. (FCD)	Malleable C. I. (FCM, P, W)	Chilled C. I.	Alloy C. I.	Carbon Cast Steel	Alloy Cast Steel	Sintered Iron	Others
1	Ordinary Steels, $\sigma_B \leq 42Kg/mm^2$, Non-heat-treatment	Round bar	Square bar	Sections	Pipes	Plate thin	Plate thick	Cold forgings	Hot forgings	Welded	Others
2	Ordinary Steels, $\sigma_B \leq 42Kg/mm^2$, Heat-treatment	– do –	– do –	– do –	– do –	– do –	– do –	– do –	– do –	– do –	– do –
3	Ordinary Steels, $\sigma_B \geq 42Kg/mm^2$, Non-heat-treatment	– do –	– do –	– do –	– do –	– do –	– do –	– do –	– do –	– do –	– do –
4	Ordinary Steels, $\sigma_B \geq 42Kg/mm^2$, Heat-treatment	– do –	– do –	– do –	– do –	– do –	– do –	– do –	– do –	– do –	– do –
5	Steels, surface treated	Hi-Freq. Elect. or Flame Hardening Non Forging	Hi-Freq. Elect. or Flame Hardening Forging	Carbonizing Non Forging	Carbonizing Forging	Nitriding Non Forging	Nitriding Forging	Other heat treatment Non-Forging	Other heat treatment Forging	Plating or other surf. treatment Non forging	Plating or other surf. treatment Forging
6	Other Special Steel, Cutting tool materials	Stainless steel	Chrome steel	(Ni) Cr (Mo) steel	Heat resist-steel	High carbon tool steel	Alloy tool steel	High speed steel	Sintered Carbide (Tungsten Carbide etc.)	Ceramics	Others.
7	Copper & its alloys	Copper lump Copper bar	Copper plate	Copper tube	Brass lump Brass bar	Brass plate	Brass tube	Brass casting	Bronze	Special bronze	Others
8	Light metals	Al. lump Al. bar	Al. plate	Al. tube	Al. casting	Duralumin lump Duralumin bar	Duralumin plate	Duralumin tube	Duralumin casting	Mg. alloys	Others
9	Other metals or non-metals	Pb	Sb	Sn	Zn	Other metals	Bakelite	Nylon	FRP, Other plastics	Woods, Papers	Glass, Inorganic materials

Table 4 (R)

Classification of Main Dimensions, Primary Shapes & Ratio of Main Dimensions

Column	V	VI	VII	
Position	Main Dimensions		Primary Shapes, Ratio of Main Dimensions L/D	
	Max. Length L mm	Max. Diameter D mm		
0	L ≤ 16	D ≤ 16	Rotational components	L/D ≤ 0.5
1	16 < L ≤ 50	16 < D ≤ 50		0.5 < L/D ≤ 1
2	50 < L ≤ 100	50 < D ≤ 100		1 < L/D ≤ 1.5
3	100 < L ≤ 160	100 < D ≤ 160		1.5 < L/D ≤ 2
4	160 < L ≤ 240	160 < D ≤ 240		2 < L/D ≤ 2.5
5	240 < L ≤ 360	240 < D ≤ 360		2.5 < L/D ≤ 3
6	360 < L ≤ 600	360 < D ≤ 600		3 < L/D ≤ 10
7	600 < L ≤ 1000	600 < D ≤ 1000		10 < L/D
8	1000 < L ≤ 2000	1000 < D ≤ 2000	Rotational components with deviation	L/D ≤ 2
9	2000 < L	2000 ≤ D		2 < L/D

Table 4 (B)

Classification of Main Dimensions, Primary Shape & Ratio of Main Dimensions

Column	V	VI	VII		
Position	Main Dimensions (A ≧ B) Edge Length A mm	Main Dimensions (A ≧ B) Width B mm	Primary Shapes, Ratio of Main Dimensions (A B C) C=thickness mm, W=weight kg		
0	A ≦ 16	B ≦ 16	Small and Medium Size Components W ≦ 20 kg	Cube Components	A/B ≦ 3, A/C ≦ 4
1	16 < A ≦ 50	16 < B ≦ 50		Flat Components	A/B ≦ 3, A/C ≦ 4
2	50 < A ≦ 100	50 < B ≦ 100			Formed component
3	100 < A ≦ 160	100 < B ≦ 160		Long Components	A/B > 3
4	160 < A ≦ 240	160 < B ≦ 240			Formed component
5	240 < A ≦ 360	240 < B ≦ 360		Combination Shapes	
6	360 < A ≦ 600	360 < B ≦ 600	Large Size Components W > 20 kg	Light	20 kg < W ≦ 100 kg
7	600 < A ≦ 1000	600 < B ≦ 1000		Middle	100 kg < W ≦ 250 kg
8	1000 < A ≦ 2000	1000 < B ≦ 2000		Heavy	250 kg < W ≦ 1000 kg
9	2000 < A	2000 < B		Extra Heavy	1000 kg < W

Table 5 (B)

Classification of Geometrical Shape and Machining

Column	VIII		IX		X	XI	
	Geometrical Shape and Machining *						
Position	External Shape Elements		Internal Shape Element		Plane Surface Machining	Auxiliary Hole, Other Machining Process, for Inst. Forging etc.	
0	smooth, no shape elements		without through bore, blind hole		no surface machining	no auxiliary holes, no special machining	
1	Stepped to one end or smooth	no shape elements	Stepped to one end or smooth	no shape elements	external plane surface or two or more plane surfaces	Axial hole(s)	one hole or not related by a drilling pattern
2		with functional groove		with functional groove	Curved external plane surface or end surface		related by a drilling pattern
3		with screw threaded		with screw treaded	external surface or end surface with groove or split	Radial hole(s)	one hole or not related by a drilling pattern
4	Stepped to both ends (multiple increased)	no shape element	Stepped to both ends (multiple increased)	no shape elements	external spline		related by adrilling pattern in axial direction
5		with functional groove		with functional groove	outer surface a/o end surface with plane surface, groove, slit, spline		related by a drilling pattern in radial direction
6		with screw threaded		with screw threaded	internal plane surface or groove or two or more plane surfaces	hole(s) axial and radial	
7	functional taper or spherical shape		functional taper or spherical shaped part		internal spline	hole(s) in other directions, deep hole(s), hole(s) with special machining	
8	operating thread		operating thread		external, internal and end surface with groove, split and spline	Plastic forming	no auxiliary hole(s)
9	segment and others		segment and others		others		with auxiliary hole(s)

* except gear cutting

Table 5 ([illegible])

Classification of Shape Detailes & Kinds of Machining Processes

Column	VIII	IX	X	XI
Position	Shape Detailes & Kind of Machining Processes			
	Plane Surface Machining	Rotational Surface	Surface with Special Machining	Auxiliary hole(s)
0	no surface machining	no rotational machining or bore(s)	no special machining	no auxiliary hole(s)
1	functional chambers (e.g. welding preparation)	one principal bore, smooth	gear cutting	Auxiliary hole(s): drilled in one direction only
2	one or stepped plane surfaces	one principal bore stepped to one or both ends	machining curved surface	Auxiliary hole(s): * drilled in one direction and opposite
3	stepped plane surfaces at right angle a/o opposite	one principal bore with shape elements	plastic forming	Auxiliary hole(s): * drilled in more than one direction (2 directional)
4	component with uniform cross section	several principal bores parallel	(1) + (2)	Auxiliary hole(s): * drilled in more than one direction (3 directional)
5	groove a/o slit	* several principal bores, other than parallel	(1) + (3)	Auxiliary hole(s): (1) a/o (2) + inclined hole
6	(4) + (5)	with extend cylindrical surface: one principal bore	(2) + (3)	Auxiliary hole(s): (3) + inclined hole
7	one guide surface	with extend cylindrical surface: several principal bores	(1) + (2) + (3)	Auxiliary hole(s): (4) + inclined hole
8	several guide surfaces	annular surfaces annular grooves	other machining or forming	Auxiliary hole(s) with special drilling: drilled in one direction only
9	others	others	[(1) + (7)] + (8)	Auxiliary hole(s) with special drilling: drilled in more than one direction

* do not mean, each axis of holes meet at one point.

Table 6

Classification of Accuracy and Main Machine Tools to be used at Primary Stage of Machining

Column	XII		XIII
Position	Accuracy		Main machine tools to be used at primary stage of machining (Principal each tool among GT line)
0	no accuracy specified		lathe (chucking machine)
1		internal a/o external surface (cylindrical)	lathe (centre-type turing machine)
2	cutting	plane surface	vertical boring & turning mill, facing lathe
3		(1) + (2)	horizontal milling machine, production milling machine
4		internal a/o external surface (cylindrical)	vertical milling machine
5	grinding	plane surface	shaper, slotter
6		(4) + (5)	planer, planomiller
7	higher accuracy surface finishing, including surface finishing with hand operating		horizontal boring and milling machine
8	high accuracy positioning		drilling machine
9	high accuracy surface finishing with special machining		machining center, single purpose machine tools, others

WORKSHEET FOR PRODUCTION FLOW ANALYSIS

MACHINE \ PART NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
L	✓	✓		✓	✓		✓	✓	✓		✓	✓		✓	✓		✓	✓	✓	✓
M_1	✓	✓	✓		✓	✓	✓		✓		✓		✓	✓		✓				✓
M_2			✓	✓				✓		✓		✓	✓		✓		✓	✓	✓	
D	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓		✓
G	✓	✓	✓	✓		✓			✓			✓	✓		✓			✓		✓

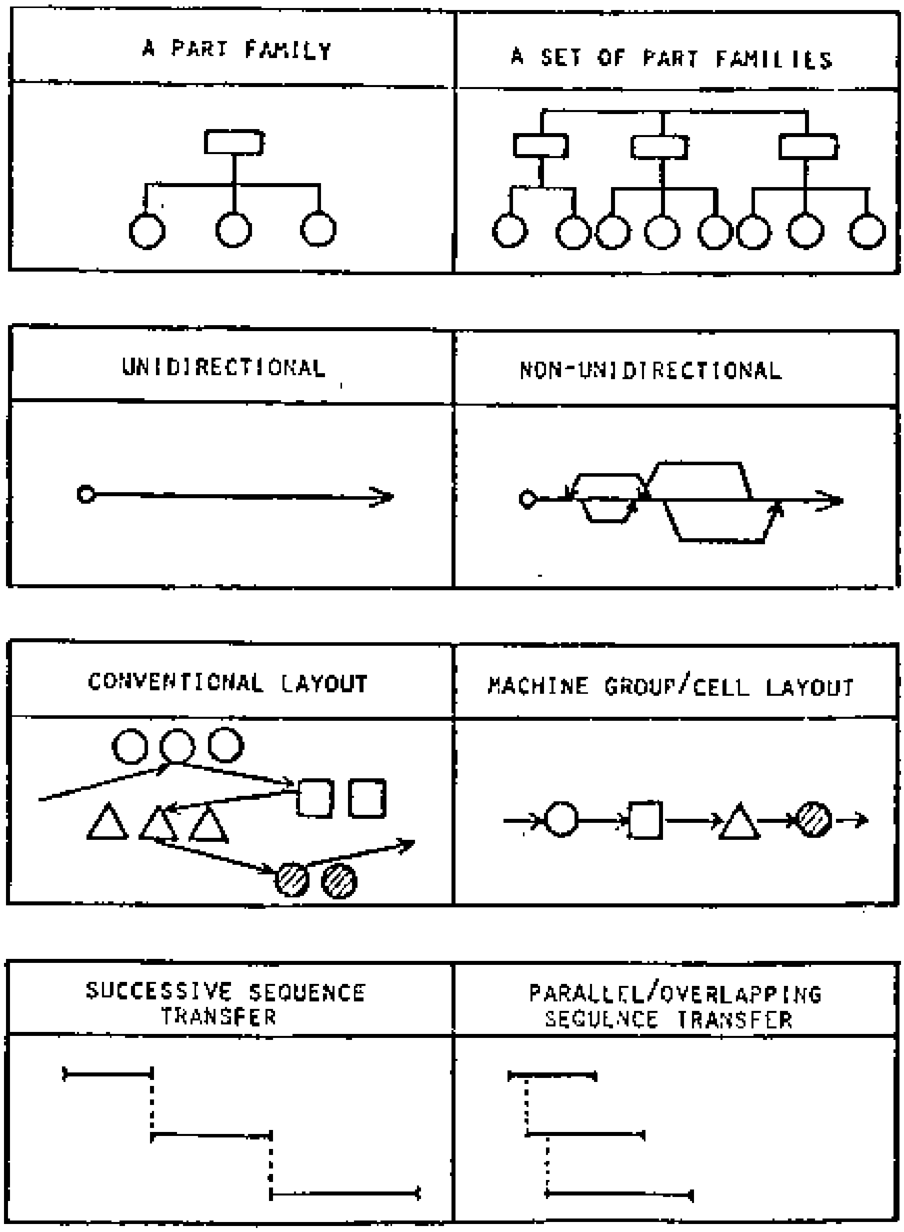
BASIC DATA FOR MACHINE LOADING ANALYSIS

PT. NO.	CODE NO.	LOT SIZE	TURNING S/T	TURNING M/T	MILLING(I) S/T	MILLING(I) M/T	MILLING(II) S/T	MILLING(II) M/T	DRILLING S/T	DRILLING M/T	GRINDING S/T	GRINDING M/T
1	010 120	115	20	9	13	5	-	-	15	3	6	20
2	010 124	30	15	12	15	7	-	-	23	6	7	15
3	002 123	55	-	-	13	5	16	8	23	12	6	10
4	111 121	105	33	14	-	-	15	6	25	8	8	9
5	010 120	25	23	10	10	8	-	-	-	-	-	-
6	002 123	10	-	-	15	8	-	-	18	10	8	23
7	011 123	5	15	9	11	9	-	-	15	15	-	-
8	110 124	12	15	15	-	-	10	9	24	11	-	-
9	011 124	18	23	12	10	8	-	-	-	-	5	23
10	002 120	35	-	-	-	-	13	6	30	11	-	-
11	011 123	10	23	14	12	6	-	-	24	7	-	-
12	112 122	10	30	8	-	-	12	10	18	10	7	15
13	001 123	21	-	-	11	7	10	9	25	11	6	15
14	011 123	61	15	8	10	5	-	-	24	4	-	-
15	111 121	4	15	17	-	-	12	9	-	-	5	18
16	002 120	5	-	-	10	6	-	-	20	13	-	-
17	110 120	24	23	10	-	-	10	8	20	11	-	-
18	111 123	46	30	11	-	-	11	17	30	7	5	10
19	111 120	61	20	9	-	-	13	5	-	-	-	-
20	012 124	10	15	10	11	9	-	-	20	5	5	18

COMPUTATION SHEET FOR MACHINE LOADING ANALYSIS

OPERATION: ______________________________ PART FAMILY __________

Part No.	Code No.	Lot Size (N_l)	Setup Time (S_t)	Machining Time (M_t)	$(M_t) \times (N_l)$	$(M_t) \times (N_l) + (S_t)$



A PART FAMILY
A SET OF PART FAMILIES
UNIDIRECTIONAL
NON-UNIDIRECTIONAL
CONVENTIONAL LAYOUT
MACHINE GROUP/CELL LAYOUT
SUCCESSIVE SEQUENCE TRANSFER
PARALLEL/OVERLAPPING SEQUENCE TRANSFER

GROUP SCHEDULING ALGORITHM FOR HEURISTIC SOLUTIONS

(A) RULE-I:

(a) For those jobs that the ($\Sigma T' - \Sigma T$) value is positive or zero, i.e., ($\Sigma T' - \Sigma T$) $\geq$ 0, the job sequence is in ascending order of the ΣT values.

(b) For those jobs with the ($\Sigma T' - \Sigma T$) value negative; ($\Sigma T' - \Sigma T$) < 0, the job sequence is in descending order of the $\Sigma T'$ values.

Symbolically: the job sequence is assigned

When ($\Sigma T' - \Sigma T$) $\geq$ 0, (ΣT) ↑

($\Sigma T' - \Sigma T$) < 0, ($\Sigma T'$) ↓

(B) RULE-II:

Also the job sequence is assigned in descending order based on the numerical values of ($\Sigma T' - \Sigma T$).

Symbolically: ($\Sigma T' - \Sigma T$) ↓

(C) SPECIAL CASES FOR RULE-I & RULE II:

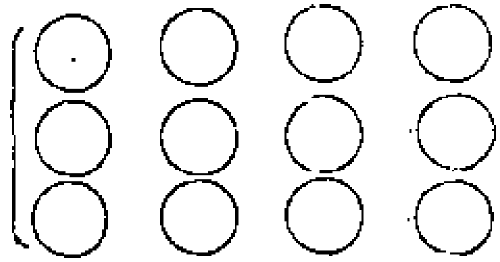
(a) If the different values of ($\Sigma T' - \Sigma T$) are exclusively positive or negative, RULE-I alone will provide a unique solution for an optimum job sequence, and RULE-II is not used.

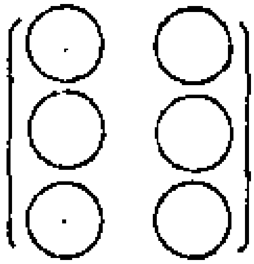
(b) Should there be several identical (ΣT) or ($\Sigma T'$) values, RULE-II is used to determine the proper sequence for the identical values.

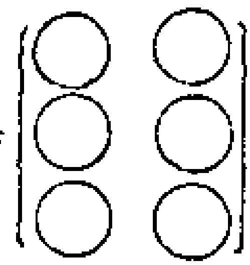
(D) RULE-III and RULE-IV:

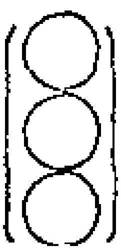
RULE-I and RULE-II are applied to the problems where each job is processed through a set of machines/operations in the same order. However, when jobs are processed with certain operations omitted or missing for some jobs, RULE-III and RULE-IV must also be applied. RULE-III and RULE-IV are essentially the same as RULE-I and RULE-II respectively, except that to apply RULE-III and RULE-IV, each row in the sectioned time matrix ΣT and T' is averaged. These average time values; $\bar{T}$ and $\bar{T}'$, are found by dividing the sectioned time matrices of ΣT and $\Sigma T'$ by the number of operations performed in each sectioned matrix respectively.

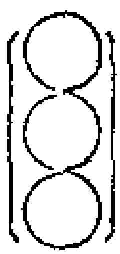
JOB	MACHINE/OPERATION			
	m_1	m_2	m_3	m_4
J_1	17	13	15	10
J_2	8	6	21	7
J_3	16	14	15	4

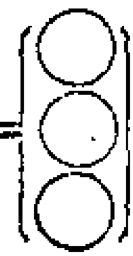
$A =$ 

$T =$ 

$T' =$ 

$\Sigma T =$ 

$\Sigma T' =$ 

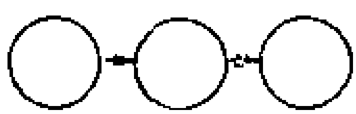
$(\Sigma T' - \Sigma T) =$ 

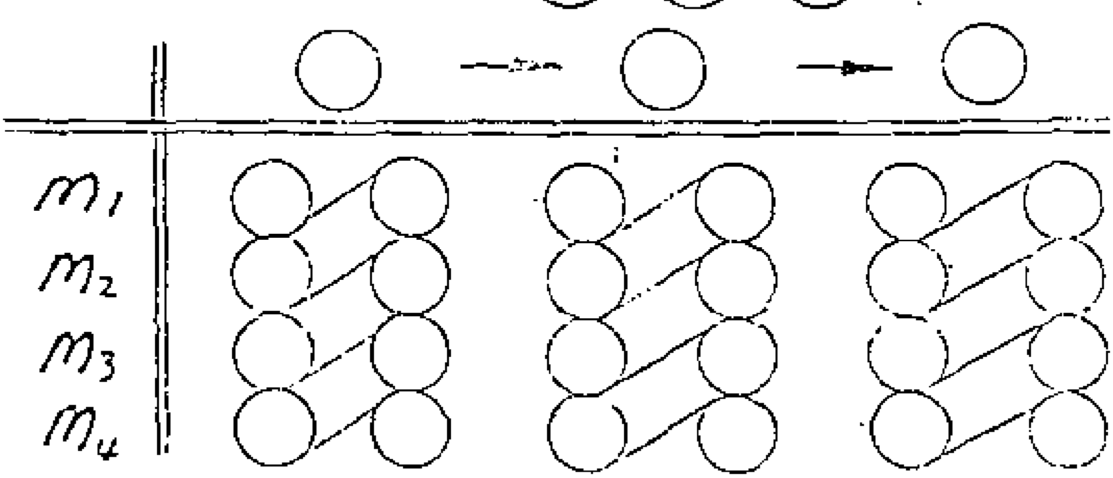
Rule-I:

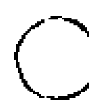
$(\Sigma T' - \Sigma T) \geq 0, (\Sigma T)\uparrow \quad (\Sigma T' - \Sigma T) < 0, (\Sigma T')\downarrow$

Rule-II:

$(\Sigma T' - \Sigma T)\downarrow$

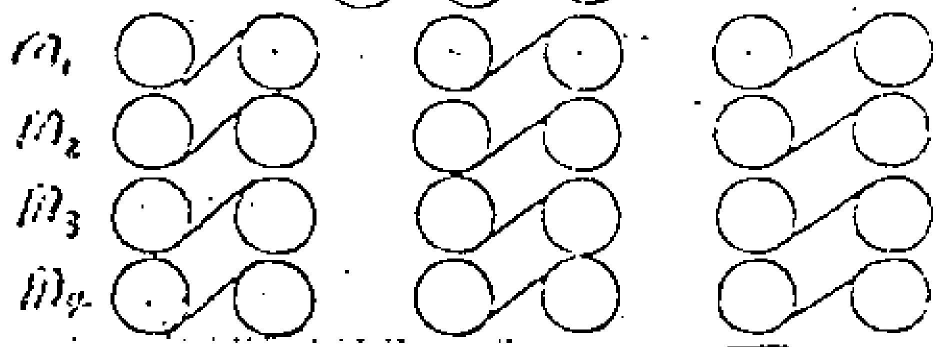




OPTIMUM TOTAL CYCLE TIME: 

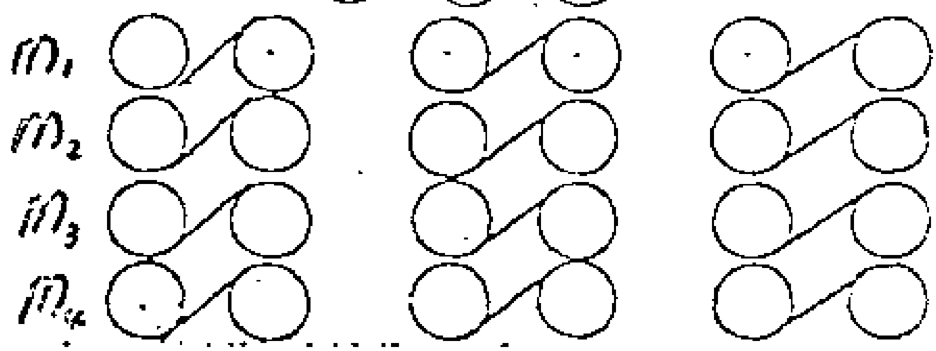
WORKSHEET FOR OTHER ALTERNATIVE SEQUENCES:

OPERATION SEQUENCE: (J) → (J) → (J)



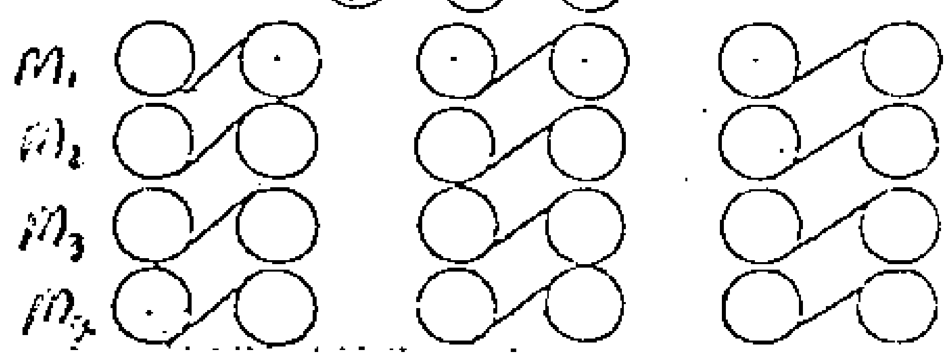
THE CUMULATIVE CYCLE TIME WILL BE ( ) HRS.

OPERATION SEQUENCE: (J) → (J) → (J)



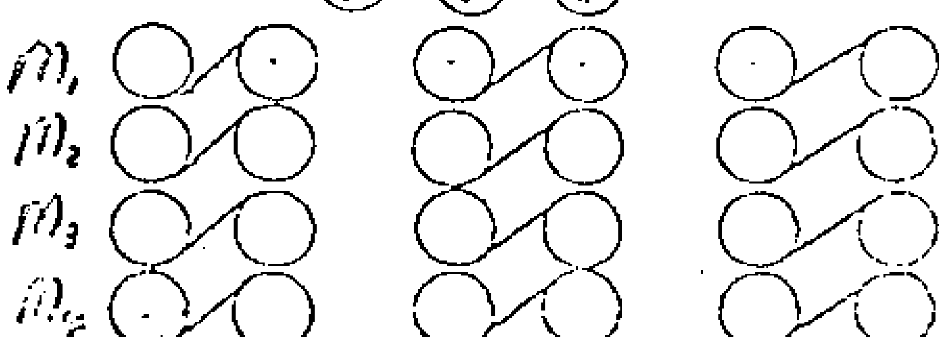
THE CUMULATIVE CYCLE TIME WILL BE ( ) HRS.

OPERATION SEQUENCE: (J) → (J) → (J)



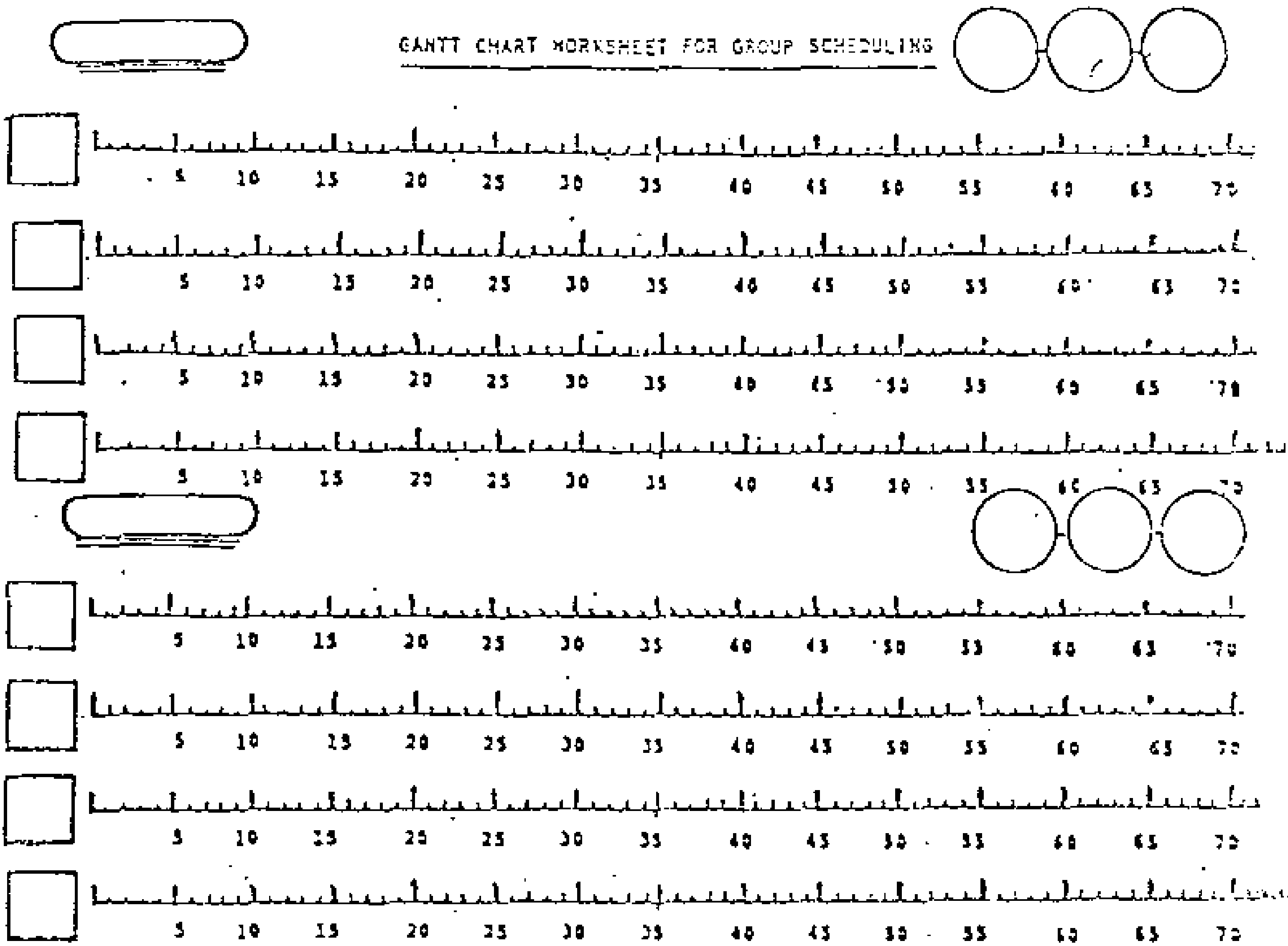
THE CUMULATIVE CYCLE TIME WILL BE ( ) HRS.

OPERATION SEQUENCE: (J) → (J) → (J)



THE CUMULATIVE CYCLE TIME WILL BE ( ) HRS.

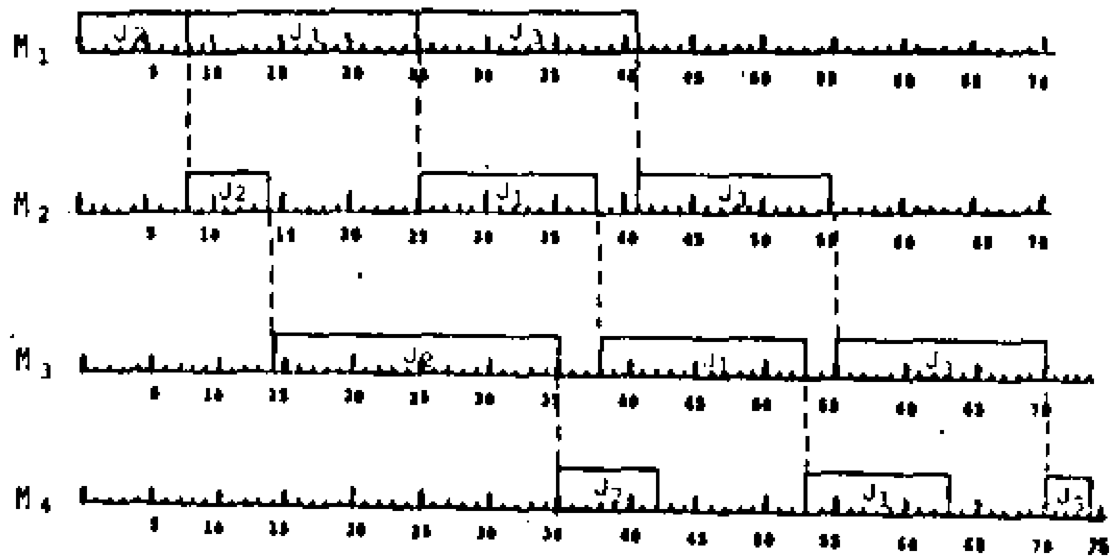
GANTT CHART WORKSHEET FOR GROUP SCHEDULING



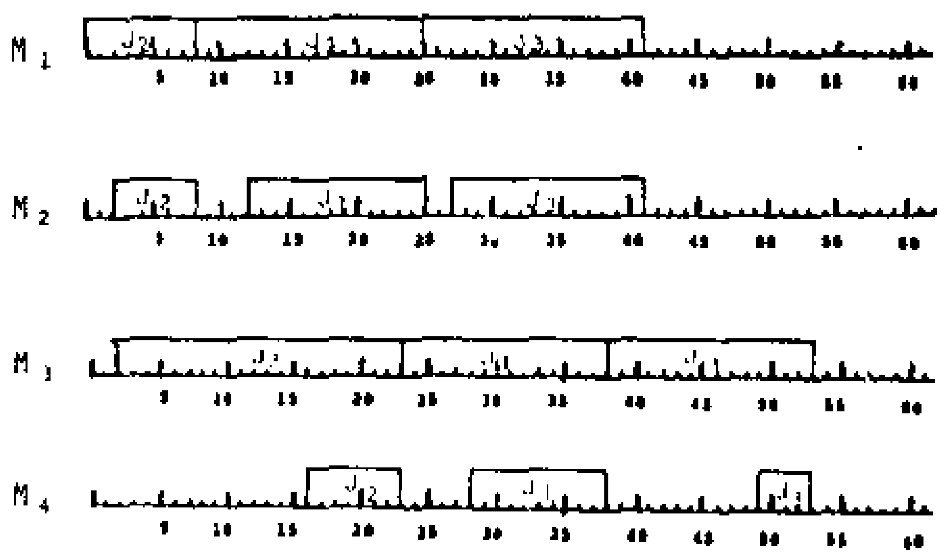
TIME (HOURS)

COMPARISON OF TOTAL THROUGHPUT TIMES BY GANTTS CHARTS

(A) SUCCESSIVE SEQUENTIAL TRANSFER (J_2-J_1-J_3) 74 HRS.



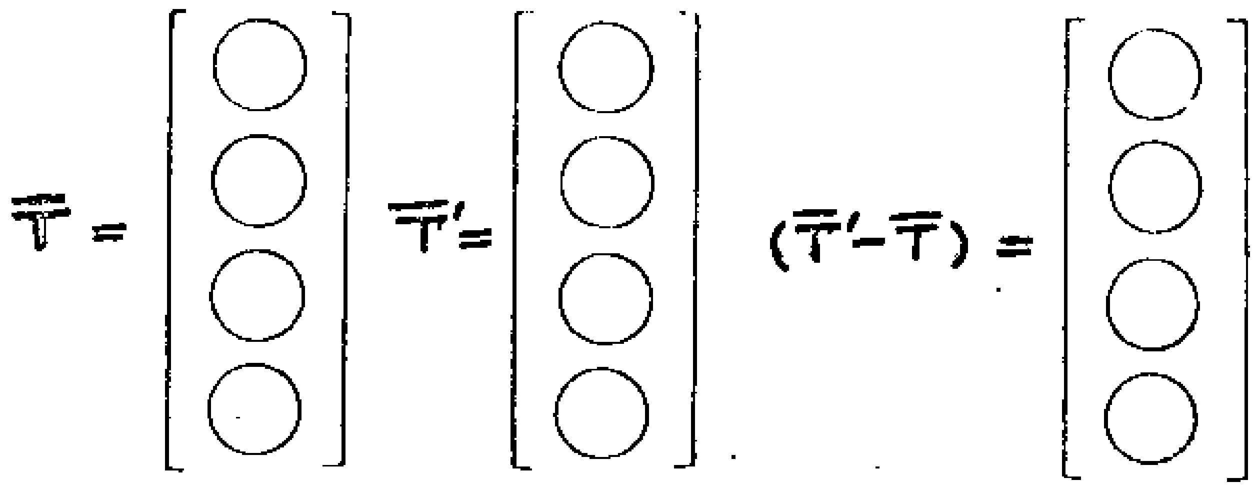
(B) PARALLEL SEQUENTIAL TRANSFER (J_2-J_1-J_3) 53 HRS.

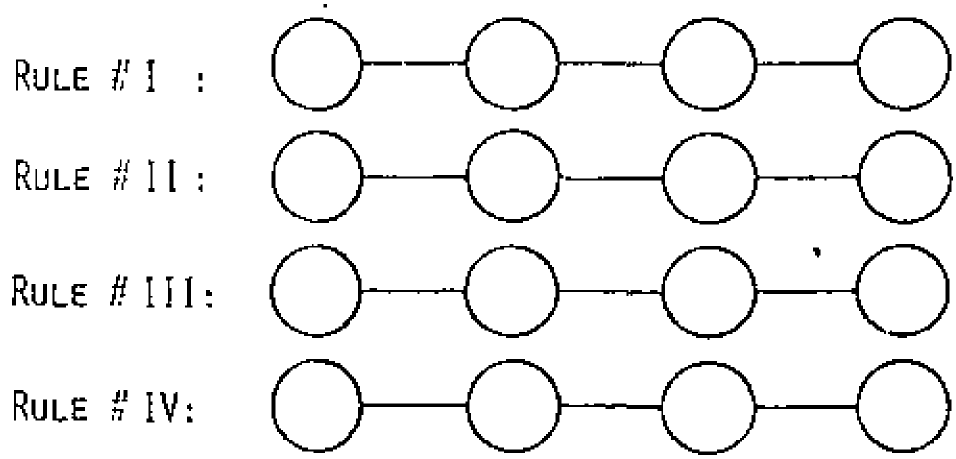


PART NUMBER	OPERATION (MACHINE) NUMBER (HRS)					
	M_1	M_2	M_3	M_4	M_5	M_6
J_1	8	-	5	4	7	2
J_2	3	15	5	9	-	10
J_3	6	2	-	-	8	6
J_4	5	11	2	6	-	7

$$T = \begin{bmatrix} \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc \end{bmatrix} \quad T' = \begin{bmatrix} \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc \end{bmatrix}$$

$$\Sigma T = \begin{bmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \end{bmatrix} \quad \Sigma T' = \begin{bmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \end{bmatrix} \qquad (\Sigma T' - \Sigma T) = \begin{bmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \end{bmatrix}$$





TOTAL CYCLE TIMES:

	SUCCESSIVE		PARALLEL	
RULE # I :		HRS.		HRS.
RULE # II :		HRS.		HRS.
RULE # III :		HRS.		HRS.
RULE # IV :		HRS.		HRS.

TOTAL PROCESSING TIME BY THE RULE # I & II SEQUENCE:

M_1

M_2

M_3

M_4

M_5

M_6

TOTAL TIME ______ HRS.

TOTAL PROCESSING TIME BY THE RULE # III SEQUENCE:

M_1

M_2

M_3

M_4

M_5

M_6

TOTAL TIME ______ HRS.

TOTAL PROCESSING TIME BY THE RULE # IV SEQUENCE:

M_1

M_2

M_3

M_4

M_5

M_6

TOTAL TIME ______ HRS.

THE OPTIMUM SEQUENCE IS BY RULE # ______

○ → ○ → ○ → ○

TOTAL PROCESSING TIME BY THE RULE # I & II SEQUENCE:

M_1

M_2

M_3

M_4

M_5

M_6

TOTAL TIME ____ HRS.

TOTAL PROCESSING TIME BY THE RULE # III SEQUENCE:

M_1

M_2

M_3

M_4

M_5

M_6

TOTAL TIME ____ HRS.

TOTAL PROCESSING TIME BY THE RULE # IV SEQUENCE:

M_1

M_2

M_3

M_4

M_5

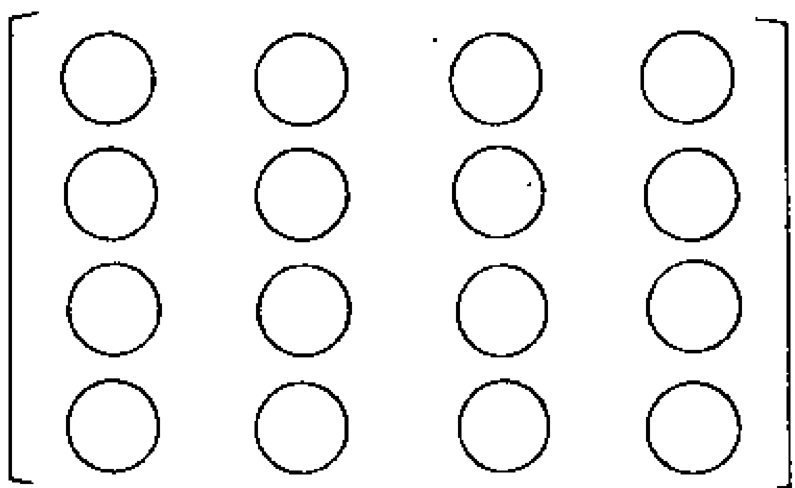
M_6

TOTAL TIME ____ HRS.

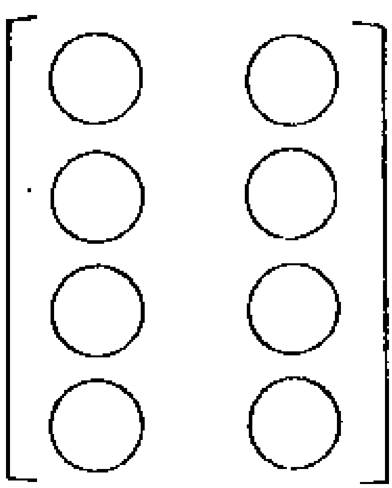
THE OPTIMUM SEQUENCE IS BY RULE # ____

PART NUMBER	OPERATION (MACHINE) NUMBER (HRS. / ROUTINGS)			
	M_1	M_2	M_3	M_4
J_1	4_1	5_2	7_3	3_4
J_2	-	6_3	8_2	6_1
J_3	4_2	5_3	2_1	-
J_4	5_1	7_3	9_4	6_2

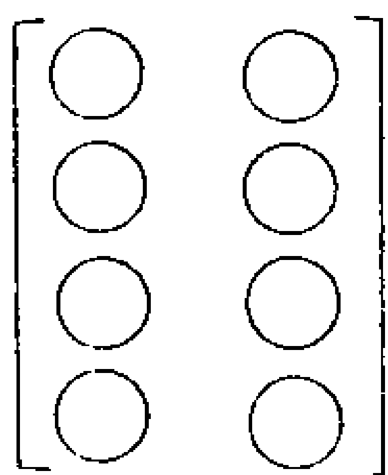
A =



T =



T′ =



$\Sigma T =$ [○ ○ ○ ○] $\Sigma T' =$ [○ ○ ○ ○] $(\Sigma T' - \Sigma T) =$ [○ ○ ○ ○]

$\overline{T} =$ [○ ○ ○ ○] $\overline{T}' =$ [○ ○ ○ ○] $(\overline{T}' - \overline{T}) =$ [○ ○ ○ ○]

RULE # I : ○—○—○—○

RULE # II : ○—○—○—○

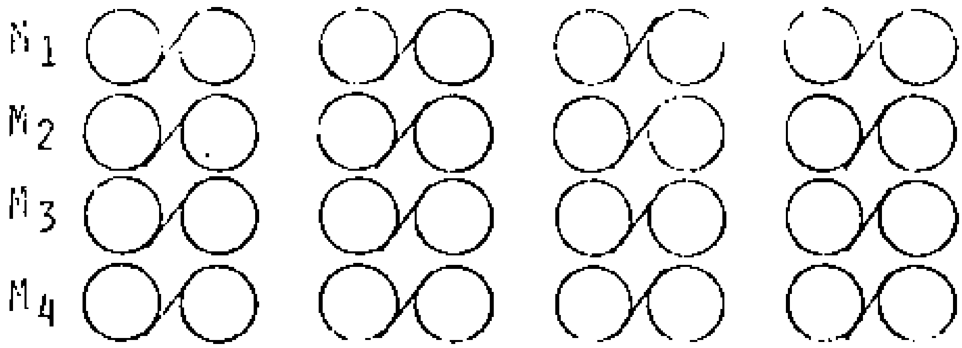
RULE # III: ○—○—○—○

RULE # IV: ○—○—○—○

TOTAL CYCLE TIMES:

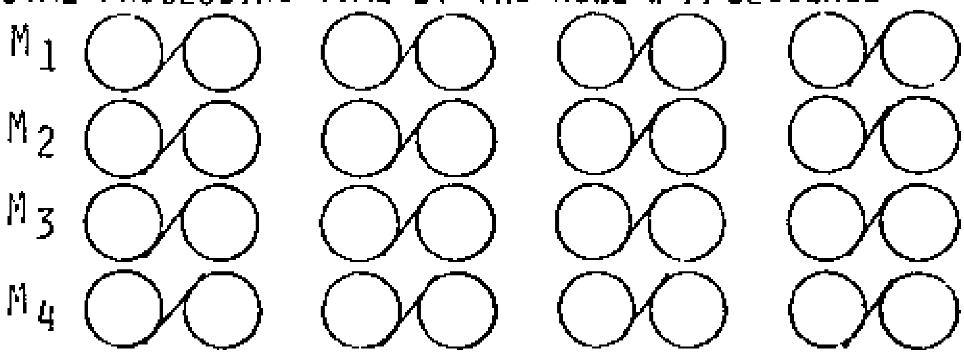
	SUCCESSIVE		PARALLEL	
RULE # I :		HRS.		HRS.
RULE # II :		HRS.		HRS.
RULE # III :		HRS.		HRS.
RULE # IV :		HRS.		HRS.

TOTAL PROCESSING TIME BY THE RULE # I SEQUENCE:



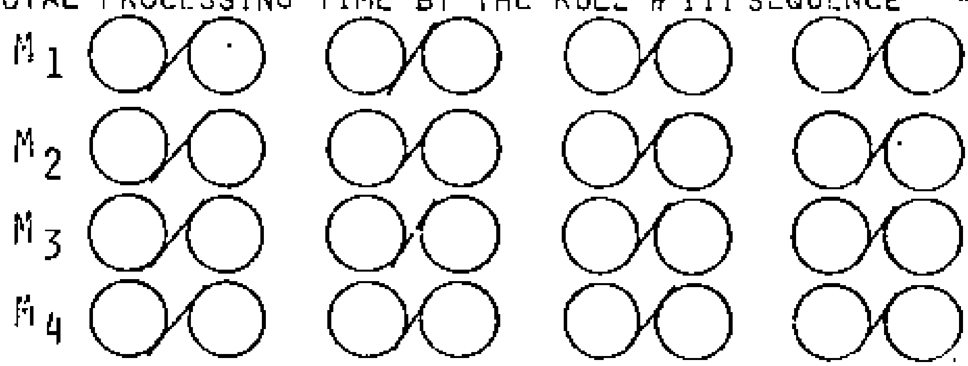
TOTAL TIME [ ] HRS.

TOTAL PROCESSING TIME BY THE RULE # II SEQUENCE



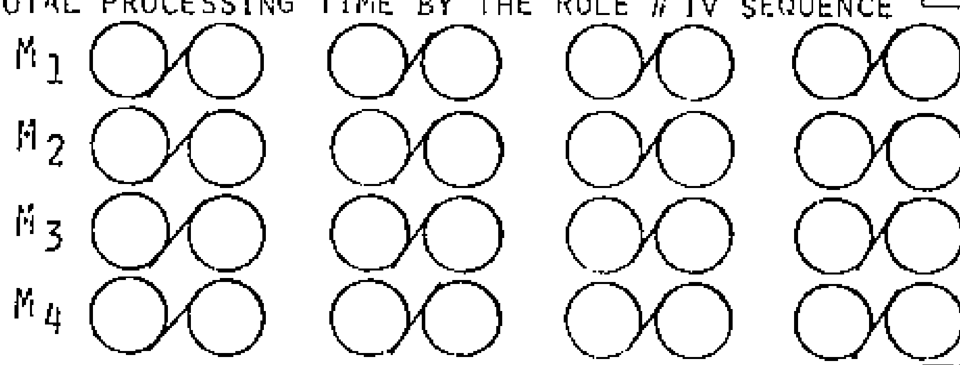
TOTAL TIME [ ] HRS.

TOTAL PROCESSING TIME BY THE RULE # III SEQUENCE



TOTAL TIME [ ] HRS.

TOTAL PROCESSING TIME BY THE RULE # IV SEQUENCE



TOTAL TIME [ ] HRS.

THE OPTIMUM SEQUENCE IS BY RULE # [ ]

TOTAL PROCESSING TIME BY THE RULE # I SEQUENCE

M_1

M_2

M_3

M_4

TOTAL TIME [ ] HRS.

TOTAL PROCESSING TIME BY THE RULE # II SEQUENCE

M_1

M_2

M_3

M_4

TOTAL TIME [ ] HRS.

TOTAL PROCESSING TIME BY THE RULE # III SEQUENCE

M_1

M_2

M_3

M_4

TOTAL TIME [ ] HRS.

TOTAL PROCESSING TIME BY THE RULE # IV SEQUENCE

M_1

M_2

M_3

M_4

TOTAL TIME [ ] HRS.

THE OPTIMUM SEQUENCE IS BY RULE # [ ]

BASIC DATA FOR GROUP SCHEDULING
(A SET OF PART FAMILIES)

[illegible]

Part Family Group	G_1			G_2				G_3			
Job	–	J_{11}	J_{12}	–	J_{21}	J_{22}	J_{23}	–	J_{31}	J_{32}	J_{33}
Set-up/ Processing Time	S_1	P_{11}	P_{12}	S_2	P_{21}	P_{22}	P_{23}	S_3	P_{31}	P_{32}	P_{33}
M_1	5	5	7	3	2	4	3	7	2	1	9
M_2	5	5	1	6	3	2	8	3	2	8	2
M_3	4	3	8	4	1	6	5	1	7	4	5

GROUP PROCESSING TIME

	G_1	G_2	G_3
M_1			
M_2			
M_3			

GROUP #1 OPTIMUM JOB SEQUENCE: ○—○

GROUP #2 OPTIMUM JOB SEQUENCE: ○—○—○

GROUP #3 OPTIMUM JOB SEQUENCE: ○—○—○

GROUP OPTIMUM SEQUENCE : ○—○—○

GROUP SEQUENCE								
JOB SEQUENCE								

Group Scheduling for "A Set of Part Families"

(I) Group #1 :

$$A = \begin{bmatrix} \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc \end{bmatrix} \quad T = \begin{bmatrix} \bigcirc & \bigcirc \\ \bigcirc & \bigcirc \end{bmatrix} \quad T' = \begin{bmatrix} \bigcirc & \bigcirc \\ \bigcirc & \bigcirc \end{bmatrix}$$

$$\Sigma T = \begin{bmatrix} \bigcirc \\ \bigcirc \end{bmatrix} \quad \Sigma T' = \begin{bmatrix} \bigcirc \\ \bigcirc \end{bmatrix} \quad (\Sigma T' - \Sigma T) = \begin{bmatrix} \bigcirc \\ \bigcirc \end{bmatrix}$$

Rule # I $\bigcirc \rightarrow \bigcirc \rightarrow \bigcirc$

Rule # II $\bigcirc \rightarrow \bigcirc \rightarrow \bigcirc$

(II) Group #2 :

$$A = \begin{bmatrix} \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc \end{bmatrix} \quad T = \begin{bmatrix} \bigcirc & \bigcirc \\ \bigcirc & \bigcirc \\ \bigcirc & \bigcirc \end{bmatrix} \quad T' = \begin{bmatrix} \bigcirc & \bigcirc \\ \bigcirc & \bigcirc \\ \bigcirc & \bigcirc \end{bmatrix}$$

$$\Sigma T = \begin{bmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \end{bmatrix} \quad \Sigma T' = \begin{bmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \end{bmatrix} \quad (\Sigma T' - \Sigma T) = \begin{bmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \end{bmatrix}$$

Rule # I $\bigcirc \rightarrow \bigcirc \rightarrow \bigcirc$

Rule # II $\bigcirc \rightarrow \bigcirc \rightarrow \bigcirc$

(III) <u>Group # 3:</u>

$$A = \begin{bmatrix} \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc \end{bmatrix} \quad T = \begin{bmatrix} \bigcirc & \bigcirc \\ \bigcirc & \bigcirc \\ \bigcirc & \bigcirc \end{bmatrix} \quad T' = \begin{bmatrix} \bigcirc & \bigcirc \\ \bigcirc & \bigcirc \\ \bigcirc & \bigcirc \end{bmatrix}$$

$$\Sigma T = \begin{bmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \end{bmatrix} \quad \Sigma T' = \begin{bmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \end{bmatrix} \quad (\Sigma T' - \Sigma T) = \begin{bmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \end{bmatrix}$$

Rule # I $\bigcirc \rightarrow \bigcirc \rightarrow \bigcirc$

Rule # II $\bigcirc \rightarrow \bigcirc \leftarrow \bigcirc$

(IV) <u>Group Sequence:</u>

$$A = \begin{bmatrix} \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc \end{bmatrix} \quad T = \begin{bmatrix} \bigcirc & \bigcirc \\ \bigcirc & \bigcirc \\ \bigcirc & \bigcirc \end{bmatrix} \quad T' = \begin{bmatrix} \bigcirc & \bigcirc \\ \bigcirc & \bigcirc \\ \bigcirc & \bigcirc \end{bmatrix}$$

$$\Sigma T = \begin{bmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \end{bmatrix} \quad \Sigma T' = \begin{bmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \end{bmatrix} \quad (\Sigma T' - \Sigma T) = \begin{bmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \end{bmatrix}$$

Rule # I $\bigcirc \rightarrow \bigcirc \rightarrow \bigcirc$

Rule # II $\bigcirc \rightarrow \bigcirc \leftarrow \bigcirc$

EXAMPLE OF "BRANCH AND BOUND METHOD" FOR GROUP SCHEDULING

Part Family Group	G_1			G_2				G_3			
Job	-	J_{11}	J_{12}	-	J_{21}	J_{22}	J_{23}	-	J_{31}	J_{32}	J_{33}
Set-up/ Processing Time	S_1	P_{11}	P_{12}	S_2	P_{21}	P_{22}	P_{23}	S_3	P_{31}	P_{32}	P_{33}
M_1	5	5	7	3	2	4	3	7	2	1	9
M_2	5	5	1	6	3	2	8	3	2	8	2
M_3	4	3	8	4	1	6	5	1	7	4	5

1. Branch and make group nodes (r=1): $N_1 = \{G_1\}, \{G_2\}$, and $\{G_3\}$.

2. Branch and make job nodes (r=1, s=1): $N_{11} = \{J_{11}\}, \{J_{12}\}, \{J_{21}\}, \{J_{22}\}, \{J_{23}\}, \{J_{31}\}, \{J_{32}\}$, and $\{J_{33}\}$. Compute LB (the lower bound):

   $\hat{F}_{N_{11}}$ = 59, 57, 55, 55, 58, 58, 63, and 65.

3. Find a least LB: 55 (if there is a tie, take one of the highest level [larger values of r and s] and the most left-hand side). At this node, $\{J_{21}\}$ in G_2 (i=2), since $s \neq n_i$ (1≠3), branch and make job nodes (s=2): $N_{12} = \{J_{21}, J_{22}\}$ and $\{J_{21}, J_{23}\}$. Compute LB: $\hat{F}_{N_{12}}$ = 55 and 60.

4. Find a least LB: 55 at the node $\{J_{21}, J_{22}\}$ in G_2; since $s \neq n_i$ (2≠3), branch and make job node (s=3): $N_{13} = \{J_{21}, J_{22}, J_{23}\}$. Compute LB: $\hat{F}_{N_{13}}$ = 57.

5. Find a least LB: 55 at the node $\{J_{22}\}$ in G_2; since $s \neq n_i$ (1≠3), branch and make job nodes (s=2): $N_{12} = \{J_{22}, J_{21}\}$ and $\{J_{22}, J_{23}\}$. Compute LB: $\hat{F}_{N_{12}}$ = 55 and 56.

6. Find a least LB: 56 at the node $\{J_{22}, J_{21}\}$ in G_2; since $s \neq n_i$ $(2 \neq 3)$, branch and make job node $(s=3)$: N_{13} = $\{J_{22}, J_{21}, J_{23}\}$. Compute LB: $\hat{F}_{N_{13}} = 57$.

7. Find a least LB: 56 at the node $\{J_{22}, J_{23}\}$ in G_2; since $s \neq n_i$ $(2 \neq 3)$, branch and make job node $(s=3)$: $N_{13} = \{J_{22}, J_{23}, J_{21}\}$. Compute LB: $\hat{F}_{N_{13}} = 56$.

8. Find a least LB: 56 at the node $\{J_{22}, J_{23}, J_{21}\}$ in G_2; since $s = n_i$, then branch and make new group nodes $(r=2)$: N_2 = $\{G_2, G_1\}$ and $\{G_2, G_3\}$.

9. Branch and make job nodes $(r=2,\ s=1)$: $N_{21} = \{J_{11}\}$, $\{J_{12}\}$, $\{J_{31}\}$, $\{J_{32}\}$, and $\{J_{33}\}$. Compute LB: $\hat{F}_{N_{21}}$ = 59, 56, 57, 63, and 61.

10. Find a least LB: 56 at the node $\{J_{12}\}$ in G_1 $(i=1)$; since $s \neq n_1$ $(1 \neq 2)$, branch and make job node $(s=2)$: $N_{22} = \{J_{12}, J_{11}\}$. Compute LB: $\hat{F}_{N_{22}} = 56$.

11. Find a least LB: 56 at the node $\{J_{12}, J_{11}\}$ in G_1; since $s = n_i$, then branch and make group node $(r=3)$: $N_3 = \{G_2, G_1, G_3\}$.

12. Branch and make job nodes $(r=3,\ s=1)$: $N_{31} = \{J_{31}\}$, $\{J_{32}\}$, and $\{J_{33}\}$. Compute LB: $\hat{F}_{N_{31}}$ = 56, 61, and 63.

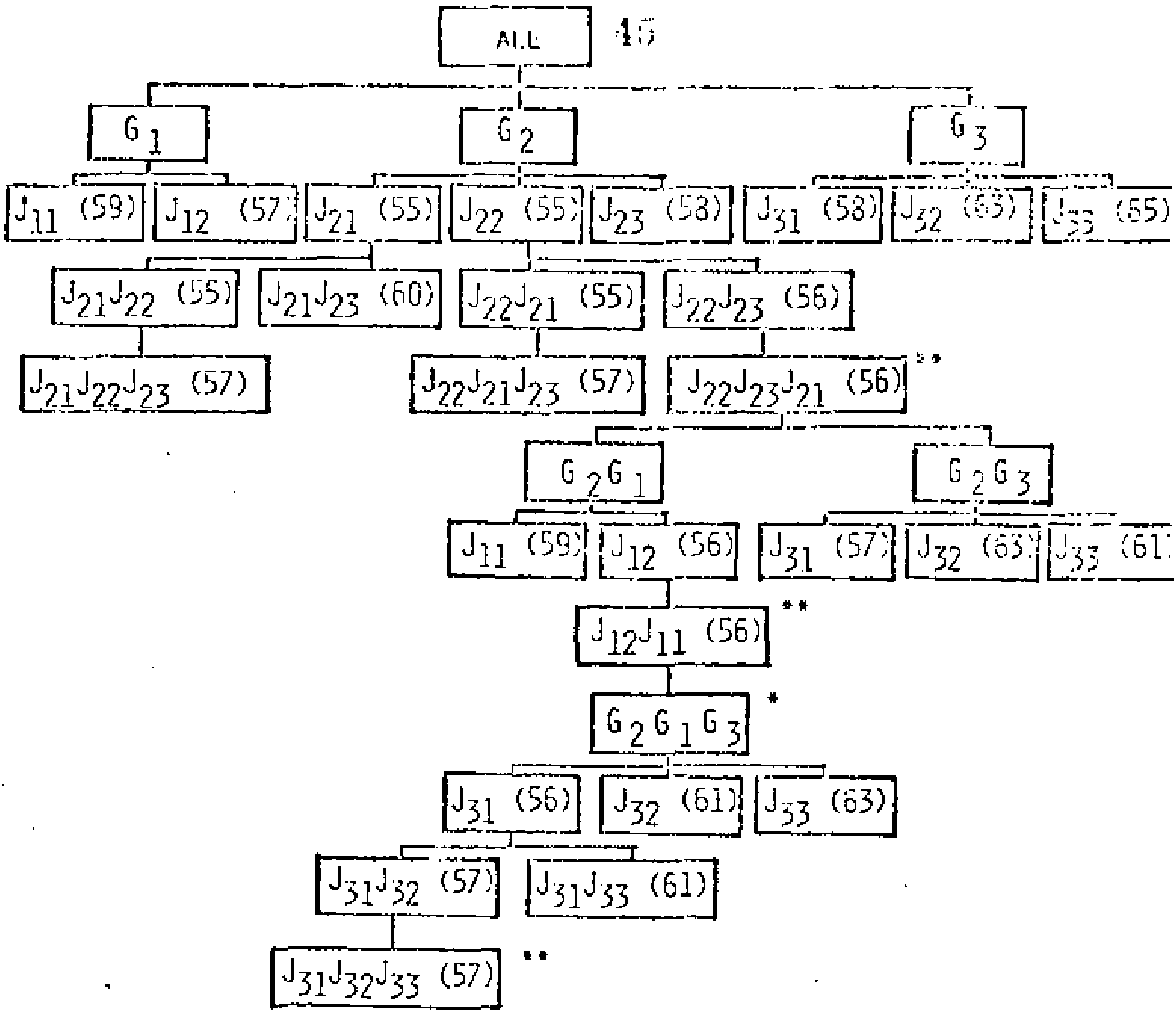
13. Find a least LB: 56 at the node $\{J_{31}\}$ in G_3 $(i=3)$; since $s \neq n_i$ $(1 \neq 3)$, branch and make job nodes $(s=2)$: $N_{32} = \{J_{31}, J_{32}\}$ and $\{J_{31}, J_{33}\}$. Compute LB: $\hat{F}_{N_{32}}$ = 57 and 61.

14. Find a least LB: 57 at the node $\{J_{31}, J_{32}\}$ in G_3; since $s \neq n_i$, branch and make job node $(s=3)$: $N_{33} = \{J_{31}, J_{32}, J_{33}\}$. Compute LB: $\hat{F}_{N_{33}} = 57$.

15. Find a least LB: 57. Since all groups and jobs are sequenced, the optimal solution for group sequence and job sequence for minimizing the total flow time is obtained as shown in Table.

"BRANCH AND BOUND" METHOD SOLUTION

(GROUP SCHEDULING FOR A SET OF PART FAMILIES)

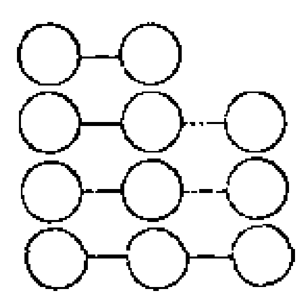


GROUP #1 OPTIMUM JOB SEQUENCE:

GROUP #2 OPTIMUM JOB SEQUENCE:

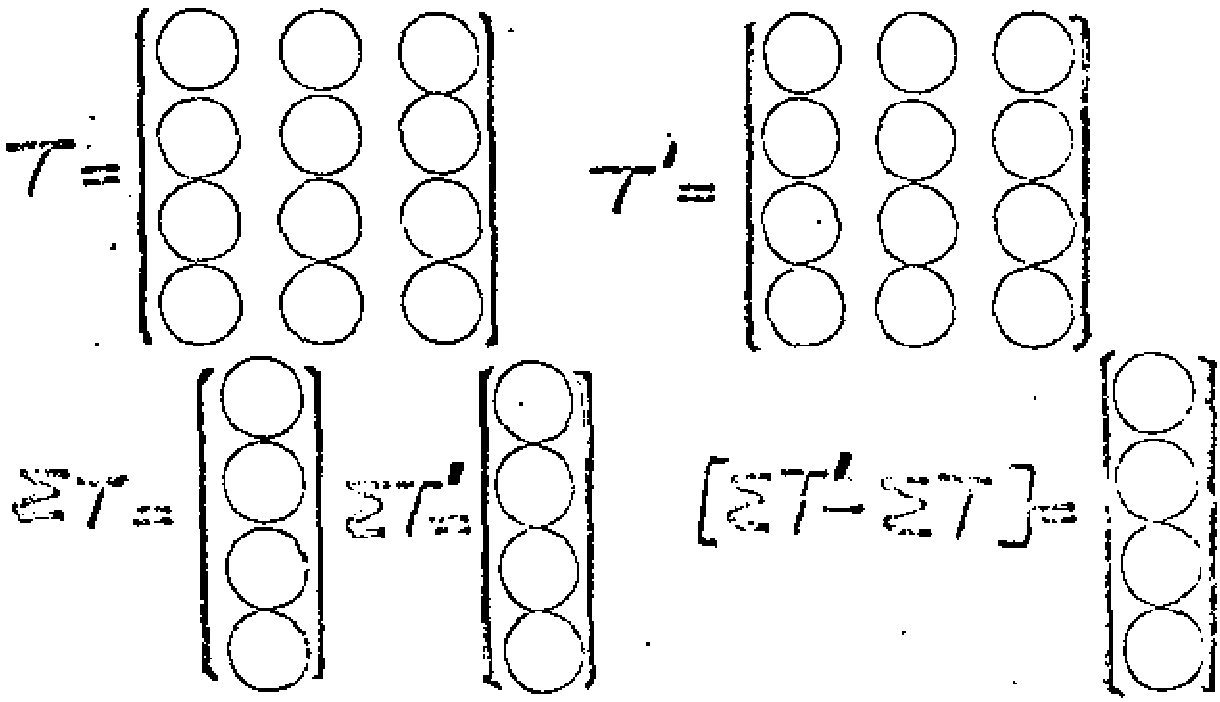
GROUP #3 OPTIMUM JOB SEQUENCE:

GROUP OPTIMUM SEQUENCE :

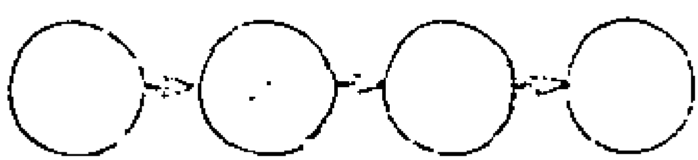


GROUP SEQUENCE								
JOB SEQUENCE								

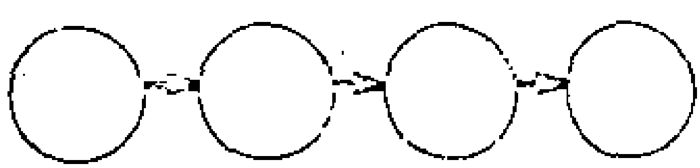
PART NO.	OPERATION (MACHINE) NUMBER				
	M_1	M_2	M_3	M_4	M_5
J_1	15	11	5	20	8
J_2	8	25	9	15	4
J_3	16	19	17	8	19
J_4	4	13	20	14	12



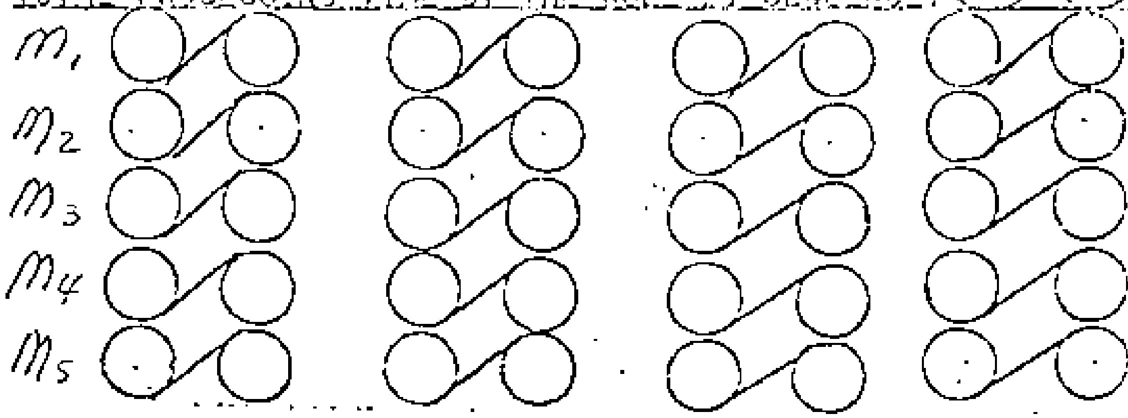
SEQUENCE BY RULE #I:



SEQUENCE BY RULE #II:

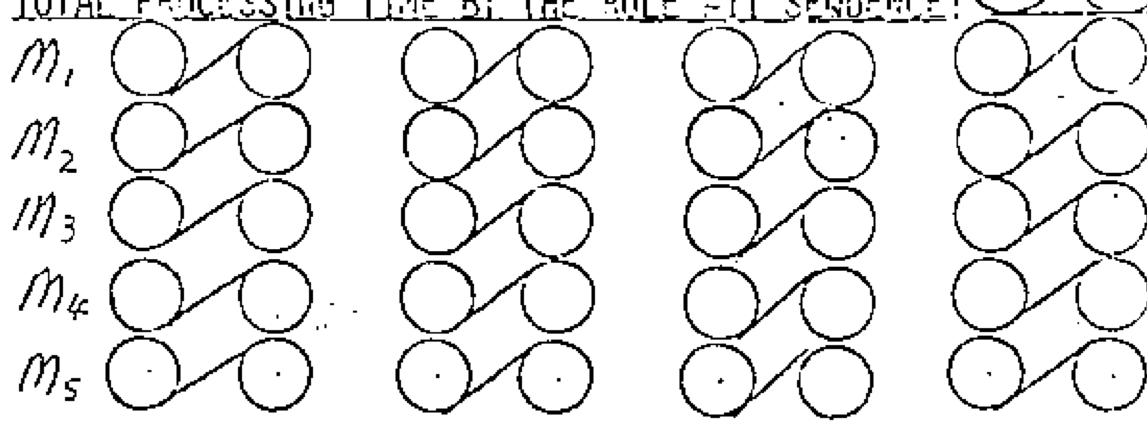


TOTAL PROCESSING TIME BY THE RULE #I SEQUENCE:



TOTAL PROCESSING TIME = Hours

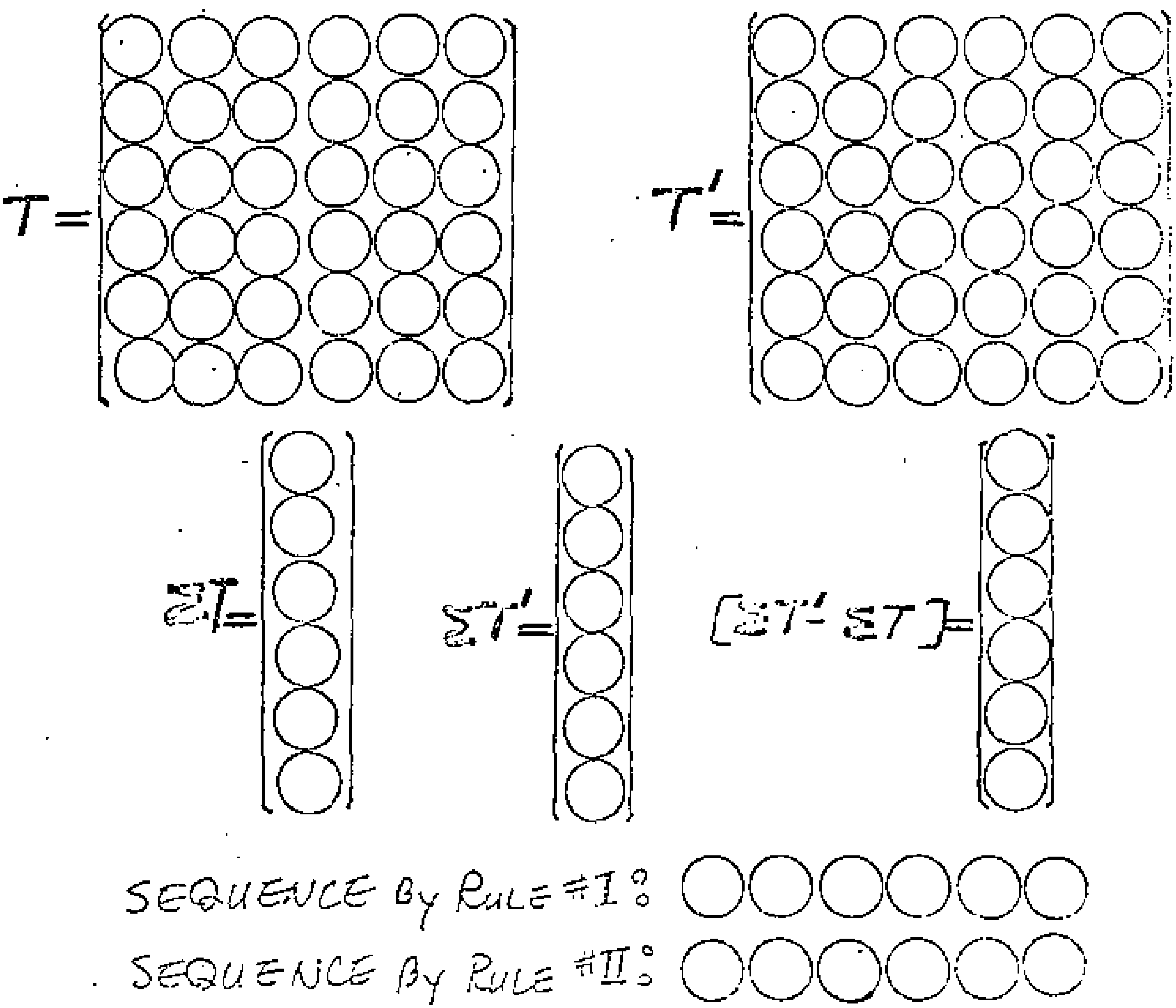
TOTAL PROCESSING TIME BY THE RULE #II SEQUENCE:



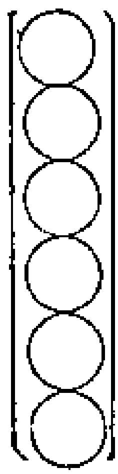
TOTAL PROCESSING TIME = Hours

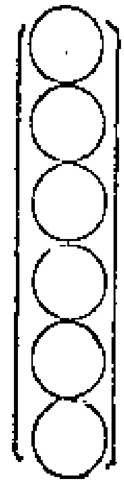
SELECT THE SEQUENCE BY RULE # :

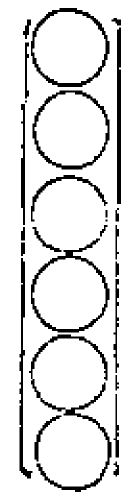
PART NO.	OPERATION (MACHINE) NUMBER (TIMES IN HOURS)											
	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}	M_{11}	M_{12}
J_1	6	--	3	13	5	-	-	7	5	4	-	2
J_2	10	8	3	-	5	9	4	3	8	5	3	-
J_3	5	-	6	-	9	-	4	-	10	-	8	-
J_4	8	3	15	18	20	-	10	6	9	3	5	4
J_5	4	7	-	16	-	15	11	3	-	2	18	-
J_6	3	5	-	2	3	6	-	2	3	4	8	5



$$\bar{T}_i = \left(\frac{\sum T_i}{N_i}\right) \qquad \bar{T}_i' = \left(\frac{\sum T_i'}{N_i}\right)$$

$\bar{T} =$ 

$\bar{T}' =$ 

$[\bar{T}' - \bar{T}] =$ 

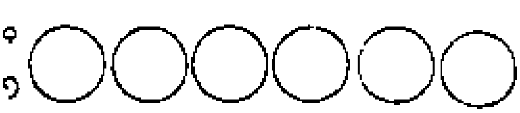
RULE #III:

$[\bar{T}_i' - \bar{T}_i] \geq 0 \qquad \bar{T}_i\ (\uparrow)$

$[\bar{T}_i' - \bar{T}_i] < 0 \qquad \bar{T}'\ (\downarrow)$

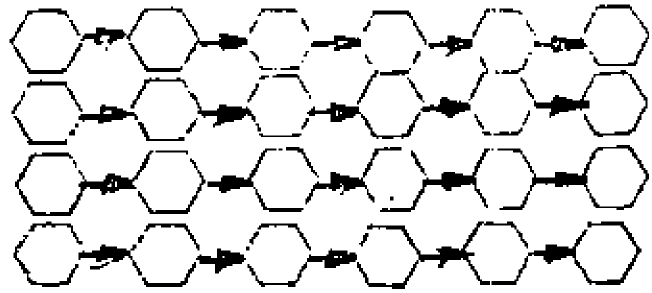
RULE #IV:

$[\bar{T}' - \bar{T}]\ (\downarrow)$

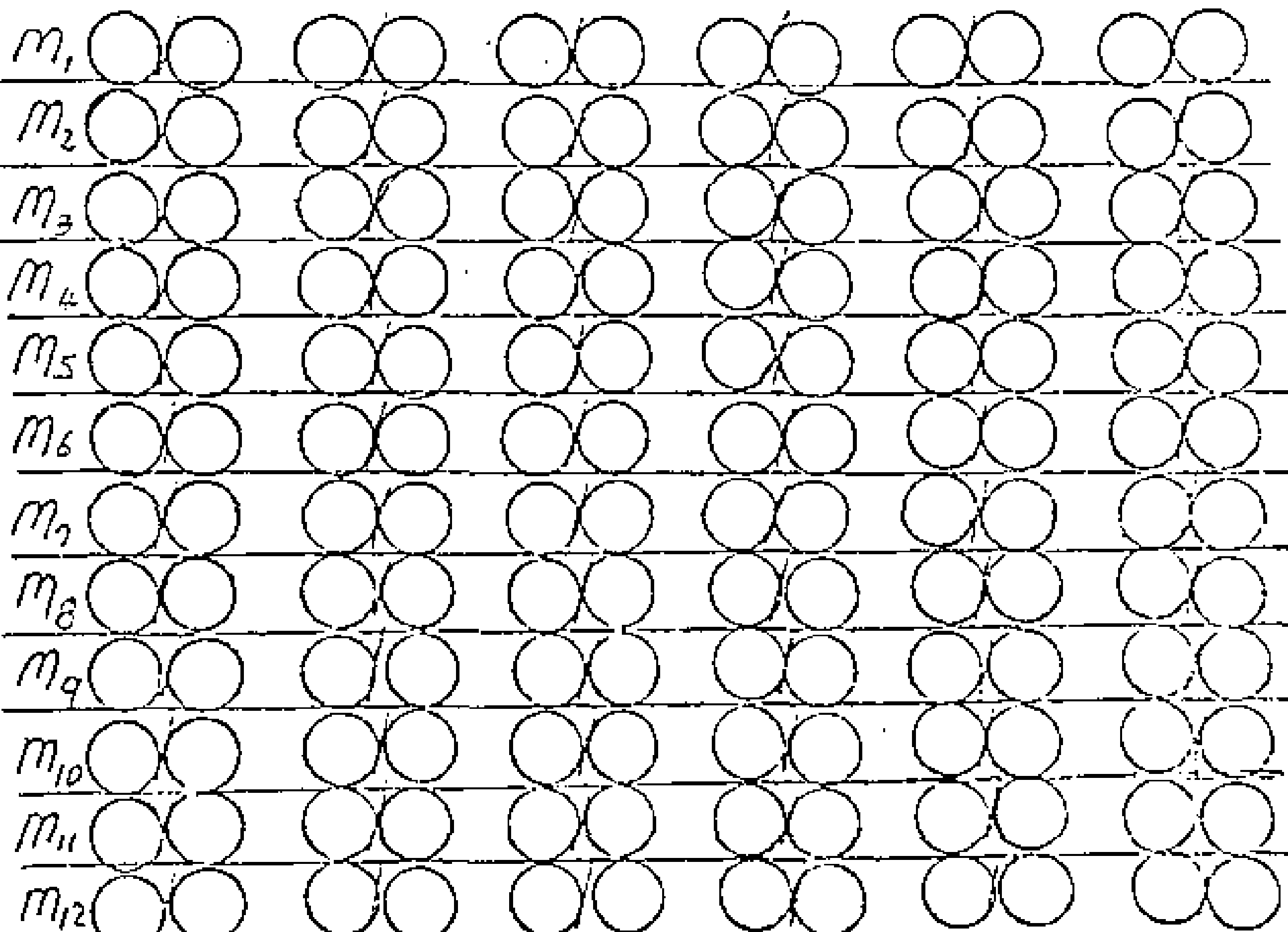
SEQUENCE BY RULE #III: 

SEQUENCE BY RULE #IV: 

RULE #I :
RULE #II :
RULE #III:
RULE #IV :



TOTAL PROCESSING TIME BY THE RULE #III SEQUENCE:



TOTAL PROCESSING TIMES BY:

RULE # I SEQUENCE - - - - [ ] HOURS

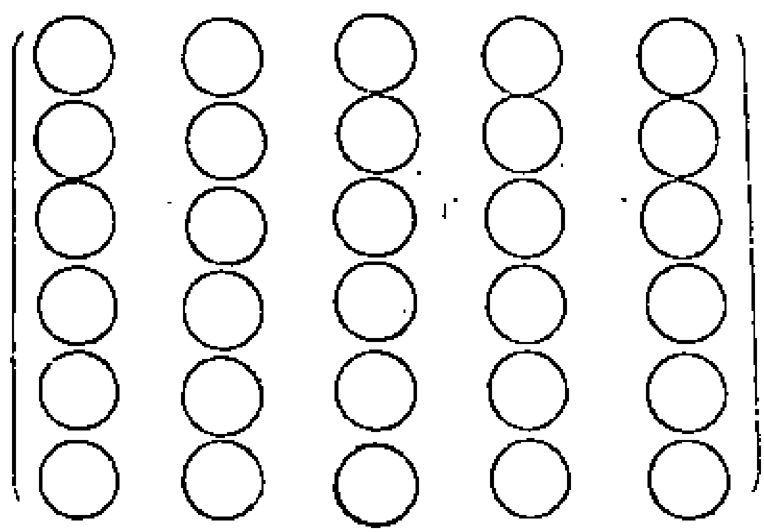
RULE # II SEQUENCE - - - - [ ] HOURS

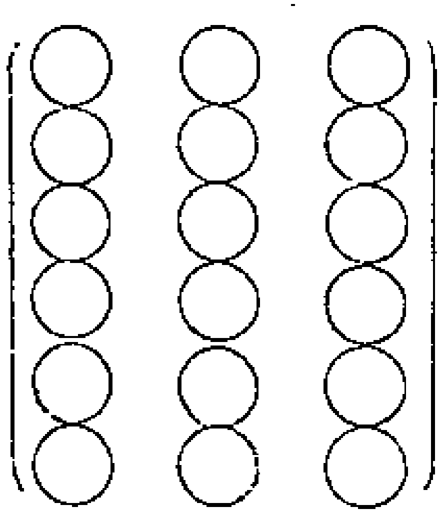
RULE #III SEQUENCE - - - - [ ] HOURS

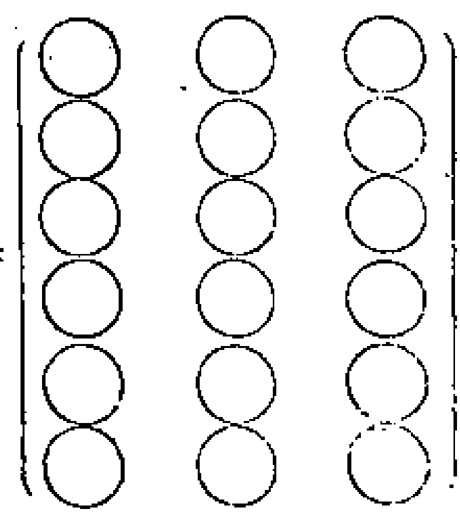
RULE # IV SEQUENCE - - - - [ ] HOURS

THE OPTIMUM SEQUENCE IS . BY RULE # [ ]

JOB	MACHINE/OPERATION				
	m_1	m_2	m_3	m_4	m_5
J_1	9_1	6_2	--	8_3	3_4
J_2	5_4	--	8_3	6_2	2_1
J_3	7_1	8_2	--	5_3	4_4
J_4	6_3	10_2	5_1	4_5	3_4
J_5	4_4	--	6_3	3_2	10_1
J_6	7_3	8_2	4_1	10_5	5_4

$A =$ 

$T =$ 

$T' =$ 

$$\Sigma T = \begin{pmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \end{pmatrix} \quad \Sigma T' = \begin{pmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \end{pmatrix} \quad (\Sigma T' - \Sigma T) = \begin{pmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \end{pmatrix}$$

$$\bar{T} = \begin{pmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \end{pmatrix} \quad \bar{T}' = \begin{pmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \end{pmatrix} \quad (\bar{T}' - \bar{T}) = \begin{pmatrix} \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \\ \bigcirc \end{pmatrix}$$

RULE # I : ○ — ○ — ○ — ○ — ○ — ○

RULE # II : ○ — ○ — ○ — ○ — ○ — ○

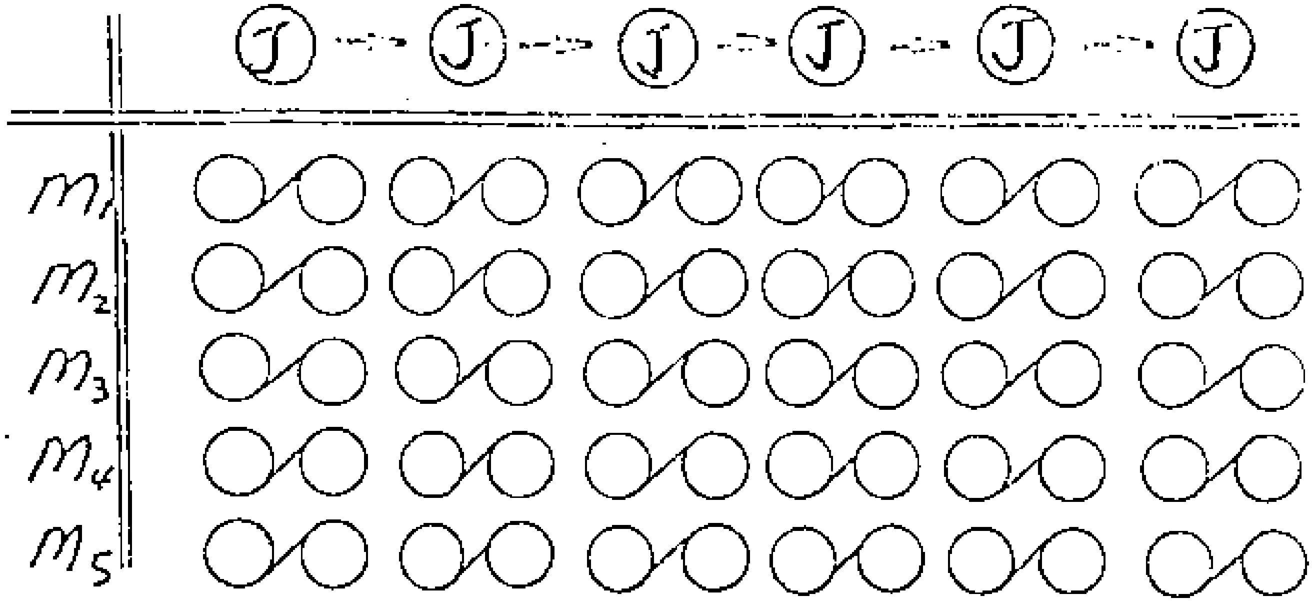
RULE # III : ○ — ○ — ○ — ○ — ○ — ○

RULE # IV : ○ — ○ — ○ — ○ — ○ — ○

TOTAL CYCLE TIMES:

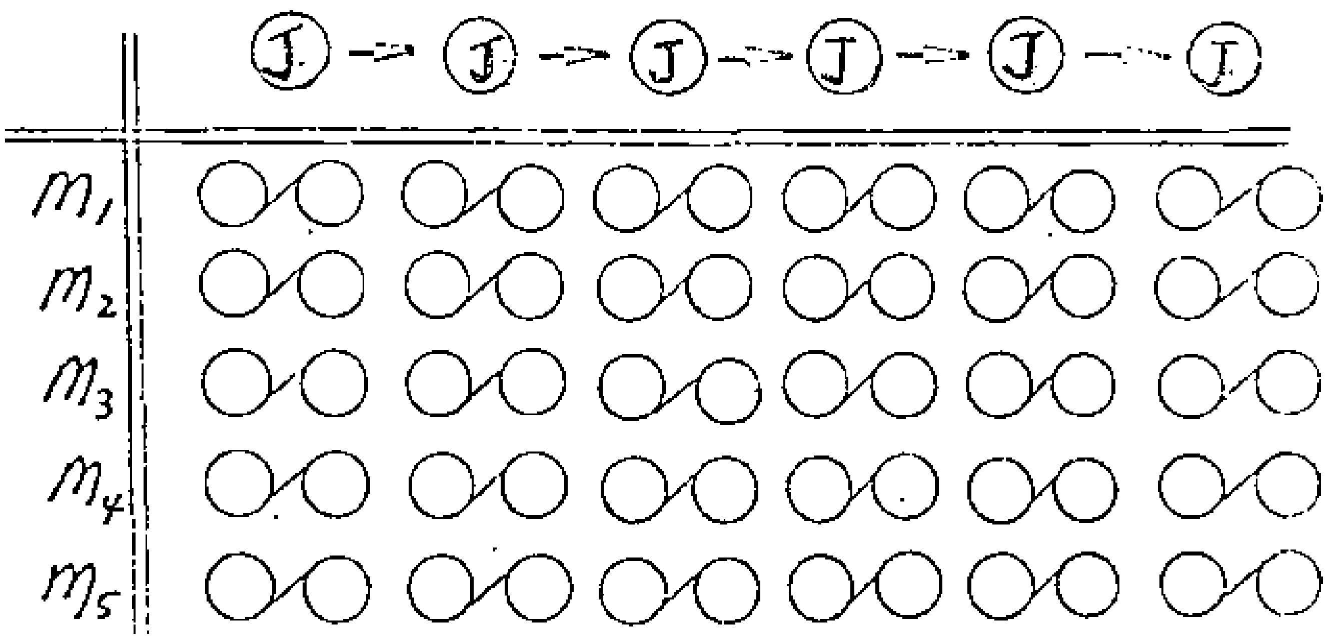
RULE # I :	______ hrs.	______ hrs.
RULE # II :	______ hrs.	______ hrs.
RULE # III :	______ hrs.	______ hrs.
RULE # IV :	______ hrs.	______ hrs.

(I) Succesive Sequential Transfer



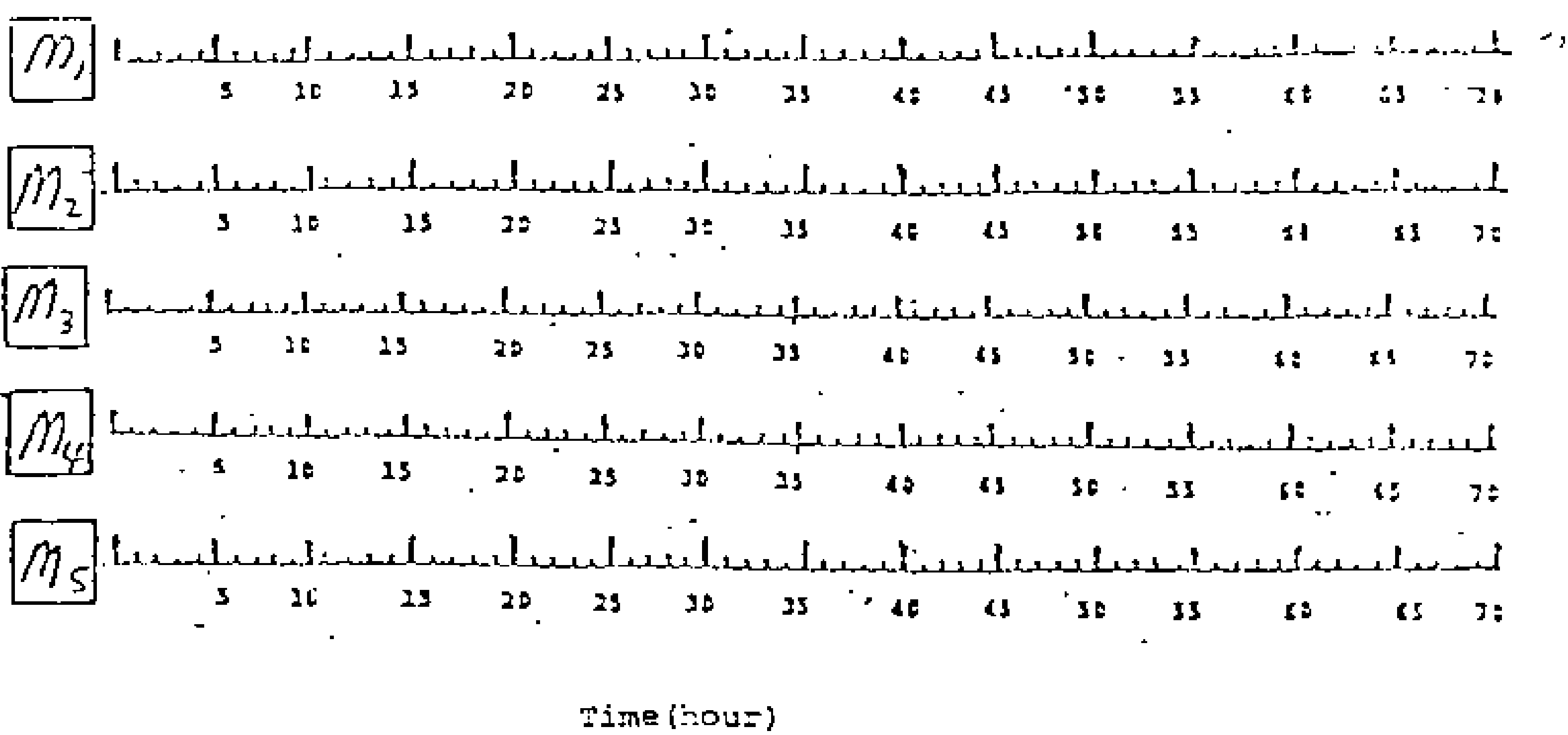
OPTIMUM TOTAL CYCLE TIME: ( ) HRS.

(II) Succesive Parallel Transfer

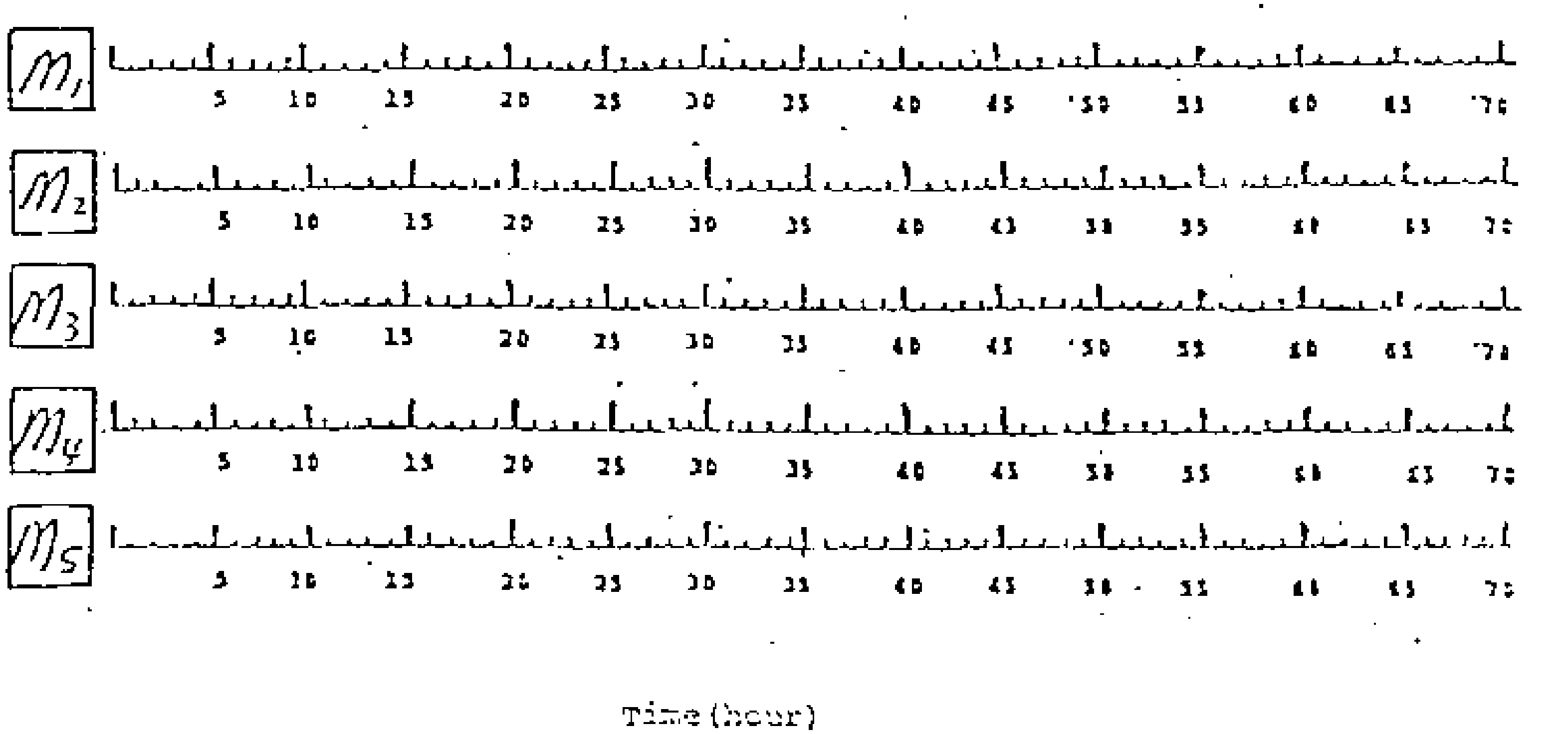


OPTIMUM TOTAL CYCLE TIME: ( ) HRS.

(I) SUCCESSIVE SEQUENTIAL TRANSFER



(II) SUCCESSIVE PARALLEL TRANSFER



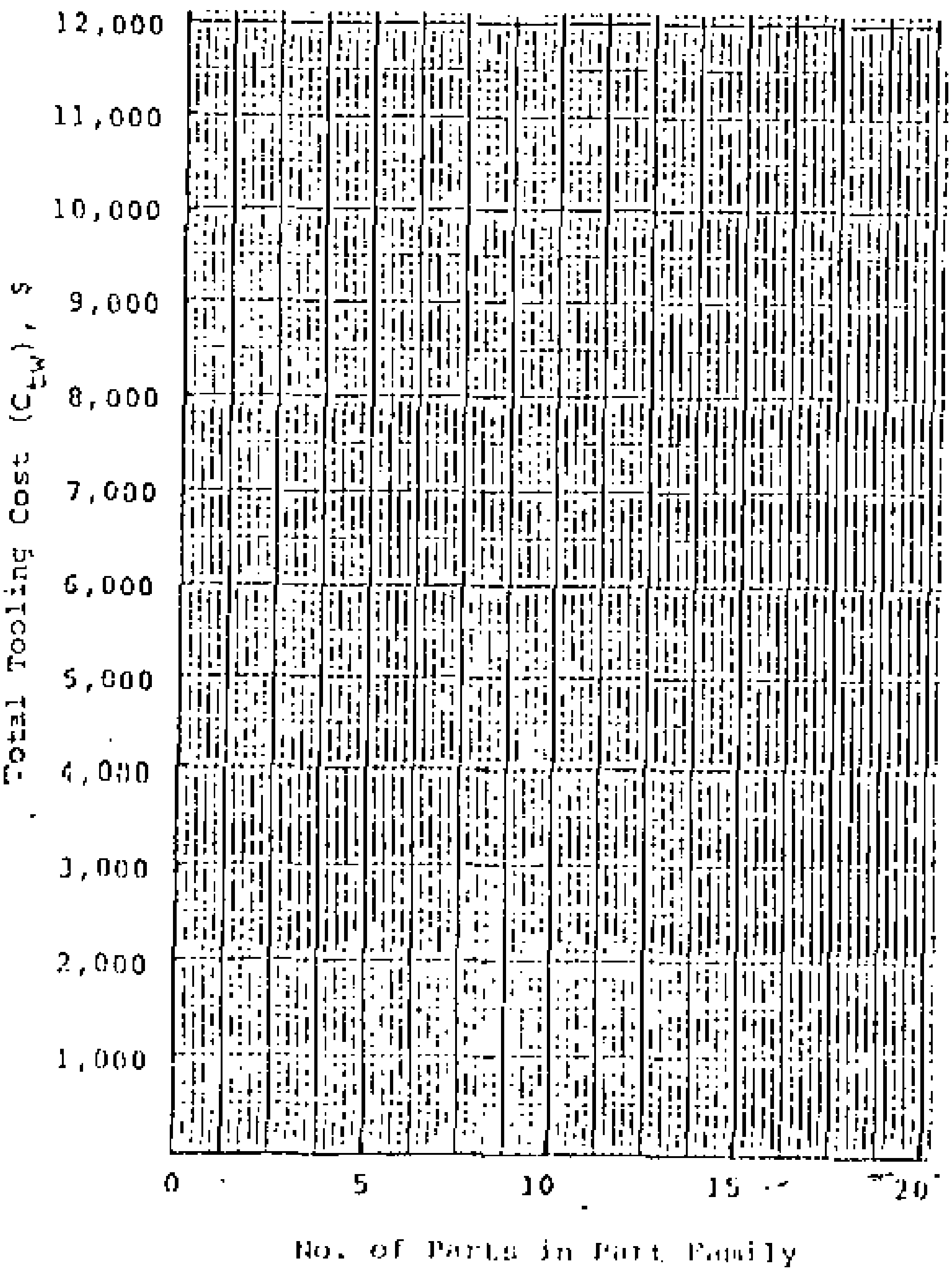
COMPARATIVE ANALYSIS FOR ECONOMICS OF GROUP TOOLING

Item	Conventional tooling Method	Group Tooling Method
Cost of the Drill jig	$815	$2208
Number of jigs required	6	1
Cost of an adapter	-	$450
Number of adapters required	-	5
Number of pieces to be prod.	240	240

COMPUTED EXAMPLE OF TOOLING COSTS FOR COMPARISON

No. of parts in part family	Conventional Method		Group tooling Method	
	C_{tw_1}	C_{u_1}	C_{tw_2}	C_{u_2}
1	$ 815	$3.40	$ 2,658	$11.08
2	1,630	3.40	3,108	6.48
3	2,445	3.40	3,558	4.94
4	3,260	3.40	4,008	4.18
5	4,075	3.40	4,458	3.72
6	4,890	3.40	4,908	3.41
7	5,705	3.40	5,358	3.19
8	6,520	3.40	5,808	3.03
9	7,335	3.40	6,258	2.90
10	8,150	3.40	6,708	2.80
11	8,965	3.40	7,158	2.71
12	9,780	3.40	7,608	2.64
13	10,595	3.40	8,058	2.49
14	11,410	3.40	8,508	2.58
15	12,225	3.40	8,958	2.49
20	16,300	3.40	11,208	2.34

(A) Total Tooling Cost (C_{tw}) vs. No. of Parts in Part Family



(B) Unit Tooling Cost (C_u) vs. No. of Parts in Part Family