OPTIMIZATION OF A CELLULAR STRUCTURE IN FLEXIBLE MANUFACTURING SYSTEM

A Thesis
By
MUNIR UDDIN AHMAD

Submitted to the Department of Industrial and Production Engineering, Bangladesh University of Engineering and Technology, Dhaka in partial fulfilment of the requirement for the degree of M.Sc. Engg. (IP) from the Department of Industrial and Production Engineering.

October 1, 1992

Department of Industrial & Production Engineering
Bangladesh University of Engineering & Technology
Dhaka-1000

OPTIMIZATION OF A CELLULAR STRUCTURE IN FLEXIBLE MANUFACTURING SYSTEM

A Thesis
By
Md. Munir Uddin Ahmad

Approved to the style and content by:

1.	Dr. Md. Mizanur Rahman Professor & Head Dept. of I.P.E., BUET	Chairman (Supervisor)
2.	Dr. Ahsan Ali Khan Associate Professor Dept. of I.P.E., BUET	Member
3.	Dr. Md. Ruhul Amin Sarker Assistant Professor Dept. of I.P.E., BUET	Member
4.	Dr. Md. Khalilur Rahman Assistant Professor Dept. of N.A.M.E., BUET	Member (External)

October 1, 1992

Department of Industrial & Production Engineering
Bangladesh University of Engineering & Technology

CERTIFICATE

This is to certify that this work has been done by me and it was not submitted elsewhere for the award of any degree or diploma or for any publication.

Supervisor

Author

C O N T E N T S

C O N T E N T S (Contd)

CONTENTS (Contd)

ACKNOWLEDGEMENTS

The author acknowledges his profound indebtness and expresses his sincere gratitude to Dr. Md. Mizanur Rahman, Professor and Head, Department of Industrial and Production Engineering for his constant guidance, supervision and suggestions at all stages in conduction of this research work. The author deeply appreciates the time and effort he took to provide the author with valuable comments. The author also expresses his thanks to him for his enormity of help to go over the entire manuscript, valuable critique and sharing insights.

A special note of thanks is due for Dr. Md. Ruhul Amin Sarker, Assistant Professor, Department of Industrial and Production Engineering, who was deeply involved in the conceptualization and initial structuring of this work. He uncovered the problems and suggested his resolution and continued to critique the manuscript.

The author is also greatful to Dr. Ahsan Ali Khan, Associate Professor , Department of Industrial and Production Engineering, for his valuable advice and suggestions time to time.

His indebtness is due to Dr. Md. Khalilur Rahman, Assistant Professor, Department of Naval Architect and Marine Engineering, for his kind cooperation and valuable advice.

The author wishes to express his heartiest thanks to his respected teachers and to all those who directly or indirectly helped him in this thesis work.

The author also thanks Mr. Siddiqur Rahman, who beautifully prepared draft upon draft from some throughly mulilated materials.

Author

ABSTRACT

Cellular manufacturing is considered to be an organizational approach for manufacturing parts with similar processing requirements in machine cells. Among the various approaches to the cell formation problem clustering techniques based on similrity index such as, the Single LInkage Clustering Algorithm, the Average Linkage Clustering Algorithm, the Weighted Linkage Clustering Algorithm are widely used. In the present work, a mathematical model has been developed for a cellular manufacturing structure. The model considers both the machines and parts similarity together to minimize the total cost of the system. The cost elements considered are tool cost, machine amortization cost and processing cost. The model is a binary linear program. The model has been solved using LP relaxation and a heuristic algorithm. The heuristic algorithm has been developed based on similarity index and it minimizes the total cost of the system. A few test problems are solved, using both the methods and the results are compared. The heuristic algorithm produces a good solution and takes much less computational time compared to LP approach.

List of Figures

List of Tables

In some instances the tables spread over more than one page. Where this is the case the page number given refers to the page on which the table begins.

Page No.

Chapter - 1

INTRODUCTION

CHAPTER-1

INTRODUCTION

1.1 Introduction:

In the recent manufacturing world, productivity in manufacturing has continually been on the increase. To achieve this small and medium sized parts manufacturers have attempted to incorporate the modern manufacturing methods. In this end cellular manufacturing has been found to be an important manufacturing method.

While the trend of technology is toward the Computer Integrated Manufacturing(CIM), as yet, the full CIM has not been realized . However on the factory floor, computer integration has proceeded further than any other sector of the manufacturing system. It has taken the form of Flexible Manufacturing System(FMS). The cellular manufacturing technique is a very important concept used in flexible manufacturing system. A flexible manufacturing system consists of several work cells. Generally the term cell can be used to refer to a machine grouping that consists number of machines, possibly four or few. The term flexible manufacturing system can be used when whole the factory system is considered. From a comprehensive study of current production systems(chapter 2), it may be justifiably said that CIM is the complete integration within the industry and FMS is integration of computer with just the factory floor.

1.2 Trends in Manufacturing:

Certain trends are occurring in manufacturing that will shape the factory of the future. These trends result from management's desire to find new ways to increase productivity and from new opportunities afforded by developing technologies. The trend includes[30]:

- *Shorter product life cycle:* The manufacturing company is now in a very competitive pressure to develop and produce new generations of products. This new products are becoming increasingly complex in less time.This technological 'rat race' results in shorter product lives not because the older products wear out but because new offerings make previous items technologically obsolete. The use of CAD/CAM systems makes it possible for companies to accomplish the synthesis, analysis, evaluation, and documentation of the design in much less time than with manual methods.

- *Increased emphasis on quality and reliability: The Japanese* have demonstrated that it is possible to manufacturer high quality products at relatively low cost[19]. The manufacturing company now in continuous pressure to attract the consumer due to a very competitive environment. It is now essential to produce high quality products just to enter into the market.

- *More customized products:* The products available to consumers are becoming more individualized and custom engineered. There are more special options and features to meet the particular needs of the customer. This results in smaller lot sizes. The number of products and components made in small batch sizes (50 or fewer items) is expected to represent the majority of future manufacturing activity[30] .

- *Pressure to reduce inventories:* During the late 1970s and during much of the 1980s, interest rates increased to very high levels. Companies realized that there was a very high investment cost associated with keeping inventories. Attempts were made to reduce inventories of all types. In manufacturing the focus was on reducing work-in-process. Work-in-process inventory represents a significant investment in the cost of materials and work already performed that cannot be recovered until the parts get to the consumer.

1.3 Scope and Objective of the present work:

Considering the underdeveloped economy context of Bangladesh, strategy is forwarded to adapt appropriate production system. It may be mentioned that in Bangladesh the most neglected area of productivity and technological research is the Industrial sector. A brief study is performed in this regard. From critical assessment of manufacturing capability and appropriateness in Bangladesh the author believes that FMS with emphasis on group technology and cellular manufacturing will be rather easy. Thus the current research work has been directed in this regard.

Researches carried on cellular manufacturing and group technology were many. A comprenhensive literature review would reveal the various findings on these subjects. In this present work, a completely different approach of cost minimization is taken for the part machine grouping problem. A suitable model is developed; this can simultaneously consider both the machines and parts to optimize the cost that includes processing cost, cost of tool and cost of machines. A heuristic is also developed to solve the mixed integer programming model and a comparison is made. The stochastic nature of different product mixes is considered. Also a model for machine cell layout and machine layout problem within the cell is outlined .

To demonstrate the potentiality of implementing the approach in cellular manufacturing system, two different case problem examples were taken and solved using

i) linear programming model relaxation solution and

ii) the heuristic .

A good agreement is found between them. However different objectives are also considered. These include, maximum number of machines, maximum allowable machine time, tool availability etc.

Chapter - 2

LITERATURE SURVEY

CHAPTER-2

LITERATURE SURVEY

The use of groups in production organization has two main origins. One is part grouping and another is the machine grouping. In part grouping methodologies, the researchers attempt to find a part group where a set of parts laid out in one researved area, which is designed to complete a specified set of products. The workers in a group share a series of common output targets in terms of lists of products to be completed by a series of common due dates. In machine grouping major concern is machine and a set of workers and a set of machines laid out in one researved area and the parts are grouped according to machines. A brief literature survey on use of groups in production organization is outlined here.

2.1 Part grouping methodologies:

Over the past decade many researches have been carried out on the cell formation problem. Production Flow Analysis (PFA) developed by Burbidge[2] is one of the earliest and widely used analytical methods . The PFA, makes use of the information contained on route sheets rather than part drawings. Workparts with identical or similar routings are classified into part families. PFA is used to analyze the operation sequence and machine routing for the parts to be produced in a given shop. These families can then be used to form logical machine cells in a group technology layout. Out of the three levels of analysis in PFA namely : factory flow analysis, group analysis, and line analysis, the group analysis may be the major portion and the most difficult part of his approach. As discussed by King and Nakornchai[21], Burbidge's approach often requires the ability of pattern recognition, subjective evaluations and production know-how throughout the design work, and hence cannot be effectively performed by the computer. The main feature of PFA is that it involves the systematic listing of the parts in various ways, wuth the expectation that groups of machines and parts may be found by very careful inspection.

Hitomi and Ham[15] have formulated an integer programming(IP) model for scheduling a cell-based multistage flow-shop manufacturing system. They used a branch-and-bound method to solve the model and found the optimum sequences of cells that the jobs ought to visit. Then they proceeded to find the optimum machining speed by using the optimum solution of the Integer Programming model. Ham *et al.*[16] have developed and expanded this model to include the due-date constraints and the primary objective of their modified IP model is to minimize the number of tardy jobs. Hitomi and Ham[17] have considered the loading problem of a cellular shop where each cell contains a single machine, and the lot sizes of the items are predetermined. An integer programming model is used to maximize the total of lots of items produced such that the constraint on the total available shop production time is not violated. Again a branch-and-bound method is employed to find the optimum product-mix and this result is used in a nonlinear programming model to determine the optimum machining speed.

Gupta[11] presents a similarity coefficient that incorporates relevant production data such as part types, production volume, routing sequence and unit operation time at the early stages of grouping decisions. The model also suggests a methodology for evaluating alternative solutions from one or more algorithm on a quantitative basis. Richardson[29] proposed a methodology to create part families and machine cells based on the combination of three proximity measures. The basic criteria of these measures are tooling, processing machines, and the sequence of operations of manufacturing parts. The proximity measures are integrated into one similarity index called "Weighted Similarity". Each proximity measure contributes a specified fraction or weighted value toward the final grouping index. The weighted similarity measure is used as a flexible tool for part and machine groupings. An algorithm is developed to generate part families and machine cells based on this measure.

2.2 Machine grouping methodologies:

McAuley[24] for the first time used a single linkage (SLINK) clustering algorithm to form machine cells. His analysis to form machine groups was based on "Jaccard similarity coefficients" between machines. The method is a hierarchial process of machine grouping, represented as a tree diagram(often called a dendogram) using similarity coefficients between pairs of machines. Machines were grouped having mutually high similarity coefficients. The machine group formation was considered first, to be followed by the assignment of parts to machine groups. The major disadvantage of McAuley's approach was that the decision in grouping machine M_i into machine cell MC-j is strictly based on the similarity factor of machine M_i with the similarity of only one of the machines in machine cell MC-j. The major advantages of SLINK are its simplicity and minimal computational requirements. In SLINK, once pairwise similarity coefficients are calculated and the similarity matrix is constructed, the letter can be used to develop the dendogram which represents the machine cells at different threshold values. This is true because the similarity coefficient between two machine cells is defined based on a single link(similarity coefficient) between two members of the two cells which is already stored in the similarity matrix[35]. The major drawback of SLINK is the chaining problem which is the process of joining cells together based on a link between two of their members. Due to the chaining problem, two machine cells may join together just because two of their members are similar, while the remaining members may remain far apart in terms of similarity. This may result in formation of machine cells containing machines which do not contribute to the improvement of the cell performance in terms of better scheduling.

Another group of algorithm works on the matrix ($B=AxA^T$) to form the groups where A is the machine component matrix. These include bond energy algorithm of McCormick *et al.*[23], clustering and data recognition algorithm of Slagle *et al*[37]. The network formulation methods represent the matrix (A) in the form of a bi-partite graph and use the network decomposition methods to form the groups. Examples are the methods of Chandrasekaran and Rajagopalan[9]. Many of the methods of part family/machine group formation are based on the machine-component matrix. One group of algorithms successively rearranges the rows and columns of the matrix(A) to form the groups. These include rank order clustering method (ROC) of King[18], direct clustering algorithm(DCA) of Chan and Milner[6], ROC2 of King and Nakornchai[21], occupancy value method of Khator and Irani[22]. The ROC algorithm was proposed by King as a hierarchical process of machine grouping which include the different production strategies, such as tooling requirements. The ROC was generated as a diagonalized groupings of part-machine matrix entries. ROC2 and DCA may be well organized algorithm for cell formation at present. They are human-computer interactive algorithms and both system to be effective for the treatment of exceptional elements and bottleneck machines. In each algorithm, cell entries are either $x_{ij}=1$ or $x_{ij}=0$, for all i and j where i is the index of parts and j is the index of machines. A cell entry of $x_{ij}=1$ does not include the quantity such as machining load but merely means a flag for machining requirement. The ROC2 algorithm is the extensive version of the ROC algorithm, which overcomes a weakness of ROC having a computational complexity of cubic order. The ROC2 algorithm consists of row reordering and column reordering routines. These routines are carried out in an iterative manner to rearrange rows and columns of the matrix until no more changes of the matrix form are obtained. Although this algorithm does not use binary weights utilized for the rearrangements of rows and columns in the ROC algorithm, the reordering operations are equivalent to those of ROC in essence. That is, the row reordering and column reordering are equal to the rearrangement of rows and columns in a descending order of binary ranking respectively. Thus the ROC2 algorithm clusters cell entries of $x_{ij}=1$ along the diagonal of the machine part matrix in a resultant form.

Seifoddini [35] used an average linkage clustering (ALC) algorithm to form machine cells for cellular manufacturing applications, and thus overcome the machine chaining problem. In ALC, the similarity coefficient between two machine cells is defined as the average of pairwise similarity coefficients between all members of the two cells. Since in ALC, two machine cells merge based on the overall similarity coefficient between all their members, it is unlikely that two similar members in two cells, cause the cells to merge while other members are not similar enough. ALC usually works the same way as SLINK except that any time a new machine cell is formed the similarity matrix should be revised. There are more intercellular moves in the solution generated by SLINK than in the solution given by ALC. The ALC eliminates the formation of enlarged cells due to the chaining problem, generates machine cells with higher overall similarity among their members and reduces the number of intercellular moves by assigning machines to cells that their members have the largest number of common operations with them. The limitation of ALC is that, the dendogram cannot be constructed as easily as in SLINK. As reported by **Chow and Hawaleshka**[7], the major drawback of ALC algorithms lie in the definition of their similarity factor, which is computed as a percentage of the total number of similarity of parts required to be processed by the both machines M_i and M_j divided by the total number of parts to be processed by either machines M_i and M_j. This similarity factor does not recognised the precise number of intercellular movements of parts between cells because the percentage in a cell with high intercellular movement would be the same as a cell with a low intercellular movement. So they proposed an algorithm just for the specific purpose of machine chaining problem in cellular manufacturing environment. Rajagopalan and Batra[27] developed a graph theoretic approach which uses cliques of the machine graph as a means of grouping. Steudel and Ballakar[36] suggested a two stage dynamic programming heuristic which first determines the optimum chain so that the sum of the bond values among the machines (which are calculated based upon part routing and production requirements) is maximized and then partitions the chain to form machine groups. They develop the clustering algorithm which establishes similarity among work centres based upon within- cell utilization of each work centre. The algorithm considers criteria such as work load on individual work centre, total fractional work load of a part type and maximum number of machines for the grouping of machines and components. The within-cell utilization of each work centre is determined progressively, as one or more work centres and part types are entered in a cell, and it is compared against a user provided value for a factor called Cell Admission Factor (CAF). A considerable amount of experience and subjectivity is required for the user to determine a reasonable value of CAF Carrie[8] has presented an application of numerical taxonomy of group technology and plant layout, and developed a computer program for production flow analysis.

Heragu[14] solved the machine grouping problem in three stages. In the first stage, the machine grouping problem was solved using a suitable heuristic algorithm. In the second and third stages, the machine cell and machine layout problems are solved. The heuristic algorithm used for solving the machine grouping problem indicates a relative positioning of the machines and machine cells. Sule[32] proposed a new procedure for machine grouping and job allocation in cellular manufacturing. The procedure involved in tabular method is simple in its formulation and calculations. It also provide understanding of the structure of the problem, permitting a degree of flexibility that an analyzer can utilize in satisfying additional goals or constraints such as on capital expenditure and space utilization.

2.3 Simultaneous consideratios of part and machine grouping methodologies:

Choobineh[3] proposed a two stage framework for the design of cellular manufacturing systems. At the first stage, parts are grouped according to their similarities of operations sequence to form part families. The second stage forms the machine cells using mathematical programming. The proximity measure of operations sequence is an extension to the Jaccordian Similarity Coefficient (JSC). Clustering techniques, with a new similarity measure based on the manufacturing operations and their sequences, are used to form part families. An integer programming model is then developed to determine the type and the number of machines in each cell and the assignment of part families to cells. **Kusiak**[20] presented a three stage procedure for configuring machines and parts into manufacturing cells. First, operations are assigned with the objective of minimizing the deviation between the available capacity and the workload assigned to each machine. This results in a machine-part matrix, which is then manipulated using an extension of King's algorithm to form machine-part groups. Then a direct search algorithm is used to determine the number of cells, and the composition of each cell.

2.4 GT Cell formation in FMS:

Gunasingh and Lashkari[13] deals the problem of cell formation in flexible manufacturing system with the identification and assignment of part families and their associated machines to cells. First the machines are grouped into cells based on the processing requirements. The grouping of parts and machines to form cells is based on the capabilities of the machines to process the parts under consideration.

Ozden *et al.*[26] developed a dynamic programming based formulation to schedule jobs effectively in the Flexible manufacturing environment. The jobs may form several distinct groups to be scheduled for processing on a single facility.

Dutta and Lashkari[10] proposed an external-criterion-based procedure for clustering a set of parts into families. The external criterion is the specified number of families in the design-based grouping. A design based configuration of families is initially chosen: the procedure then reallocates the parts among families to reflect identical processing and tooling requirements. A criterion entitled "overall dissimilarity coefficient" (ODC) has been defined and employed to facilitate the transfer of parts between families and an algorithm is developed to carry out the reallocation.

Rasaratnam[28] viewed the flexible cellular manufacturing philosophy by identifying the key machines representing the manufacturing cells and as such determine the final part-machine clusters. He proposed three different methods for performing this identification and a more complete method have developed taking into consideration the sequence of operations exhibited by parts for minimizing total intercell and intracell moves. The total moves contributed by all parts have been evaluated as a weighted sum of both intercell and intracell moves.

F. Oba[25] developed a systematic method of computer-based design system which is entitled as **CAFPLAN-1** (computer aided factory planning system-1) which consists of four main stages :(1) select the alternative machines, (2) construct the cellular structure with structural matrix, (3) generate mutually independent cells, (4) specify and remove the bottleneck machines or exceptional elements. In CAFPLAN-1, the quantitative treatments are possible for the problems with respect to the alternative machines, the allocation of machines to the cells, the workload balance among machines, the machine utilization and so on. The resultant structure of FMS constructed by the proposed method may be optimal in the sense that the correlation coefficient between parts and machines is maximum and the total number of machines required is minimum.

A comprehensive study of the previous researches reveals the fact that these were primarily concerned with the development of efficient algorithms so that parts and machines could be grouped together. Most of these researches were based on a single similarity criterion such as machine similarity based on parts or tools or operation and part similarity based on machine requirements or tooling requirements etc.,ignoring other parameters such as production volume, tool cost, operation cost, machine cost etc. which may prove to be relatively more important in the grouping problem. However such type of grouping technique cannot assure a optimal planning in the economic point of view. Thus in the present research work, construction of cellular structure was forwarded. This structure can simultaneously consider both the machines and parts and also can optimize the cost.

Chapter - 3

STUDY OF PRESENT MANUFACTURING SYSTEMS

3.1 Computers in Manufacturing

3.2 Computer Integrated Manufacturing

- 3.2.1 Nature and role of the elements of the CIM system
- 3.2.2 Economic advantages of CIM
- 3.2.3 Social drivers of CIM
- 3.2.4 CIM strategies for accomplishment of the goal

3.3 FMS as a microsm of Computer Integrated Manufacturing

3.4 Flexible Manufacturing System

- 3.4.1 Components of an FMS
- 3.4.2 Types of systems
- 3.4.3 Field of applicability of FMS Technology
- 3.4.4 Benefits of FMS

3.5 State of technology in Bangladesh

- 3.5.1 Need for adaptation of Adanced Manufacturing Technologies
- 3.5.2 Problems and Constraints of adaptation of Advanced Technology in Bangladesh

3.6 Available opportunities for late starters

3.7 Applicability of Flexible Manufacturing Cell in Bangladesh

CHAPTER–3

STUDY OF PRESENT MANUFACTURING SYSTEMS

The present manufacturing system is designed and adapted so as to be able to keep pace with the changing demand. The manufacturing companies would have to retain their customers by being able to produce the highest quality products at the lowest possible cost. The companies would then require continuous evaluation and perhaps redesign of the product. This necessitates the introduction of Computer Integrated Manufacturing and Flexible Manufacturing System.

3.1 Computers in Manufacturing:

In the contemporary manufacturing world and developed industrial society, the computers have become one of the basic tool. Perhaps the most readily discernible computer applications in manufacturing have been in the area of numerically controlled (NC) machine tools. From its very inception, NC has involved the use of computer assistance for program development. Direct numerical control (DNC)- in which one computer feeds data to a group of NC machines as needed. More recently, computer numerical control (CNC) - which uses a dedicated computer within a numerical control system - bring the computer into more direct contact with the machine tools.

Elsewhere in the manufacturing environment, computers are active in manufacturing engineering, materials management, machine monitoring, scheduling and production control, and management information systems (MIS). Without necessary planning in that way, many companies in the country are finding themselves deeply involved in some aspect of computer-aided manufacturing (CAM). A few effective utilization of computer technology in the country are in the quality control (PADMA Textile, BEXIMCO), operation control (MATADOR Toothbrush company), assembly (Philips) etc. The trend of future increased use of computers in manufacturing is therefore envisaged in the country.

Computer aided design (CAD) ranges from the use of computers to perform isolated calculations to the ability of a system to compile a bill of materials. Design can now be created on interactive graphic computer terminals, which place a vast data-base at the designers fingertip and, at the same time, force the use of established technology. The result can often be translated directly into such manufacturing instructions as NC machine tapes.

Perhaps the biggest motivating factor leading to the increasing application of computers in manufacturing is the changing nature of the industry, from a mass-production-oriented practice based on long model runs to a more batch like operating scheme that can respond quickly and efficiently to the rapidly changing demands of the market place. Two very interesting experiences of computer applications are given below.

"A typical system would consist of a number of basic, numerically controlled machining centres supplied by a part handling system - all under the control of a minicomputer, which would be tied to a larger supervisory computers. Such a system could be quickly programmed to do work on a number of different parts as long as they were all within the size range."- an experience in General Motors, U.S.A.

The major barrier to greater use of computer-related manufacturing, according to many manufacturers, has been the high cost involved. But that picture has changed dramatically over the years. "Today's microcomputer, as a cost of perhaps $300, has more computing capacity than the first large electronic computer, ENIAC. It is 20 times faster, has a larger memory, is thousands of times more reliable, consumers the power of a light bulb rather than that of a locomotive, occupies, 1/30,000 the volume, and costs 1/10,000 as much. It is available by mail order or at your local hobby shop"- an experience from Intel Corporation, U.S.A.

Another barrier to manufacturing engineers in their applications of computers is a basic lack of understanding. The complexity of computer-aided manufacturing technology has grown to a level such that even managers who processed through engineering-related departments often can not fully understand the details of the computer-aided manufacturing projects, their subordinates propose. But of course, an understanding of the intricacies of computer programming or the technology of solid-state electronics is not at all necessary for the wise use of computers. Things are changing, today both the hardware and software of computer is becoming more and more user friendly.

3.2 Computer Integrated Manufacturing:

Computer-integrated manufacturing (CIM) is the term used to describe the complete automation of the factory, with all processes functioning under computer-control and only digital information tying them together. In CIM, the need for paper is eliminated, and so also are most human jobs.

The technology that has had the greatest impact on production systems over the last several decades is computer technology. The computer-integrated manufacturing is a goal, not a destination. A factory cannot purchase CIM off a shelf, or even locate two experts who can agree on what it is. Instead a factory which has adopted the CIM goal of implementing in the whole manufacturing system, must integrate the different functions- design, manufacturing, and business operations into a unified, well-coordinated and smooth running system. A series of coordinated, discrete acquisitions and implementations, chosen on a basis of most effective use of company resources, is the most efficient means of managing toward CIM.

CIM represents the full range of the capability potential which the digital computer holds for manufacturing. The potential is three fold. First the computer has unique potential to provide manufacturing with two powerful capabilities, never before available, such as:

i) Online variable program (flexible) automation.

ii) Online moment by moment optimization.

Second, and the very important that, the computer has the capability to accomplish the above not only for the hard components of manufacturing (the manufacturing machinery and equipment), but also for the soft components of manufacturing (the information flow, the databases, and so on). Third and of utmost importance that, the computer has the capability to do the above not only for the various bits and pieces of manufacturing activity but also for the entire system of manufacturing. The computer therefore has tremendous potential to integrate the entire system and thereby produce what is called the computer integrated manufacturing systems.

3.2.1 Nature and role of the elements of the CIM system:

This generic concept of the CIM system is shown in Fig 3.1. It may be defined as a closed-loop feedback system in which the prime inputs are product requirements (needs) and product concepts (creativity) and the prime outputs are finished products (fully assembled, inspected, and ready for use). It is comprised of a combination of software and hardware, the elements of which include product

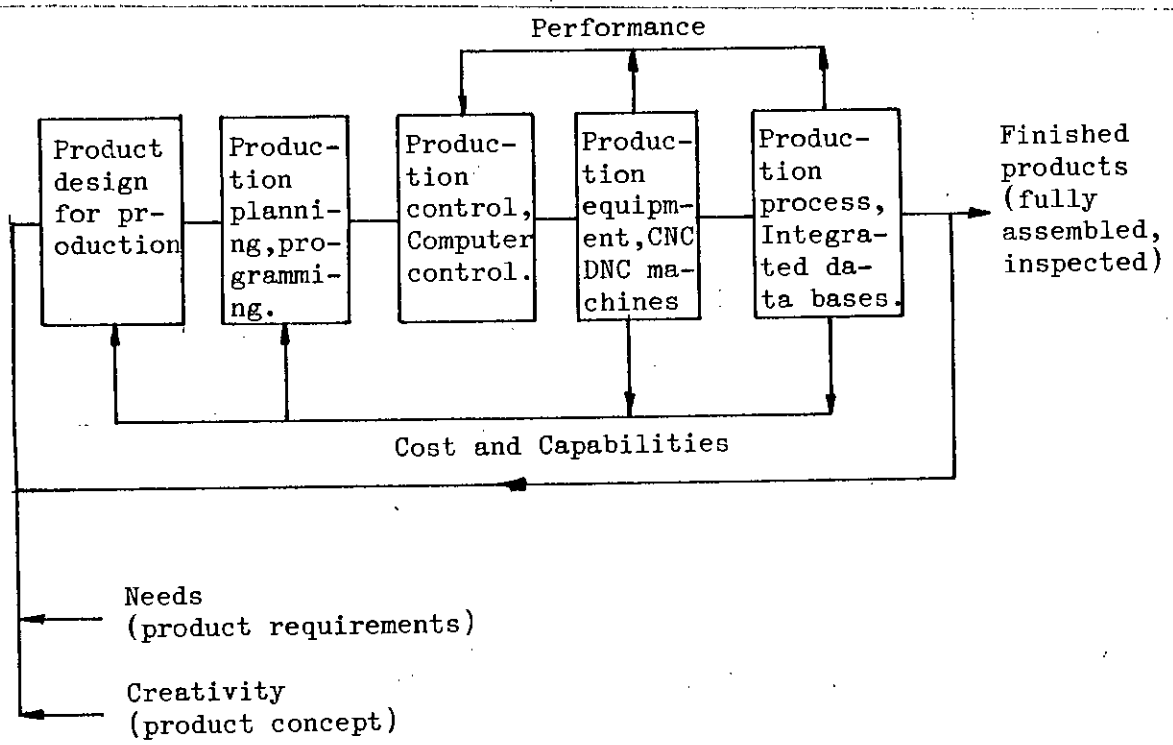

Fig 3.1 : Computer Integrated Manufacturing System[5]

design (for production), production planning (programming), production control (feedback, supervisory, and adaptive optimizing), production equipment (including machine tools), and production processes (removal, forming, and consolidative). It is amenable to being realized by application of systems engineering and has the potential of being fully automated by means of versatile automation and of being made fully self-optimizing (adaptively optimizing). The present major resources for accomplishing this are the computer-related technologies.

Figure 3.1 illustrates the five main elements of the future full CIM system: product design, production planning, production control, production equipment, and production processes. The important concept to recognize is that all the types of activities, equipment, and processes represented by these terms are, and must be, an integral part of the manufacturing system which is in the process of being automated, optimized, and integrated by applying the computer to these tasks.

It is this concept which provides the background for today's strong technological trend toward development and implementation of computer-automated, computer-optimized, and computer-integrated manufacturing- now being collectively called computer-integrated manufacturing. However, it should be recognized that, as yet, full CIM has not been realized in practice anywhere in the world.

The reason for the preceding two statements can be recognized most readily by a simplified description of the roles and interrelations of the five elements shown in Fig 3.1.

1. ***Product design*** establishes the initial database for production of proposed product. In a CIM system, this is accomplished through sub activities as geometric modelling and computer-aided-design while considering the product requirements and the product concepts generated by the creativity of the design engineer. Ideally, however, in a CIM system the design process should be constrained by the costs that will be incurred actual production and by the capabilities of existing production equipment and processes.

2. *Production planning* takes the database established by product design and enriches it with production data and information to produce a plan (program) for the production of the product. In a CIM system, this planning process should, ideally, be constrained by the production costs which the plan will engender, and by the capabilities of existing production equipment and processes, in order to generate an optimized plan.

3. *Production control* of the actual activity of producing the product according to plan, requires further enrichment of the database with performance data and information about the production equipment and processes. In a CIM system, this requires such activities as modelling, simulation, and computer-aided scheduling of the production activity. This should include, ideally, online dynamic scheduling and control based on the real time performance of the equipment and processes to assure continuous optimization of the production activity.

4. *The production equipment* further enriches the database with equipment and process data and information, resident either in the operator or the equipment, to carry out production processes. In a CIM system, the equipment consists of computer-controlled process machinery such as computer numerically controlled (CNC) machine tools, flexible manufacturing systems (FMS), computer-controlled robots, flexibly automated materials-handling systems, computer-controlled assembly systems, flexible automated inspection equipment, and so on.

5. *Production processes* that create the finished product are carried out by the production equipment. This is done under the guidance of the data, information, and knowledge resident in the operator or for CIM systems, in the equipment and the total integrated database supporting it.

3.2.2 Economic advantages of CIM:

A variety of specific economic drivers of the trend toward full CIM have already been documented, and two of these stand out as follows[5].

i) the potential reduction of the tremendous economic waste resulting from huge quantities of work in process in conventional factories and

ii) the potential reduction of the equally great economic waste resulting from the very low percentage utilization of capital equipment in those factories.

The significance of these advantages can best be illustrated by a simple example for the production of machined parts[5]. When the time spent by the average workpiece in going through a conventional factory is analyzed, it is found that only about five percent of the time is actually spent on machine tools and, of that five percent only about 30 percent (or 1.5 percent of the total time) is actually spent as productive time in removing metal. This result is illustrated graphically in Fig 3.2. The situation highlights the two main areas in which by far the greatest improvement in the economy and productivity of manufacturing can be made :

i) Reduction in idle time for parts in process in the shop. Hence,reductions can be achieved both in the extremely high inventory of unfinished parts on the shop floor and reduction in the number of finished parts waiting for others in process so that assembly of the product can be done. The application of CIM, even in its present initial state of development,has already demonstrated the capability to free up most of that idle capital.

ii) The second area of potentially major improvement is in the percentage of machine utilization. The thirty percent machine utilization, when a machine is actually being operated must be combined with the fact that the average machine is waiting approximately fifty percent of its time for parts on which to work[4]. As a result, the average machine tool in batch-type shop is being utilized (i.e., actually cutting metal) only about fifteen percent of the time. Its actual utilization may be as low as five percent or less because it is rarely operated by man 24 h/day. This represents only about five percent utilization of the capital invested in machine tools. Therefore, the amount of capital lying idle is often greater than the capital required to equip the plant with machinery for Computer Integrated Manufacturing.

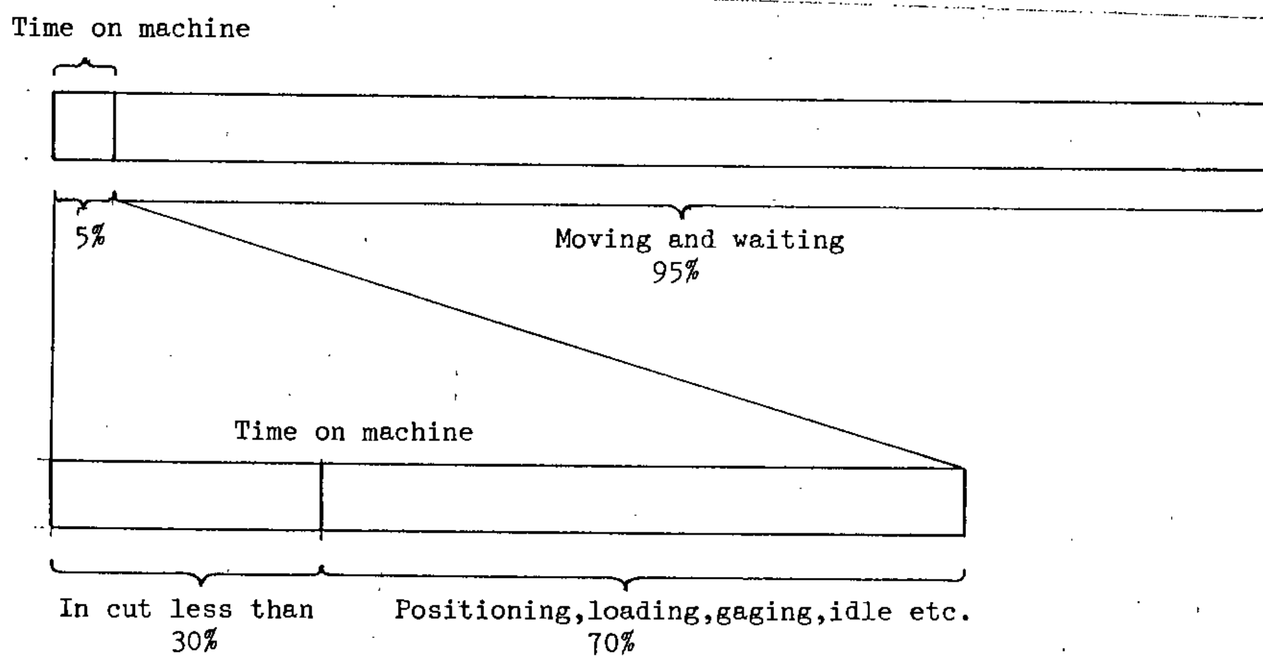

Fig 3.2 : Analysis of time spent by average workpiece in moving through a conventional plant[5].

3.2.3 <u>Social drivers of CIM:</u>

Concerning the trends, that of the changing employer attitudes, the employers are now clearly recognizing the human need for the nature of work to be such as to assure the worker of deep satisfaction from performing it (as well as freedom from potentially dangerous or unhealthful conditions). Thus, much attention is being directed to methods of accomplishing that end. Here the pioneering work on job enrichment by such investigators as Herzberg is proving to be most useful. Herzberg's significant finding[5], is that, although the so-called hygiene factors of a job (i.e. company policy and administration, supervision, work conditions, salary, and so on) can cause dissatisfaction if they are not satisfactory, they can do little to provide ongoing job satisfaction. Instead, job satisfaction derives from the adequacy of the so-called motivator factors of a job, such as, opportunity for achievement, recognition, responsibility, advancement, growth, and so on. The major feature of jobs which provide such opportunities is participation in decision making or participative management. Here again, computer-integrated manufacturing offers considerable benefit. It can substitute challenging, satisfying, participative management-type jobs (which interactive computer systems offer) for the unpleasant, physically taxing, or even unsafe and unhealthful jobs found on the conventional factory floor. Thus, CIM is already proving to be a powerful tool for management to respond positively to:

i) the trend toward increasing efforts to improve worker satisfaction and
ii) the need to provide jobs which would suit better to the educational level of present day labour force, and would help in attracting capable workers.

It will allow the worker not only to be released from operation of dangerous machines but also, eventually, to spend very little time each day on the noisy factory floor.

3.2.4 CIM Strategies for accomplishment of the goal:

As a result of current technological trend toward computer-integrated manufacturing and its perceived large economic and social benefits, realization of full CIM has now become a major long-range goal of many industrialized nations and of much of the manufacturing industry throughout the world[5]. As a result, many industrialized societies and many manufacturing companies are today pursuing large programs of research, development, and implementation of CIM to hasten the realization of fully computer-automated, computer-optimized, and computer-integrated factories.

The strategy being followed, therefore, is to develop and implement a series of viable, economic steps in the form of shorter-range programs of research, development, and implementation[1]. Each of these programs should have two main characteristics:

i) Potential for sufficient economic return to justify the program by itself and to generate or free up capital to support development and implementation of the following step(step ii below).

ii) Compatibility with the eventual attainment of the goal of full computer automation, optimization, and integration of manufacturing.

As a corollary, the strategy being followed for the technological aspects of the evolutionary development is as follows:

1. Plan from the top down (to assure compatibility of each step with all others).
2. Implement from the bottom up (to permit nondisruptive stepwise building of the total system).

Such a strategy clearly requires that a company develop a master plan for research, development, and implementation of CIM if it is to be successful in attaining its goal. This master plan should be a dynamic plan that is updated at regular intervals to take into account changes in technology, business conditions, and so on. It is interesting to note that those companies throughout the world which are achieving the most successes from their CIM programs are following the above strategy and, in most cases, are using comprehensive and dynamic master plans.

In the context of Bangladesh, it is not yet fully aware of the consequences which occur in terms of the growing importancey of the development of Computer Integrated Manufacturing techniques. Where all the other industrialist societies have already a step ahead towards CIM, in the country some prerequisities must be meet before a CIM implementation could be successful. These are as follows:

i) Top level management must have an attitude to believe in CIM. It does mean ongoing support, commitment and enthusiasm.

ii) Participation of managers and engineers in central coordinating is necessary.The CIM system design must be a joint product of those who will use it and who will operate it.

iii) Provide training in computer systems to the company employees to buildup the basic computer skills. All employees should have the opportunity to learn how the system operates and how it can serve them in their work.

Because of the inherent budgetary constraint in the country, prospective farms must plan and initiate sound steps toward CIM systems. It is now clear that rapidly advancing technology renders some existing products obsolete and process noncompetitive. Unless the company's of the country prepare themselves, to achieve rapid product design innovation, to allow efficient manufacturing process planning and to utilize sound decision support system(DSS), they can expect to be eventually forced out of business by competition. Thus when the economic and other aspects of a CIM system are considered in the country one must also compare with the losses without the system. As the investment decisions on the traditional discounted cash flow financial justification methodologies best suited to meet short term profitability criteria rather than long term strategic goals, the traditional financial justification methodologies, when used to evaluate the implementation of CIM systems, may result in the rejection of high technology equipment and systems. However a number of nontraditional accounting system to evaluate the CIM implementation process was developed and can be used[5].

The government of Bangladesh can be very instrumental in the process of moving the industry toward CIM. The implementation of CIM technology in the industry is vital for the improvement of the economy and is therefore required to be an issue of national importance and is worthy of subsidy. Liberal tax incentives in the areas of investment tax credits, CIM training credits, special CIM technology research opportunities would be required.

3.3 FMS as a microcosm of Computer Integrated Manufacturing:

The development and implementation of full CIM has not been realized anywhere in the world. Thus, there is as yet no significant performance data which can document the benefits of full integration[5]. However, on the factory floor, integration has proceeded further than in any other sector of the manufacturing system. It has taken the form of flexible manufacturing system (FMS). Their importance stems from the fact that such systems are not stand-alone pieces of equipment, they are fairly sophisticated integrated systems of a number of software and hardware modules. They include integrated automation of not only such "hard" functions as workpiece and tool transport, loading, unloading, and changing but also of such "soft" functions as planning, scheduling, and control of workpiece and tool flow and workstation load. Thus, in a sense, they are microcosms of a portion, at least, of the future computer-automated, -optimized, and -integrated factory.

3.4 Flexible Manufacturing System:

With the beginning of mass production, the demand stimulated the design of very complex and inflexible manufacturing systems. But today industrial engineers often have the question as what to do with all the dedicated machinery used in mass production at the end of the life cycle of a product. Frequent shifts in consumer preference, competitive strategies, frequent change in situation of availabilities of raw materials, different regulatory climates are all outside forces that are making manufacturers emphasis on holding open all possible options.

Insurance against unforeseen circumstances is a prime reason for the current emphasis for flexibility. Customers want tailored products, often in quantities so small as to render them unacceptable for mass production. Mass production and hard automation as a concept is becoming more and more obsolete. Even the automobile industry, which gave the world such things as the dedicated moving assembly line and the word automation, is now taking about "high-volume" manufacturing rates rather than "mass production".

Hence the manufacturing philosophy like flexible automation, families of parts, cellular manufacturing system achieves the continuous consequences of the industrial engineers. Each of the above terms irrevocably tied to developments in control technology, which have led the way for what has come to be called the second Industrial Revolution. And hence comes a single concept that tries to tie them all together, the flexible manufacturing system (FMS).

3.4.1 Components of an FMS:

A flexible manufacturing system consists of a group of processing stations (predominantly CNC machine tools), interconnected by means of an automated material handling and storage system, and controlled by an integrated computer system[12]. What gives the FMS its name is that it is capable of processing a variety of different types of parts simultaneously under NC program control at the various workstations. The machining process is presently the largest application area for FMS technology. However, it seems appropriate to interpret FMS in its broader meaning, allowing for a wide range of possible applications beyond machining. These include:

: Automatic material handling between machines
: Numerical control machine tools and CNC
: Computer control over the material handling system and machine tools (DNC)
: Group technology principles.

There are three basic components of a flexible manufacturing system:

i). Processing stations. In present-day applications, these workstations are typically Computer Numerical Control (CNC) machine tools that perform machining operations on families of parts. However, flexible manufacturing systems are being designed with other types of processing equipment, including inspection stations, assembly workheads, and sheet metal presses.

ii) Material handling and storage. Various types of automated material handling equipment are used to transport the workparts and subassemblies between the processing stations, sometimes incorporating storage into the function.

iii) Computer controlled system. Computer control is used to coordinate the activities of the processing station and the material handling system in the FMS.

One additional component in the FMS is human labour. People are needed to manage the operations of the flexible manufacturing system. Functions typically performed by people include loading raw workparts onto the system, unloading finished parts (or assemblies) from the system, changing and setting tools, equipment maintenance and repair, NC part programming, and programming and operating the computer system.

3.4.2 Types of Systems:

There are various ways to classify flexible manufacturing systems. One classification that is sometimes made in FMS terminology is the difference between a flexible manufacturing system and a flexible manufacturing cell(FMC)[12]. There is no clear dividing line. Generally, the term cell can be used to refer to a machine grouping that consists of either manually operated or automated machines, or combinations of the two. The cell may or may not include automated material handling, and it may or may not be computer controlled. The term "flexible manufacturing system" generally means a fully automated system consisting of automated workstations, automated materials handling, and computer control.

The term manufacturing cell is used largely in connection with Group Technology(GT), but both FMCs and FMSs rely on a GT approach in their design. A distinction that is sometimes made between a flexible manufacturing cell and a flexible manufacturing system is in the number of machines in the grouping. For example a grouping of four or more machines is a system, and three or fewer machines constitute a cell.

Also, flexible manufacturing systems can be described as being either a dedicated FMS or a random-order FMS. A dedicated FMS is used to produce a much more limited variety of part configurations. The geometry differences are minor and the product design is considered stable. Therefore, the machine sequence is identical or nearly identical for all parts processed on the system. This means that a flow line configuration is generally most appropriate, and that the system can be designed with a certain amount of process specialization to make the operations more efficient. Instead of using general-purpose machines, the machines can be designed for the specific processes required to make the limited part family.

The random-order FMS is the more appropriate type under the following conditions: the part family is large, there are substantial variations in the part configuration2s, there will be new part designs produced on the system and engineering changes in parts currently made on the system, and the production schedule is su8bject to change from day to day. To accommodate these variations, the random-order FMS must be more flexible than the dedicated FMS. It is equipped with general-purpose machines to deal with the variations in product and is capable of processing parts in various sequences (random order). A more sophisticated computer control system is required for this FMS type.

3.4.3 Field of applicability of FMS technology:

Flexible manufacturing systems are considered to fill a gap between high-production transfer lines and low-production NC machines. The relative position of the FMS as a means of production is shown in Figure 3.3. For high volumes and output rates, transfer lines represent the most efficient method. In terms of manufacturing efficiency and productivity, a gap exists between the high-production transfer line and the highly flexible NC machines. The solution to this mid-volume production problem is the flexible manufacturing system.

In the mid-volume range, the advantages of the FMS over stand-alone NC are that the production of several products can be intermixed, and production rates are higher. Instead of batching the products one at a time on an NC machine to meet requirements, the various products can be made simultaneously on the system. The setup time for changeover is minimized with an FMS, so the economic batch size reduces to one at the same time that the average production rate increases. Intermixing of products on the system permits the output rate of each product to be set at its corresponding demand rate. This reduces the work-in-process and final product inventories that are so typical of batch production methods.

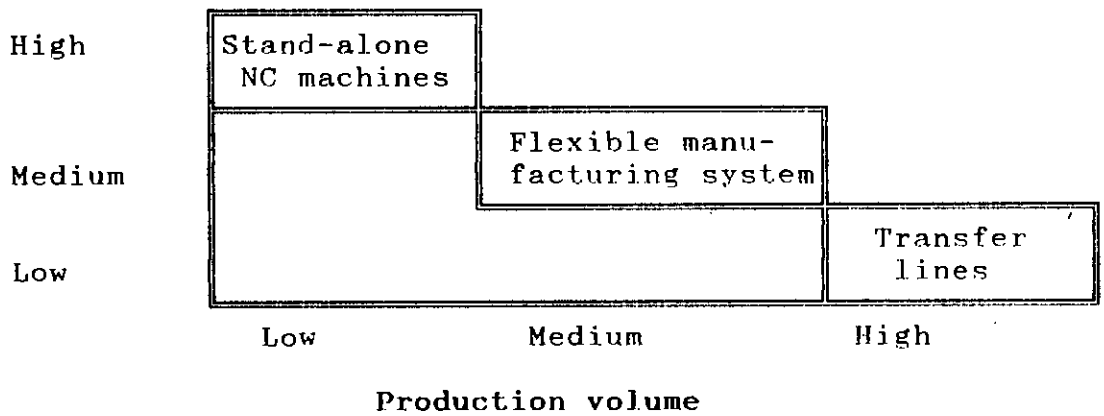

Figure 3.3 : Application characteristics of flexible manufacturing system[12]

3.4.4 <u>Benefits of FMS</u>

A sampling of some of the benefits obtained from experience with actual operation of FMS systems in various countries will serve to illustrate their nature and magnitude. The sampling set forth in Table 3.1 represents a composite of performance results, reported in the literature of there modern FMS's- one Germany, one Japan, and one American [5].

Table: 3.1 Typical Performance Benefits Experienced with Modern Flexible Manufacturing Systems over conventional batch manufacturing system

Quantitified benefits		Percent
Reduction in	Lead time for product	40
	Lead time for parts	53-75
	Required No. of machine tools	53-81
	Required personnel	53-92
	Labour costs for part	90
	Required machining hours	65
	Required floor space	42
	Tooling costs	30
	Total annual costs	24
	Capital investment costs	10
	Inventory of work-in- progress	90

Nonquantified benefits
Improved quality: Higher accuracy and reproducibility Lower rework costs, scrap rates, and quality assurance costs **Closer adherence to production schedules:** No order chasing **Improved working conditions:** Decreased accident risk and physical labour Increased challenge **Increased flexibility:** Increased independence of batch size, types of parts, and production quantities

speaks about volumes concerning the tremendous power of FMS, even in its present elementary form, to improve the capability and cost effectiveness of manufacturing both today and in the future. However the last two entries in the table of quantified benefits are of particular and very great significance. It has been found that they are quite representative of the experience being obtained with the great majority of installations of modern FMSs. What they indicate that the implementation of flexible manufacturing system can be essentially free of cost to the user if properly utilized.

First the reduced capital investment in FMS workstations (due to the much smaller number required because of greatly increased utilization when compared to stand-alone, unintegrated workstations) more than pays for the required additional supporting, integrating facilities. These facilities include not only such entities as the control computer and the work-and-tool-transport equipment but also the software system.

The drastic reduction of work-in-process inventory and stock waiting to be assembled (virtually to zero because of the capability of these flexible systems to produce just whatever mix of parts is required for immediate assembly) frees up sufficient capital (previously lying idle in inventory) to more than pay for the total FMS. Another way of looking at this latter fact is that the just-in-time production, which is made possible by truly flexible automation, allows a plant to turn over its total inventory many more times per year than is possible in a conventional plant.

3.5 State of Technology in Bangladesh:

In Bangladesh, primitive and modern technologies exist side by side in the country. Primitive technologies of tilling the land, innovated thousand of years ago continue to dominate the economy. With a very low literacy rate more people was with primitive tools than with modern machines. Primitive tools and practices, inspite of their lower productivity, account for a greater share of national income. It is the technological primitiveness of the major sector of the economy that lies at the root of country's massive productivity and poverty problems.

The analysis of manufacturing sector currently accounts for about 8% of GDP(Gross Domestic Product) which is very poor and which is as high as 70% for the industrialized nations[31]. The present industrial sector was built up largely during the preindependence period, when industry received some 28% of the total investment. Following independence, the government nationalized about 85% of the capital assets in the sector. However from 1975 onwards, the Government has progressively redefined its approach to industrial development. Two of its central objectives have been

i) To increase participation of the private investors in industry and

ii) To improve operational efficiency and productivity in existing public sector enterprises.

In most industries, processing of raw and intermediate materials involve only simple and less sophisticated operations, such as assembling and packaging. As a result, cost of raw materials generally accounts for a large proportion of production cost, and the value added to the raw materials is low.

It may be mentioned that in Bangladesh most neglected area of productivity and technological research is the Industrial sector. Poor performance of industrial sector may be attributed to poor investment in industrial research. There is no research organization involved with research on absorption of latest technology (computer assisted manufacturing, flexible manufacturing system, ergonomics considerations etc.). Without proper assessment it is generally assumed that Bangladesh Council for Scientific and Industrial Research (BCSIR) is involved with high-tech industrial research. An assessment of the R&D projects of BCSIR will indicate that majority of the research projects are on basic sciences. Small number of research projects may have some linkages with industries. None of the research projects have any links with advanced manufacturing technologies.

In recent years some of the Public Sector corporation e.g. (BCIC, BSEC) have established Research and Productivity unit/cell. It is a positive step towards improving the condition of industrial research. However such decisions should be supported by adequate financial resources and competent manpower.

3.5.1 Need for adaptation of Advanced Manufacturing Technology:

The essence of the famous vicious circle[31] of underdevelopment(Figure 3.4) is that economically underdeveloped or less developed countries cannot overcome

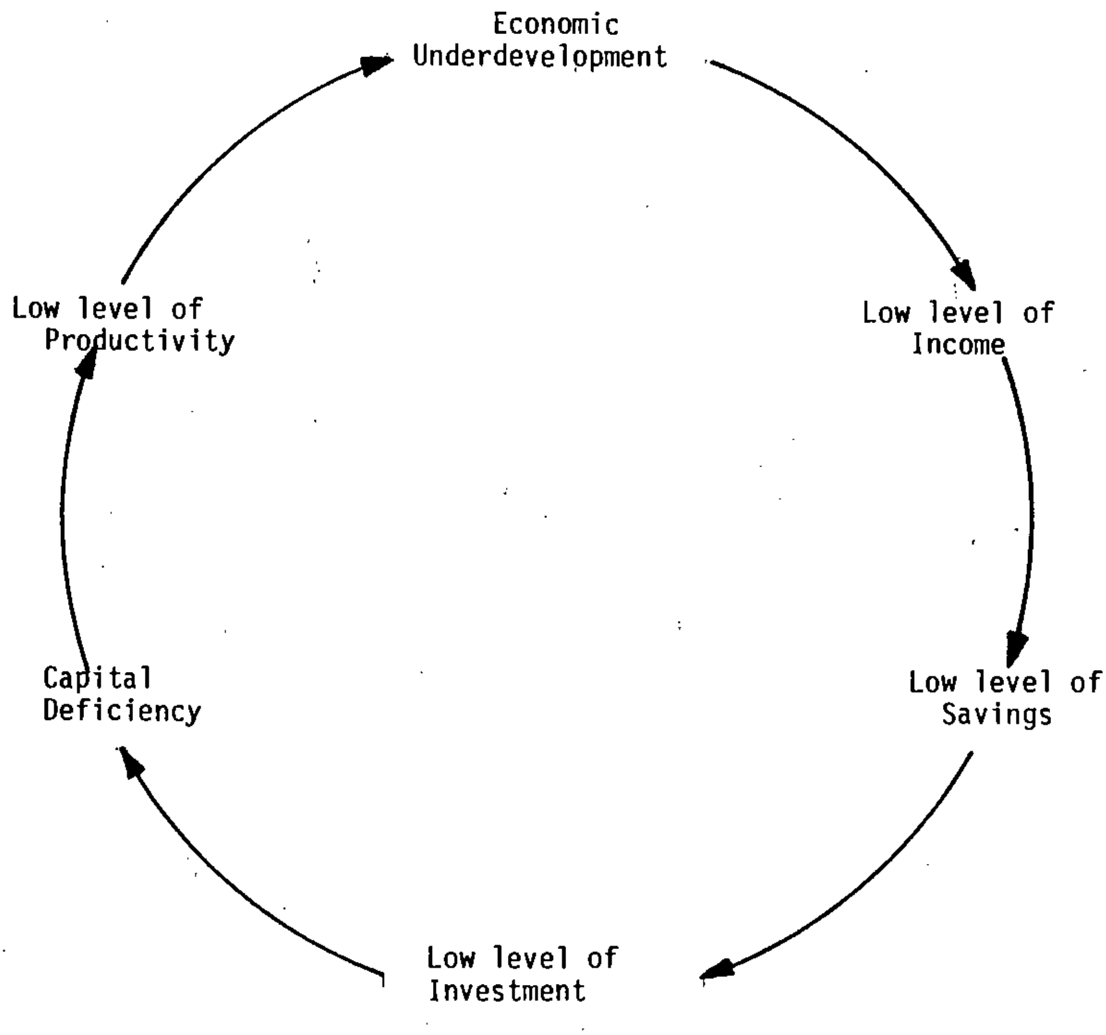

Fig 3.4 : Vicious Circle[34]

their particular status, and they end up at the same point after having tried to develop in many different ways. The concept is illustrated in Figure 3.4.

Figure 3.4 starts with the status of economic underdevelopment. Because of underdevelopment, low level of income is a natural outcome of such economy. It is an established fact that individuals or enterprises have a higher tendency to consume and a lower tendency to save at lower level of income. In economic principles, savings are equal to investment. Less investment means less capital. Although labour is a factor of productivity but its upper threshold is limited for a given technology. Thus capital, in the form of technology has a greater role to play on productivity. Definitely a capital shy economy cannot afford any thing to improve productivity. Thus, such economy with low technology and consequent low income remains in the vicious cycle of under development. Achieving a certain degree of economic development implies breaking the vicious cycle.

Different strategic alternatives to break the vicious cycle are:

i) increased savings
ii) international trade
iii) foreign aid
iv) adoptation of advanced technology.

The strategy of increased savings may be done through either of two general techniques: forced savings and voluntary savings [34]. For underdeveloped economy both techniques hardly give any useful result. The strategy of international trade can help in coming out of vicious cycle by utilizing the benefits of trade in capital formation. This is only possible if the trade is not one sided and it benefits both parties. Under carefully planned circumstances, foreign aids can be used in capital formation or can be used directly in the form of capital and hence break the vicious cycle. But the role of foreign aid today is highly controversial because of the way it is being extended to underdeveloped economies by the developed economies.

In view of the above problems with the first three strategies the fourth one, by process of elimination, because most desirable. Adoptation of advanced technology becomes most desirable to stimulate exports.

Export oriented production technology would help the country break the vicious cycle by increasing its export. But to promote the export we need to produce high quality products at a competitive price in the international market. While all the developed countries use the most sophisticated technology to produce very high quality product at low cost, it is really tough for our country to compete with international market applying lower level of technology. It is now a supreme national requirement to manufacture the industrial products of good quality at low cost which requires the use of advanced manufacturing process.

3.5.2 Problems and constraints of Adoptation of Advanced Technology in Bangladesh:

As nations are not endowed equally in terms of natural resources, development culture and human resource, technological advances had been uneven. This inequality has divided the countries of the world in two major groups - developed and developing countries. Developing countries like Bangladesh fail most of the time to adopt advanced technology successfully to reduce the technological gap. There are myriads of problems and constraints faced by the country which inhibit a successful adoptation of advanced technology in an attempt to establish a technology based development programme. These are:

Problems:[34]

- The first set of problems lies in understanding the unique characteristics and related aspects of technology. For example
  - technology is not just a physical production tool, but really a complex combination of both the tool and the know-how associated with the tool.
  - Technologies as embodiments of such complex combinations, are marketable and have both economic and political values;
  - The world is becoming increasingly inter-dependent due to technological specialisation; and
  - Technological advancement could be considered as a good measure of national development.
- The second set of problems arises due to the existence of indefinitely varied number of preferences and perceptions such as:
  - The general population's preference for common technologies rather than advanced technologies.
  - The unrealistic expectation regarding advanced technology as a by-product of foreign investment;
  - Defining technological appropriateness only with respect to labour intensiveness and
- The third set of problems is associated with the organizational infrastructure and prevailing management practices, which include -
  - Ineffective public sector research and development institutions;

- Knowing science (knowledge) being given operational command over doing science (application), the successful use of which reflects a nations ability to use technology for development;

- Missing or weak linkage between users and suppliers of advanced technologies;

- The absence of any sort of institutionalized attempt at monitoring, forecasting and assessment of technology;

- Choices of technology being generally considered only at the lowest level of planning hierchy.

▮ The fourth set of problems refer to the level of commitment of technological considerations and leadership behaviour, such as:

- Statement of policy-makers not getting sufficient financial, fiscal and legal support;

- Technologists and scientists not being exposed to management and socio-economic development concepts;

- Politicians and planners displaying their own biases or inclinations without a long term compromising approach and

▮ The fifth set of problems may be referred to as the problems of climate represented by the attitudes and preoccupations of the people, such as:

- Attention of top leadership being devoted mostly to crisis management, whether warranted or not;

- High level policy decisions being made in response to immediate political and economic pressures, while questions of long term sustainability and the implications for the less powerful actors in the development process get overridden;

- Scarcity of time, as intellectual priorities are clogged with trivia and ceremonial duties; and

- Finding fault witb others and using the excuse of uncommonness to avoid necessary actions.

<u>Constraints:</u>[34]

The first set of constraints is basically due to the dependence on external assistance, such as:

- decisions with respect to the selection of development projects being conditioned by the funding source;

- the mode of operation of international institutions inadvertently reinforcing dependence;

- assistance being conditioned by considerations other than the developmental needs of the recipient and

- non relevant research activities being undertaken with easily available money from abroad.

- The second set of constraints is primarily due to the demonstration revolution, resulting in :

- aspirations being raised to frustratingly high level by even increasing coverage in mass-media.

- the wide spread use of the power of collective indiscipline for non-developmental expenditures.

- The third set of constraints may be attributed to the situational change faced by the late starters, such as:

- the ratio of naturally available resources to population being worse;

- a high propensity for sub optimization due to narrow specialization and professional isolation; and

- the adverse skill structure of the labour force due to brain drain and degradations of craftsmanship.

3.6 Available opportunities for late starters:

However the situation is not disappointing in the country due to the problems and constraints listed above. On the contrary, as a late starter, the country may have many late starter opportunities. Some of these opportunities are:

- Technical persons do not need to reinvent the wheel. It is possible for them to tap accumulated technologies and knowledge in many ways

  - knowledge can be gained through formal and informal education.
  - effective learning is possible from the experience of both developed and other developing countries.
  - many production technologies are available internationally, however most through transnational companies.

- information about technologies is available from public and private information centres, and
- expertise is available from foreign consultancy service firms.

The country can also take the advantage of the inherent characteristics of the technological change process. Since technological change occurs through a series of successive substitution and diffusion process, there are two significant implications.

- eventual catch up is possible due to the s-shaped growth pattern of any particular technology, and
- leap-frogging is possible sometimes by skipping the intermediate stages of technological change.

Another advantage is the opportunity for avoiding known pitfall, through,

- effective learning from experience of both developed and other developing countries.
- preventing or minimizing the possible negative impacts of certain advanced technologies and

Most of the problems are internal. These problems can be resolved with strong determination and whole hearted commitment at all levels. On the other hand, most of the constraints are external where very little can be done. However the opportunities as late starters are not less important for successful adoptation of advanced manufacturing technology if these are exploited fully.

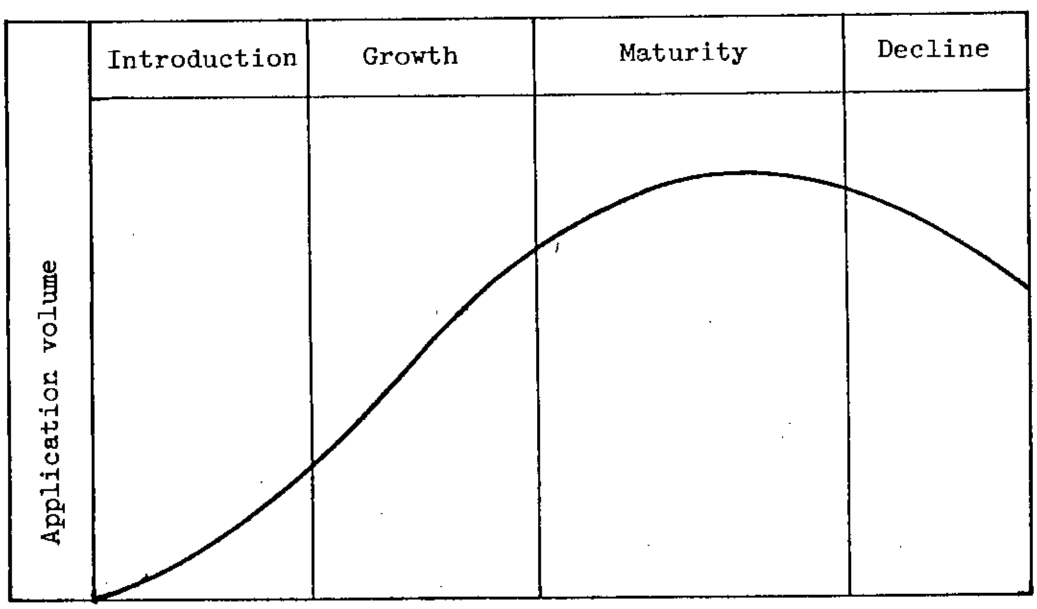

Fig 3.5 : Technology Development Process[34]

As the existing pattern of international flow of technology, is as shown above Fig 3.5, it is now our supreme national requirements to avoid a stagnated situation, our country should adopt strategies to take advantage of late starters opportunities and catch up (even overtake) with the early starters .

3.7 Applicability of Flexible Manufacturing Cell in Bangladesh:

Most manufacturing in Bangladesh is not done with endless assembly lines or other mass technologies. Status of the engineering industry with size of production in the country is shown in bar charts in Figure 3.6[31].

It is shown that size of production of greater than 50 in only about 12% and the rest of all manufacturing is carried out in smaller batches - in lots ranging in size from one or two to fifty. Until recently very little has been done to

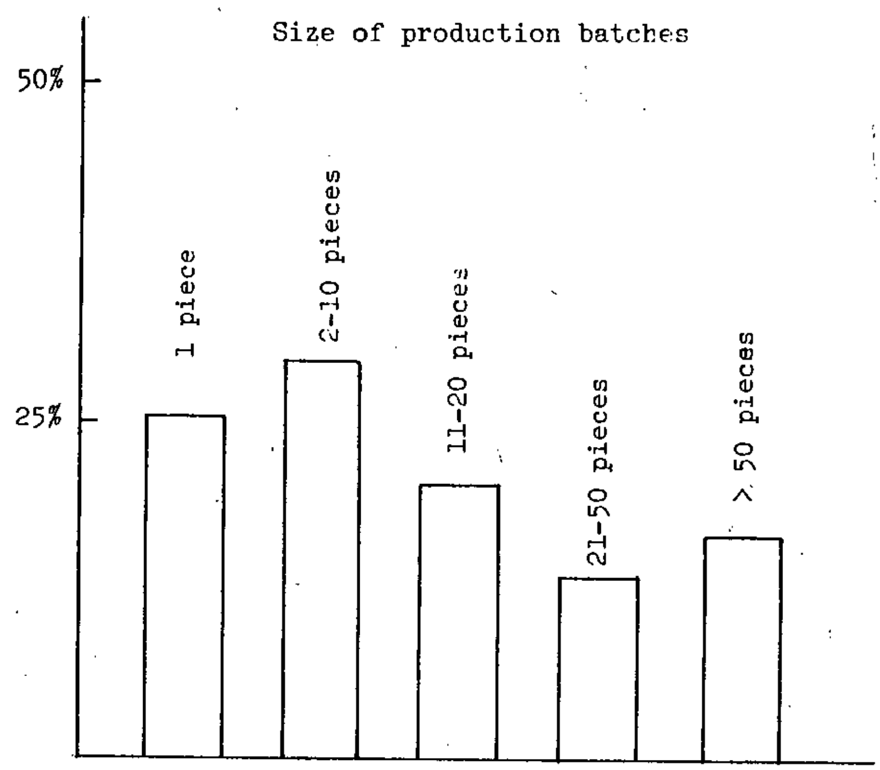

Fig 3.6 : Size of production batches in Bangladesh[31]

improve batch manufacturing worldwide, despite its importance. The seemingly random nature of both design and manufacturing activities in the batch environment have made it difficult to even define approaches to optimization. There were approaches to queuing and sequencing programs in batch manufacturing and to standardization of certain design and manufacturing activities, but these efforts were somewhat limited and never had a great impact.

The problem, of course, is that improvements made to batch manufacturing must be generic if they are to be cost effective. They cannot focus on the production of specific products, instead, they must deal with principles which can be applied to all or at least almost all, the items produced in a batch manufacturing environment. Considering the random nature of batch manufacturing, solving tbis problem has not been easy.

For the survival of Bangladeshi people without abundant natural resources within the country, it is a supreme national requirement to manufacture the industrial products of good quality at relatively low cost and export them to foreign countries. With the low level of technology in manufacturing industry it is impossible to produce high quality products at low cost. Currently, high performance is required first to qualify for the starting line. Quality has become a mandatory requisite for competing. In every corner of the world manufacturers are focusing their attention on quality as a top priority. As the human component of manufacturing, the most expensive and error prone ingredients, becoming lesser and lesser, thereby the world class producers, now come up with products of high quality at low cost. The low labour cost advantage is also becoming a fancy concept, because human involvement in manufacturing industry of industrialized nations becoming lesser and lesser. As discussed earlier, flexibility is the central concept. World class producers must hold their customers by being able to turn out the highest quality product at the lowest cost in small lots while looking at continuous redesign of the product. Honda Motor Co. Ltd., lives and wins by this philosophy. In 1948, Honda was rebuilding small engines for bicycles. In 1949, they began manufacturing 50 cc two-cycle engine themselves. The following year they developed a new four-cycle engine. Then in 1952, Honda started producing frames, chains and sprockets for motor cycles. Less than eight years later, they had made Honda the world's largest motor cycle company[1].

Honda and other world class manufacturers clearly recognize today that the new, continually shrinking product life cycles can no longer support the lengthy design processes typical of most contemporary engineering. To win in today's market place, manufacturers must design and introduce new products rapidly to beat the competition.

According to Foster[38], the key to attacking competitors and defending one's own advantages is in picking the right technology: "Identifying the alternatives and recognizing their limits does not usually lead to an obvious answer. The best strategy may be to pick the adolescent technology with the highest limit because it is never clear when a new technology is really going to emerge.

Foster also gives the following good indications when the current technology may be approaching obsolescence:

1. There is increasing discomfort about the productivity of system developers.
2. Development costs may be increasing, and delays become more common.
3. New applications, innovation, and general creativity wanes.
4. Across-the-board improvements become rate, and system users must be segmented to find productivity increases.
6. There are wide differences in technology spending among competitors that use the same technology, with little or no apparent effects.
7. Frequent changes in management seem to have no impact on technology productivity.
8. Smaller competitors in select niches and/or supposed weaker competitors start succeeding with radical approaches that everyone else says cannot work.

The ultimate solution to be a world class winner is Computer Integrated Manufacturing. But, as discussed earlier, the development and implementation of full CIM has not been realized any where in the world. Again, in CIM, capital is extensive and payback periods are long. The most difficult task is that CIM requires a total commitment from the entire work force including the top management, furthermore, CIM is a complex system and must be supported by many skilled labours. As discussed earlier, implementation of CIM is not a revolutionary process rather than a evolutionary one. One of the key elements of computer integrated manufacturing is Group Technology (GT). As integration of computer with manufacturing is rather easy on the factory floor, the form of flexible manufacturing system with emphasis on group technology will be rather easy for our country. As CIM is the complete integration within the industry and FMS is integration of computer with just at the factory floor which is rather easy as discussed earlier, a step towards flexible manufacturing system , will also be a step towards the complete industry integration that is Computer Integrated Manufacturing. As CIM is a evolutionary process one has to adopt first the flexible manufacturing system to be a world class manufacturer. The present work is therefore directed in this line.

Chapter - 4

MATHEMATICAL MODEL DEVELOPMENT FOR CELLULAR STRUCTURE IN MANUFACTURING

CHAPTER 4

MATHEMATICAL MODEL DEVELOPMENT FOR CELLULAR STRUCTURE

4.1 Stages in Machine Cell placement:

A part that has been designed for manufacturing usually has to be produced by several succeeding manufacturing operations. For this reason it is advantageous to group parts together to families either according to their geometric similarities or to similar fabrication methods. In group technology only the design attributes are considered. But in cellular manufacturing system, considerations are given for part families that have similar manufacturing operations, sequences, tooling requirements etc. The basis for designing cellular manufacturing system is a detailed analysis of the production task, which yields the information on the number of different kinds of parts to be produced, production quantities of each part and process routes given in the form of machining sequence for each process and the operation time on each machine.

Upon initial investigation of the previous work on cellular manufacturing system, it was revealed that, economic studies on cellular manufacturing are yet to be done and to direct its application to parts that can be grouped in a family optimally .

In order to successfully implement the cellular manufacturing technique, the following three problems have to be solved:

- part machine grouping problem
- machine layout problem
- machine cell layout problem.

Diagrammatically this can be depicted as shown in Figure 4.1 below.

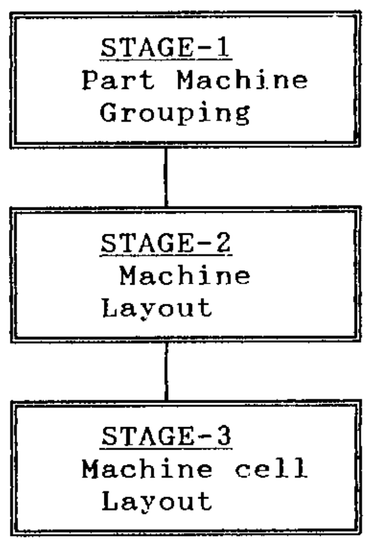

Figure 4.1: Stages in the machine cell placement problem

The first stage deals with the development of a clustering algorithm suitable for identifying machine cells and corresponding part families. The second stage of the project involves determining a layout for the machine identified in stage 1. In stage 3, a layout of the machine cell should be determined.

Researches on cellular manufacturing system in the cell formation problem was carried on various criteria. Most of the researches in this regard considered the similarity between parts and machines. The cellular structure was established through matching the similarity coefficients. Algorithms were developed and these differ greatly in their solution methodology. Various heuristic approaches with production data, such as production volume or routing sequence were forwarded. Some of the researches concerned the machine chaining problem in cellular structure.

Formulation of an integer programming was also developed by some of the researchers for scheduling effectively in a GT-based production environment. The optimum machining speed, optimum product-mix, optimum machine loading were also considered by some of the researchers.

In the following section, use of integer programming which can simultaneously consider both the machines and parts to optimize cost is being investigated.

4.2 Formulation of Part Machine Grouping:

The zero-one integer programming problem is one in which each solution variable is restricted to only binary values. Any general integer programming can be converted to a zero-one integer programming. A 0 - 1 mixed integer programming model would been developed for part machine grouping to optimize the cost that includes processing cost, cost of tool and machine amortization cost.

The model is formulated under the following assumptions:

1. Information regarding tooling requirements, processing costs, processing times and production quantities for each part are available.

2. Information regarding the tools, their types, lives, machine cost and the available processing time in a machine are available.

3. There, exist, alternative machines, when flexible manufacturing system is considered. Information regarding alternative machines, their required operations on some parts are available.

It would be, however evident from the above cell formation process that as the number of cells increases, the contribution made by parts to the intercell movement increases, while that made to the intracell moves by parts decreases. The minimum number of cells(k_{min}) in any cellular manufacturing problem has to be at least two because it would be trivial to consider a problem with just one cell as it represents functional grouping. Factors such as workforce, machine utilization, space and budgetory limitations which are usually under the control of the management are the deciding factors in determination of the maximum number of cells(k_{max}). Thus number of cells k, can be a priori set by the management.

<u>Notation:</u> The following notations are used

Indices:

i	-	index of part,	i	=	1, p
j	-	index of machine,	j	=	1, m
k	-	index of cell,	k	=	1, n
o	-	index of operation,	o	=	1, q
t	-	index of tool,	t	=	1, r

Where m,n,p,q,r have their usual implicit meaning and values

C_{iojt} = processing cost for operation o of part i, using tool t and machine j

C_t = cost of replacing tool type t.

f_j = annual depreciation cost rate of machine j.

J_k = maximum number of parts in a cell.

q_i = annual production requirement of part i.

T_j = annual available processing time on machine j.

TL_t = life of tool type t.

S_i = Set of tools required for part i.

U_{iojt} = processing time for operation o of part i using tool t on machine j.

T_c = total cost.

The processing time depends on the machining conditions, such as depth of cut, feed rate and machining speed. Equations are available to calculate the processing time for various operations (turning, boring, drilling, milling etc.) in any standard handbook of metal cutting. Thus it could be assumed that processing times are known.

Decision variables:

$$P_{iojtk} = \begin{cases} 1, & \text{if tool } t \text{ is required for operation } o \text{ of part } i \text{ using machine } j \text{ and in cell } k. \\ 0, & \text{otherwise.} \end{cases}$$

$$X_{ik} = \begin{cases} 1, & \text{if part } i \text{ belongs to cell } k \\ 0, & \text{otherwise.} \end{cases}$$

Y_{jk} = index utilization of machine type j in cell k.

W_t = required number of tools to be used of type t.

The cell formation model:

The combined problem of forming cells and providing tools is formulated using a 0 - 1 integer programming model.

$$\text{Minimize } T_c = \sum_i \sum_o \sum_t \sum_j \sum_k C_{iojt}\, q_i\, P_{iojtk} + \sum_j \sum_k f_j\, Y_{jk} + \sum_t C_t\, W_t \qquad (1)$$

Subject to,

$$\sum_i \sum_o \sum_t U_{iojt}\, q_i\, P_{iojtk} = T_j\, y_{jk}; \text{ for all } j \text{ and } k \qquad (2)$$

$$\sum_i \sum_o \sum_j \sum_k U_{iojt}\, q_i\, P_{iojtk} \leq TL_t\, w_t\,; \text{ for all } t \qquad (3)$$

$$\sum_k X_{ik} = 1\,; \text{ for all } i \qquad (4)$$

$$\sum_{i} X_{ik} \leq I_k \text{ ; for all } k \tag{5}$$

$$\sum_{j} P_{iojtk} - X_{ik} = 0; \text{ for all } t \text{ and } t \text{ is a subset of } S_i \text{ and for all } i \text{ and } k \text{ and operation } o \tag{6}$$

$$P_{iojtk} \in [0, 1] \text{ ; for all } i, o, j, t \text{ and } k \tag{7}$$

$$X_{ik} \in [0, 1]; \text{ for all } i \text{ and } k \tag{8}$$

$$W_t \geq 0 \text{ and integer; for all } t \tag{9}$$

$$y_{jk} \geq 0; \text{ for all } j \text{ and } k \tag{10}$$

On the objective function, the first term represents the annual cost of processing all the parts in the system. The second term represents the annual amortized cost on machine investment and the third term represent the annual tooling cost. Constraint eqn.(2) represents the machine utilization and it ensures that processing capacity of each machine type in each cell is not violated. Constraint eqn.(3) ensures that tool life limit of each tool type is not violated and it represents the required number of tool type t required. Constraint eqn.(4) ensures that one part is allocated to only one cell. Constraint eqn.(5) expreses the restriction on the maximum number of parts in a cell in order to have good control and supervision over the individual groups. Equality constraint eqn.(6) ensures that if part i belongs to cell k, then the tools required for part i should be available at least one of the machines in cell k. Constraint eqn.(7) and constraint eqn.(8) ensure that the decision variables of P_{iojtk} and X_{ik} one of binary type and can assume any value of either 0 or 1. Constraint eqn.(9) ensures that integrality of the decision variable of the number of tool type t required and constraint eqn.(10) assures the non-negativity of the decision variable Y_{ik}.

The constraints for obtaining different criteria could now be modified. If the tool availability is restricted to a value r_t , where r_t is the maximum allowable number of tool type t ,constraint eqn.(9) can than be changed to

$$W_t \leq r_t \quad \text{integer for all } t \tag{11}$$

To obtain a good cell balance for overall smoothness of production plan, constraint eqn. (10) can also be changed as

$$y_{jk} \geq \beta_{jk}; \quad \text{for all } j \text{ and } k \tag{12}$$

Where β_{jk} is the minimum machine utilization of machine type j in cell k

The desired objective would be that the cells are loaded with machines which are of nearly equal capacity. However to achieve this objective it may produce an infeasible solution which may be made feasible by relaxing the constraint eqn.(12) and allowing β_{jk} to be smaller.

When the management assigns restriction on the maximum number of machines to a value MC_j then constraint eqn.(2) and constraint eqn.(10) can be changed as

$$\sum_i \sum_o \sum_t U_{iojt}\, q_i\, P_{iojtk} \leq T_j\, y_{jk} \quad \text{for all } j \text{ and } k \tag{13}$$

$$\sum_j y_{jk} \leq MC_j \quad \text{for all } k \tag{14}$$

$$y_{jk} \geq 0 \quad \text{integer} \tag{15}$$

4.3 Data files and System reports:

FMS data files

To exercise control over the FMS, the computer system relies on data contained in computer storage files. The principal data files that are considered here for the flexible manufacturing system are:

1. Part program6 f6ile: The part program for processing each workpart on the system is maintained in this file. For any given workpart, a separate program is required for each workstation performing operations on the part.

2. Routing file: This file contains the list of workstations through which each workpart must be processed. It also contains alternate routings for the parts.

3. Part production file: A file of production parameters is to be maintained for each workpart. It contains data relative to production rates for the various machines in the routing.

4. Station tool file: A file is to be kept for each machine, identifying the codes of the cutting tools stored at that machine. This file should be used for tool control purposes.

6. Tool-life file: This data file keeps the tool-life value for each cutting tool in the system. The cumulative machining time of each tool is compared with its life value so that a replacement can be made before complete failure occurs.

<u>System reports</u>

Performance data collected during monitoring of the FMC can now be given into the following types of reports.

1. Structure reports: These reports summarize the optimized cellular structure of parts and machines.

2. Utilization reports: These reports summarize the utilization of individual workstations as well as overall average utilization for the FMS.

3. Tool reports: These reports give the various aspects of tool control.

4. Machine reports: These reports summarize the number of machines required.

5. Cost Report: This report can give the major components of cost that are minimized.

4.4 Development of Heuristic :

It was observed that in obtaining a solution for the integer problem of 10 types of parts, 6 types of tools and 5 types of machines, the computer takes about 1000 seconds of CPU time and hence in real life problem, where the number of parts could be very big and solving the problem with integer programmining may take many of hours. Thus due to the computational difficulty of the integer programmining methods, heuristic algorithms have been developed as alternative for solving real life problem involving large set of machines and jobs. However, the drawback of the heuristic algorithms would not guarantee an optimal solution.

4.4.1 Philosophy of Part-Machine Grouping:

While a given set of parts being processed in machines, it is required that each part would make visits to certain machines in definite sequences so that specific operations could be performed on the part. This piece of information is the starting point in the mechanics of formation of part-machine grouping in the present work. In this regard of part-machine grouping a pair is conceived to be 100% similar if all machines visited by both the parts are the same. The objectives in pairing parts are as follows:

1. to find the minimum cost part-machine matrix so that the constraints are not violated.

2. to form a group of parts and machines so that number of machines required is not violated by constraints.

4.4.2 Steps in Part-Machine grouping:

The steps to be followed in part-machine grouping are as follows:

1. Calculate the three elements of costs such as processing cost, tool cost and machine amortization cost. Calculate the total cost.

2. Search for the minimum process cost, minimum tool cost and minimum machine amortization cost.

3. Multiply the production volume to each cost part-machine matrix element.

4. Calculate the required annual workload on each machine for the minimum cost part-machine matrix for each part using the formula as follows:

$$WL_{i,j} = q_i B_{ij} / T_j \tag{16}$$

Where, q_i = the amount of the part i to be produced annually,

B_{ij} = operation time of the part i on machine j and

T_j = annual available time on machine j.

$WL_{i,j}$ = annual workload on machine j to produce part i

According to the workload the relationship between part and machines can be represented by the part-machine relation matrix R_{pm} as shown . In this matrix, Q_j is the number of machine type j to be used to produce parts. The vector M and P are the machine vector and part vector.

$$M = \begin{bmatrix} Q_1 & \cdots & Q_j & \cdots & Q_m \end{bmatrix} \qquad [P]$$

$$\begin{bmatrix} WL_{1,1} & \cdots WL_{1,j} & \cdots & WL_{1,m} \\ WL_{i,1} & \cdots & WL_{i,j} & \cdots & WL_{i,m} \\ WL_{p,1} & \cdots & WL_{p,j} & \cdots & WL_{p,m} \end{bmatrix} \qquad \begin{bmatrix} P_1 \\ P_i \\ P_i \end{bmatrix}$$

5. Calculate the sum of workload on each machine

$$L_j = \sum_i WL_{i,j}; \quad \text{for all } j \tag{17}$$

If the values of L_j for any j exceed the maximum allowable workload on machine j, a further step called step (A) is to be followed as given in page 63.

6. Construct the part similarity diagonal matrix $SP_{i,i'}$ using the formula:

$$SP_{i,i'} = \frac{\sum_j P_{i,j} \times P_{i',j}}{\sum_j (P_{i,j} + P_{i',j} - P_{i,j} \times P_{i',j})} \tag{18}$$

The above formula is for all i and i'

$$\begin{aligned} i &= 1,2, \quad \dots \quad p-1 \\ i' &= i+1, i+2 \quad \dots \quad p \end{aligned}$$

$$P_{i,j} = \begin{cases} 1, & \text{if machine } j \text{ is the minimum cost machine for part } i \\ 0, & \text{otherwise} \end{cases}$$

$$P_{i',j} = \begin{cases} 1, & \text{if machine } j \text{ is the minimum cost machine for part } i' \\ 0, & \text{otherwise.} \end{cases}$$

7. Pairwise similarity coefficient between parts are given in the similarity diagonal matrix as shown below:

$$\text{Parts} \quad \begin{bmatrix} P_1 & \cdots & P_i & \cdots & P_p \end{bmatrix}$$

$$\begin{bmatrix} P_2 \\ P_{i+1} \\ P_p \end{bmatrix} \; \begin{bmatrix} SP_{1,2} & - & - \\ SP_{1,i+1} & SP_{i,i+1} & - \\ SP_{1,p} & SP_{i,p} & - \end{bmatrix}$$

8. Input similarity cut-off level α(Cell Admission Factor) between 0 and 1. The similarity cut-off level is the value assigned by the management and α will give the designer the flexibility to increase or reduce the number of cells. As the value of α is increased, more similar parts would be combined to form a cell and hence there will be more number of cells to be formed and vice versa.

9. The two or more similar parts with a certain similarity value $SP_{i,i'}$, join to from the first part group. If the number of parts in a cell is greater than the allowable value, the cell is broken arbitrarily into two cells.

10. After two or more parts enter into a cell the value of the similarity coefficients for other parts will be changed with respect to that group. Here the recalculated similarity index π for different parts with respect to a group π is found out using ALC method as proposed by Seifoddini[58].

11. Step 9 is repeated until all the parts are grouped in cells. If in any case $SP_{i,i'} < a$, step (A) is to be followed.

12. Calculate the number of machines required.

13. Calculate the workload on each machine within a cell.

14. If the number of machines is greater than the allowable machine number but workload is within the allowable limit, then check if intercellular movement is possible. Otherwise step (A) is to be followed.

15. If the workload is greater than the allowable value step (A) is to be followed.

16. Terminate the process.

Step (A):

Start: Let PM is the group of primary machines to produce parts and AM^f is the group of f-th alternative machines. The cell entry of PM matrix, $Q_{i,o}$ is an index of machines for part i and operation o. The cell entry of $D_{i,o}^{f}$ is an index f-th alternative machines for part i and operation o. If the value of f is one then AM^1 will be the first alternative machine groups.

The primary machines with the minimum cost and the first alternative machine groups to be used in each process can be expressed as follows:

$$PM = \begin{bmatrix} Q_{1,1} & \cdots & Q_{1,o} & \cdots & Q_{1,q} & \cdots \\ \vdots & & \vdots & & \vdots & \\ Q_{i,1} & \cdots & Q_{i,o} & \cdots & Q_{i,q} & \cdots \\ \vdots & & \vdots & & \vdots & \\ Q_{p,1} & \cdots & Q_{p,o} & \cdots & Q_{p,q} & \cdots \end{bmatrix} \begin{bmatrix} P_1 \\ \vdots \\ P_i \\ \vdots \\ P_p \end{bmatrix}$$

$$AM^1 = \begin{bmatrix} D_{1,1}^1 & \cdots & D_{1,o}^1 & \cdots & D_{1,q}^1 & \cdots \\ \vdots & & \vdots & & \vdots & \\ D_{i,1}^1 & \cdots & D_{i,o}^1 & \cdots & D_{i,q}^1 & \cdots \\ \vdots & & \vdots & & \vdots & \\ D_{p,1}^1 & \cdots & D_{p,o}^1 & \cdots & D_{p,q}^1 & \cdots \end{bmatrix} \begin{bmatrix} P_1 \\ \vdots \\ P_i \\ \vdots \\ P_p \end{bmatrix}$$

In each alternative machine group, a machine and part is to be selected so as to minimize the cost using the branch and bound method. For example if machine type 1 is selected and has to be replaced which may be indexed as $Q_{1,1}$, $Q_{5,3}$, $Q_{6,2}$ etc., then all the alternatives for that machine type is to be searched. If it is found that the alternatives for machine type 1 are machine type 2,3,4 etc. which is indexed as $D_{1,1}^1$, $D_{5,3}^1$, $D_{6,2}^1$ etc. then search should be carried out on that group. The lowest cost among these is to be selected and to be chosen as an alternative of machine type 1 for a particular part and operation.

The heuristic logic has been coded in WATFOR87, a PC-based FORTRAN language, and is implemented on an IPC/386 microcomputer. Using the computer programme and along with 50% cutoff level of similarity, part families and machine cells can be formed. The 50% cut-off level of similarity chosen in this study was considered as the middle point and had to be fixed first in order to facilitate the rest of the analysis. It is possible to conduct a separate study to determine the various cellular structure at different cut-off points.

Once the machine part cell is formed, then each cell may be staffed with one or more operators whose tasks are to load parts into machines, to unload parts and to transport parts between machines. To maximize productivity, it is therefore necessary to pay close attention to the sequence of operations, including loading, walking, waiting that operators must perform to carry parts through cell.

4.5 Consideration of different product mix:

In real life applications, usually, not all parts in a part family can be fully processed within a single cell. The above formulation treat the machine cell formation as a deterministic process. This may adversely affect the performance of the related cellular manufacturing system when the product mix changes. When a machine cell arrangement is designed for a particular product mix, its performance may deteriorate when it is used under different product mix. To overcome this problem the above integer programining model can be used. This can be done by incorporating the probabilistic nature of the product mix in the early stage of the machine cell formation process.

To incorporate the uncertainty of the product mix in the machine cell formation problem, the first step is to express the product mixes in the form of a probability density function. Such a function in its simplest form, can be set for different product mixes with the associated probabilities of occurrence. Based on this, a set of part charts with their probabilities may develop and can be used as input to the probabilities machine cell formation model. The objective function of the above mathematical model can now be written as :

$$Z_p = \sum_i \sum_o \sum_t \sum_j \sum_k C_{iojt}\ q_i\ P_{iojtk}$$

$$+ \sum_j \sum_k f_j\ y_{jk} + \sum_t C_t\ W_t \qquad (19)$$

The expected total cost for a particular product mix now can be calculated as follows:

$$E_l = \sum_L Z_p\ P_p \qquad (20)$$

Where Z_p = total cost for a particular product mix

L = no. of product mixes

P_p = probability of occurrence for product mix p

E_t = expected total cost for different product mix

Then the design with the minimum expected total cost can be selected as the best design.

4.6 Machine and Machine Cell layout:

In this section, the model for the solution of machine cell layout problem and machine layout problem is proposed with a little modification of method used by **Kusiak**[20]. In the second and third stages, mathematical programming models of the machine cell and machine layout problems are outlined which can be solved using any suitable LP package.

Once the machine cells have been identified, machine layout has to be determined. As mentioned previously, research on this problem has been rather limited. However, a number of researchers have attempted to solve a related problem, i.e. the facility layout problem. Kusiak and Heragu have reviewed the various models and algorithms developed for the facility layout problem.

In order to formulate a model for the machine cell layout problem, the notation provided below is used.

$f_{j,j'}$ number of trips to be made between machine j and j'

$c_{j,j'}$ cost per trip between machine j and machine j'

l_j length of the horizontal side of machine j

b_j length of the vertical side of machine j

$dh_{j,j'}$ minimum distance by which machine j and machine j' are to be separated horizontally

$dv_{j,j'}$ minimum distance by which machine j and machine j' are to be separated vertically

x_j distance between centre of machine j and vertical reference line VRL

w_j distance between centre of machine j and horizontal reference line HRL.

The parameters and decision variables relevant to the model are illustrated in figure below:

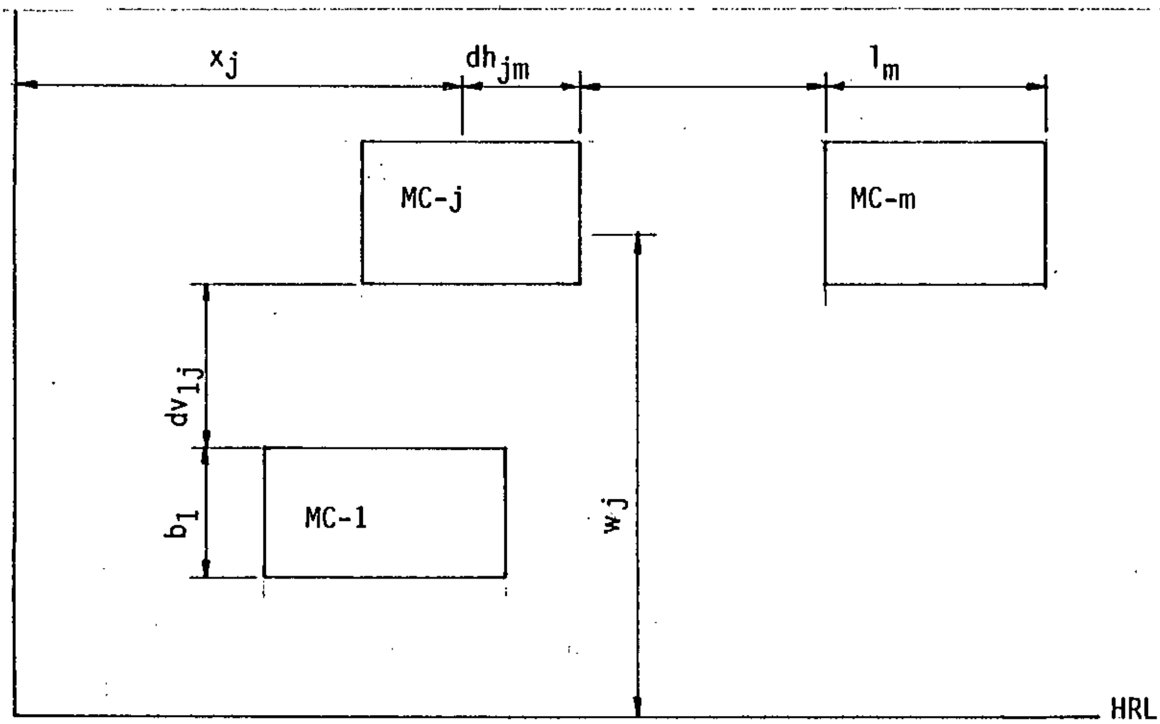

Figure 4.1 : Illustration of parameters and decision variables in the machine layout model

4.7 Model for the machine layout problem:

The objective function of the following model minimizes the total cost involved in making the required trips between the machines.

$$\text{Min} \quad \sum_i \sum_j \sum_k c_{j,j'} \; f_{j,j'}(|x_j - x_{j'}| + |w_j - w_{j'}|) \tag{21}$$

subject to

$$|x_j - x_{j'}| + Mz_{j,j'} \geq 1/2(l_j - l_{j'}) + dh_{j,j'} \tag{22}$$

$$|w_j - w_{j'}| + M(1 - z_{j,j'}) \geq 1/2(b_j - b_{j'}) + dv_{j,j'} \tag{23}$$

$$z_{j,j'}(1 - z_{j,j'}) = 0, \tag{24}$$

The letter M in the above model denotes a large positive number. Constraints eqn.(22) and (23) together ensure that no two machines in the layout overlap. Note that the terms $dv_{j,j'}$ and $dh_{j,j'}$ can be interpreted as the width of the material handling carrier paths between machine j and machine j' in the horizontal and vertical directions respectively. Constraint eqn.(24) ensures that $z_{j,j'}$ can take the value of 0 or 1, and therefore, only one of the two constraint eqns. (22) and (23) holds.

Furthermore, if the dimensions of the floor plan are known, then one may add suitable constraints to ensure that the machine cells are located within the boundaries of the floor plan. In the following discussion, the transformation of model (21)-(24) into an integer programming model is shown.

To develop the integer programming model, the following transformations are to be made:

$$x^{+}_{j,j'} = \begin{cases} x_j - x_{j'} & \text{if } x_j > x_{j'} \\ 0 & \text{otherwise} \end{cases} \quad (25)$$

$$x^{-}_{j,j'} = \begin{cases} 0, & \text{if } x_j > x_{j'} \\ x_j - x_{j'} & \text{otherwise} \end{cases} \quad (26)$$

Thus,

$$x^{+}_{j,j'} - x^{-}_{j,j'} = |x_j - x_{j'}| \quad (27)$$

$$x^{+}_{j,j'} - x^{-}_{j,j'} = x_j - x_{j'} \quad (28)$$

With the similar notations, it can be deduced that:

$$w^{+}_{j,j'} - w^{-}_{j,j'} \doteq |w_j - w_{j'}| \quad (29)$$

$$w^{+}_{j,j'} + w^{-}_{j,j'} = w_j - w_{j'} \quad (30)$$

Then the integer programming transformation of model (21)-(24) is

$$\text{Min} \sum_i \sum_j \sum_k C_{j,j'} f_{j,j'} (x^{+}_{j,j'} - x^{-}_{j,j'} + w^{+}_{j,j'} - w^{-}_{j,j'}) \quad (31)$$

Subject to

$$x^{+}_{j,j'} - x^{-}_{j,j'} + M\, z_{j,j'} \geq 1/2(l_j - l_{j'}) + dh_{j,j'} \tag{32}$$

$$w^{+}_{j,j'} - w^{-}_{j,j'} + M\, (1 - z_{j,j'}) \geq 1/2(b_j - b_{j'}) + dv_{j,j'} \tag{33}$$

Once the machine layout is determined in each cell, the final layout of the machine cells is determined. The final layout developed will indicate the material handling carrier paths, the shape and size of each machine cell, clearance between machines, etc.

Chapter - 5

FORMULATION OF CELLULAR MANUFACTURING SYSTEM

5.1 Solution of Problems using Mixed Integer Programming and Heuristic Model

5.2 Product-mix in Cell Formation Solution

CHAPTER-5

FORMATION OF CELLULAR MANUFACTURING SYSTEM

In the previous chapter the mechanics of cell formation on the newer concept of part-machine grouping has been evolved. Economics of cell formation with an objective of cost minimization in part-machine grouping has been considered. Although integer programming solution would have been appropriate with the present problem yet a heuristic model has been developed. It is argued that this model would be capable to solve real life problems with large set of machines and jobs although its inherent limitation exists in its incapability in providing the optimal solution. In this chapter two numerical examples are considered in a way to demonstrate the practical implementation of the optimization procedure.

5.1. Solution of problems using Integer Programming and Heuristic:

Problem 1

A numerical example of the cellular manufacturing model is presented. A FMS with 10 parts, 5 machines and 6 tools are considered. Information regarding the tooling requirements, annual production quantities, processing costs and processing times are given in Table-5.1. The details of the machines and tools, i.e., whether a tool can be mounted on a machine, available time on a machine, tool lives, cost of tools and the amortized annual cost of machines are given in Table 5.2. It is assumed that the upper limit on number of parts in any group is restricted to four.

Table - 5.1 : Processing requirements of the parts for problem 1

Part no. i	Annual demand q_i	Operation number o	Tool-machine combination $t-j$	Processing cost C_{iotj}	Processing time T_{iotj}
1	1000	1	1-1	8.0	50.0
			1-2	12.0	30.0
			1-3	7.0	60.0
		2	5-1	4.5	90.0
			5-3	3.5	100.0
			5-5	5.2	155.0
		3	6-1	6.7	65.0
			6-2	8.7	50.0
			6-4	8.0	85.0
2	1600	1	4-3	5.3	75.0
			4-4	5.2	80.0
		2	3-2	10.7	60.0
			3-5	9.8	75.0
		3	2-2	18.5	25.0
			2-4	5.5	50.0
			2-5	9.6	35.0

Table Cont'd

Table 5.1 *Continued*

Part no. i	Annual demand q_i	Operation number o	Tool-machine combination t-j	Processing cost C_{iotj}	Processing time T_{iotj}
		1	6-1	5.8	60.0
			6-2	20.0	20.0
			6-4	6.2	50.0
3	1000				
		2	5-1	7.8	60.0
			5-3	10.0	35.0
		1	2-2	15.0	25.0
			2-4	7.2	55.0
4	1600	2	4-4	8.2	60.0
			4-5	11.1	50.0
		3	6-1	6.5	70.0
			6-2	5.3	80.0
		1	5-1	8.0	50.0
			5-3	6.7	60.0
			5-5	10.0	40.0
5	1200				
		2	1-1	4.5	90.0
			1-2	5.0	80.0
			1-3	4.3	92.0
		1	1-1	4.5	89.0
			1-2	5.0	80.0
			1-3	4.3	91.0
6	1000	2	3-2	5.3	75.0
			3-3	4.4	90.0
		3	6-1	5.7	70.0
			6-2	8.0	50.0
			6-4	5.0	80.0

Table Cont'd

Table 5.1 *Continued*

Part no. i	Annual demand q_i	Operation number o	Tool-machine combination t-j	Processing cost C_{iotj}	Processing time T_{iotj}
		1	2-2	5.3	75.0
			2-4	4.2	95.0
			2-5	5.0	80.0
7	800	2	4-3	4.5	88.0
			4-4	4.2	94.0
			4-5	4.9	82.0
		3	6-1	4.9	82.0
			6-2	5.4	74.0
			6-4	4.2	94.0
		1	5-1	4.5	90.0
			5-3	4.2	94.0
8	600		5-5	4.7	85.0
		2	3-2	5.3	75.0
			3-3	4.5	89.0
		1	3-2	5.7	70.0
			3-3	4.5	90.0
9	9				
		2	2-2	5.3	75.0
			2-4	4.2	94.0
			2-5	5.0	80.0
		1	6-1	4.7	84.0
			6-2	5.6	72.0
10	1000		6-4	4.3	93.0
		2	5-1	4.5	88.0
			5-3	4.3	92.0
			5-5	4.9	81.0

Table 5.2 : Details of machines and tools for problem 1

Machine / Tools	1	2	3	4	5	Cost of Tool replacement C_t	Tool life TL (min)
1	1	1	1	0	0	80	440
2	0	1	0	1	1	70	440
3	0	1	1	0	1	50	420
4	0	0	1	1	1	60	460
5	1	0	1	0	1	50	420
6	1	1	0	1	0	75	430
Annualized cost of machine f_j	8000	12000	7000	5000	9000		
Available machining Time(min)	450,000	450,000	450,000	450,000	450,000		

Note: Tool-machine matrix element 1 means that tool can be mounted on the corresponding machine and 0 means tool cannot be mounted on that machine

5.1.1 Solution with linear programming for problem 1:

The example was solved using a linear programming software QSOM on an IBM compatible 386 machine. The required data entry format is Mathematical Programming System (MPS). The data entry format is generated by WATFOR77.

It is observed that the above proposed mixed integer model presented in the previous chapter has (p.r.m.n + p.n) 0 - 1 integer variables and r integer variables, where p is the number of parts, r is the number of tools, m is the number of machines and n is the number of cells. The number of decision variables P_{iojtk} are p.r.m.n which are binary type. The number of decision variables X_{ik} are p.n which are also binary type. W_t, that is the number of required tool type t has a large integer value and can be relaxed as continuous variable with no harm. The solution procedure takes 1100 seconds to solve the problem. The results are summarized in Table 5.3 , Table 5.4, Table 5.5 and Table 5.6. Table 5.3 summarizes the machines and parts in each cell. The required number of copies of tool types and required number of machines of each type are given in Table 5.4 and Table 5.5. Table 5.6 gives the machine utilization report.

Table 5.3 : Cell formation and tool assignment for problem 1 using linear programming

Cell	Parts	Machines	Tool assigned
1	1, 5, 7, 10	2, 3, 5	1, 2, 4, 5, 6
2	4, 8	1, 2, 5	2, 3, 4 5, 6
3	2, 3, 6, 9	2, 3, 4	1, 2, 3, 4, 5, 6

Table 5.4 : Number of Tools required for problem 1 using linear programming

Tool type	Required number of copies
1	455
2	392
3	522
4	306
5	591
6	690

Table 5.5 : Number of Machine required for problem 1 using linear programming

Machine type	Required number of machines
1	1
2	3
3	2
4	1
5	2

Table 5.6: Machine Utilization report for problem 1 using linear programming

Machine type	Cell	Utilization (operation time/total time)
2	1	0.72
3	1	0.50
4	1	0.32
1	2	0.31
2	2	0.27
4	2	0.42
5	2	0.30
1	3	0.27
2	3	0.98
5	3	0.29

Total Minimized objective value= 485025.9

Total Number of iterations needed= 394

It is to be noted that the above model may assign a tool type to one or more machines (constraint eqn. (6) in chapter 4). This allows the system to have the potential of routing parts through alternate machines. Also constraint eqn. (6) ensures that if a part belongs to a particular cell, then all the tools required for that parts is available on one or more machines.

Table 5.8 : Number of Tools required for problem 1 using heuristic

Tool type	Required number of copies
1	333
2	450
3	521
4	327
5	607
6	590

Table 5.9 : Number of Machine required for problem 1 using heuristic

Machine type	Required number of machines
1	1
2	3
3	2
4	1
5	2

Table 5.10 : Utilization report for problem 1 using heuristic

Machine type	Cell	Utilization (operation time/total time)
2	1	0.72
3	1	0.51
4	1	0.29
1	2	0.36
2	2	0.37
4	2	0.41
5	2	0.40
1	3	0.21
2	3	0.99
5	3	0.27

Total Minimized objective value= 489512.3

Total Number of iterations needed= 3

Problem 2

Another numerical example is presented in this section. Information regarding the tooling requirement, annual production quantities, processing times are given in table 5.11. The details of the machines and tools i.e., whether a tool can be mounted on a machine or not, available time on a machine, tool lives, cost of tools and anualized annual cost of machines are given in Table 5.12.

Table 5.11 : Processing requirements of the parts for problem 2

Part no. i	Annual demand q_i	Operation number o	Tool-machine combination t-j	Processing cost C_{iotj}	Processing time T_{iotj}
1	1500	1	1-1	8.0	50.0
			1-2	12.0	40.0
			1-3	7.0	50.0
		2	5-1	4.5	100.0
			5-3	3.5	155.0
			5-5	5.2	65.0
		3	6-1	6.7	90.0
			6-2	8.7	100.0
			6-4	8.0	85.0
2	1600	1	4-3	5.3	75.0
			4-4	5.5	80.0
		2	3-2	11.7	65.0
			3-5	10.8	75.0
		3	2-2	20.0	25.0
			2-4	7.5	50.0
			2-5	9.6	35.0
3	1700	1	6-1	5.9	60.0
			6-2	20.0	20.0
			6-4	7.2	50.0
		2	5-1	8.8	60.0
			5-3	10.0	35.0

Table 5.11 Cont'd

Table 5.11 *Cont'd*

Part no. i	Annual demand q_i	Operation number o	Tool-machine combination t-j	Processing cost C_{iotj}	Processing time T_{iotj}
4	1600	1	2-2	15.0	25.0
			2-4	7.2	55.0
		2	4-4	9.2	60.0
			4-5	12.0	50.0
		3	6-1	6.5	70.0
			6-2	6.0	80.0
5	1200	1	5-1	8.0	50.0
			5-3	6.7	60.0
			5-5	10.0	40.0
		2	1-1	4.5	90.0
			1-2	5.0	80.0
			1-3	4.3	92.0
6	1200	1	1-1	4.5	89.0
			1-2	5.0	80.0
			1-3	4.3	91.0
		2	3-2	5.3	75.0
			3-3	4.4	90.0
		3	6-1	5.7	70.0
			6-2	8.0	50.0
			6-4	5.0	80.0

Table 5.11 cont'd

Table 5.11 *Cont'd*

Part no. i	Annual demand q_i	Operation number o	Tool-machine combination t-j	Processing cost C_{iotj}	Processing time T_{iotj}
7	1200	1	2-2	5.3	75.0
			2-4	4.2	95.0
			2-5	5.0	80.0
		2	4-3	4.5	88.0
			4-4	4.2	94.0
			4-5	4.9	82.0
		3	6-1	4.9	82.0
			6-2	5.4	74.0
			6-4	4.2	94.0
8	1600	1	5-1	4.5	90.0
			5-3	4.2	94.0
			5-5	4.7	85.0
		2	3-2	5.3	75.0
			3-3	4.5	89.0
9	1000	1	3-2	5.7	70.0
			3-3	4.5	90.0
		2	2-2	5.3	75.0
			2-4	4.2	94.0
			2-5	5.0	80.0
10	1000	1	6-1	4.7	84.0
			6-2	5.6	72.0
			6-4	4.3	93.0
		2	5-1	4.5	88.0
			5-3	4.3	92.0
			5-5	4.9	81.0

Table 5.12 : Details of machines and tools for problem 2

Machine / Tool	1	2	3	4	5	Cost of Tool replacement C_t	Tool life TL (min)
1	1	1	1	0	0	90	400
2	0	1	0	1	1	80	440
3	0	1	1	0	1	50	420
4	0	0	1	1	1	60	460
5	1	0	1	0	1	70	420
6	1	1	0	1	0	85	430

Annualized cost of machine fj	8000	12000	7000	5000	19000
Available machining Time(Min)	400,000	400,000	400,000	400,000	400,000

<u>Solution with linear programming:</u>

The results with the LP software QSOM are summarized in Table 5.13, Table 5.14 and Table 5.15 and Table 5.16.

Table 5.13 : Cell formation and tool assignment for problem 2 using linear programming

Cell	Parts	Machines	Tool assigned
1	5, 8, 10	1, 2	1, 2, 3, 5
2	2, 3, 7	2, 3, 4	1, 2, 3, 5, 6
3	1, 4, 6 9	1, 2, 4	1, 2, 3, 4, 6

Table - 5.14 : Number of Tools required for problem 2 using linear programming

Tool type	Required number of copies
1	593
2	757
3	896
4	700
5	1159
6	1146

Table 5.15 : Utilization report for problem 2 using linear programming

Machine type	Cell	Utilization (operation time/total time)
1	1	0.73
2	1	0.72
2	2	0.69
3	2	0.72
4	2	0.42
1	3	0.62
2	3	1.28
4	3	0.46

Total Minimized objective value= 658783.2

Total Number of iterations needed= 356

Total CPU time needed = 1036.21 Sec

Solution with the heuristic model

The solution after solving the heuristic model allowing intercellular movement is summarized in Table 5.16, 5.17, 5.18. A detail solution procedure in the form of computer output was given in Appendix A.

Table 5.16 : Cell formation and tool assignment for problem 2 using heuristic

Cell	Parts	Machines	Tool assigned
1	5, 8, 10	1, 2	1, 2, 3 5
2	1, 2, 3 4	1, 2, 3 4,5	1, 2, 3, 5, 6
3	6, 7, 9	2, 3	1, 2, 4 6

Table 5.17 : Number of Tools required for problem 2 using heuristic

Tool type	Required number of copies
1	610
2	720
3	921
4	550
5	1209
6	1176

Table 5.18 : Utilization report for problem 2 using heuristic

Machine type	Cell	Utilization (operation time/total time)
1	1	0.51
2	1	0.73
1	2	0.38
2	2	0.35
3	2	0.67
4	2	0.99
5	3	0.25
2	3	1.43
3	3	0.31

Total Minimized objective value= 672691.00

Total Number of iterations needed= 3

Total CPU time needed = 7.5 Sec

If the inter cellular movement is not allowed then obviously cost will increase and the number of machines will also increase, thereby possible decrease in machine utilization.The solution after solving the heuristic model without intercellular movement is summarized in Table 5.19, 5.20, 5.21.

Table 5.19 : Cell formation and tool assignment for problem 2 using heuristic when number of machines is restricted

Cell	Parts	Machines	Tool assigned
1	1, 2, 3 4	1, 3, 4 5	1, 2, 3 5
2	5, 8, 10	1, 2, 3	1, 2, 3, 4
3	6, 7, 9	2, 3	1, 2, 4 6

Table 5.20 : Number of Tools required for problem 2 using heuristic when number of machine is restricted

Tool type	Required number of copies
1	590
2	632
3	1034
4	645
5	1165
6	1157

Table 5.21 : Utilization report for problem 2 using heuristic when number of machine is restricted

Machine type	Cell	Utilization (operation time/total time)
1	1	0.30
3	1	0.65
4	1	0.99
5	1	0.55
1	2	0.52
2	2	0.73
2	3	0.25
2	3	1.43
3	3	0.31

Total Minimized objective value= 675735.80

Total Number of iterations needed= 6

Total CPU time needed = 10.5 Sec

A comparative study of the above two problems using the integer programming model and heuristic model is given below in Table 5.22 and 5.23.

Table 5.22 : Comparative Study for problem 1

		Integer Programming Model	Heuristic Model
Construction of cells according to parts		1, 5, 7, 10	1, 7, 8, 9
		4, 8	5, 6, 10
		2, 3, 6, 9	2, 3, 4
Construction of cells, according to machines		2, 3, 5	2, 5
		1, 2, 5	1, 2, 3, 4
		2, 3, 4	2, 3, 5
Construction of cells according to tools assigned		1, 2, 4, 5, 6	1, 2, 3, 4, 6
		2, 3, 4, 5, 6	1, 2, 5, 6
		1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6
Required number of tools	1	455	333
	2	392	450
	3	522	521
	4	306	327
	5	591	607
	6	690	590
Required number of machines	1	1	1
	2	3	3
	3	2	2
	4	1	1
	5	2	2
Objective value		485025.9	489512.3
Number of iterations		394	3
Time needed in seconds		1100	7

Table 5.23 : Comparative Study for problem 2

		Integer Programming Model	Heuristic Model
Construction of cells according to parts		5, 8, 10 2, 3, 7 1, 4, 6, 9	5, 8, 10 1, 2, 3, 4 6, 7, 9
Construction of cells, according to machines		1, 2 2, 3, 4 1, 2, 4	1, 2 1, 2, 3, 4, 5 2, 3
Construction of cells according to tools assigned		1, 2, 3, 5 1, 2, 3, 5, 6 1, 2, 3, 4, 6	1, 2, 3, 5 1, 2, 3, 4, 5, 6 1, 2, 4, 6
Required number of tools	1	593	610
	2	757	720
	3	896	921
	4	700	550
	5	1159	1209
	6	1146	1176
Required number of machines	1	2	2
	2	4	4
	3	1	2
	4	2	1
	5	0	1
Objective value		658783.2	672691.0
Number of iterations		356	3
Time needed in seconds		1036.21	7.5

The above results shows that the heuristic approach are in good accord with the linear programming method. The objective value, ie., the minimized cost value is slightly higher in heuristic approach than the LP model. A number of problems was also taken which shows a good accord between these two approaches.

5.2 Product-mix in Cell Formation Solution:

To incorporate the uncertainty of the product mix in the above machine cell formation problem, the first step is to express the product mixes in form of a probability density function. Such a function, in its simplest form, can be set with different product mixes with the associated probabilities of occurrence. To demonstrate how the product-mixes can be handled a third problem was taken and solved. Only the final machine-part matrix is given in Table 5.26. The model can be easily explained with the three numerical examples whose part-machine matrix is given below. It is only additionaly assumed that the three problems are three different product mixes. It could be suggested that since the proposed heuristic procedure almost yielded the optimum solution and to avoid the computational difficulty the solution obtained from the heuristic model could be used in the present product-mix case also. The final machine component chart obtained from the heuristic with the three different product mixes are given in Tables 5.24, 5.25, 5.26. The table entry 1 means that a part is required that machine.

Table 5.24: Final machine component chart showing the formation of cells using the heuristic model(Problem 1)

Components

Cell	Machines	1	7	8	9	2	3	4	5	6	10
Cell 1	2	1	1	1	1						
	5	1	1	1							
Cell 2	2					1					
	3					1	1				
	4					1	1	1			
Cell 3	2								1	1	1
	3								1		
											1

Total Cost to produce all parts=485025.90

Table 5.25: Final machine component chart showing the formation of cells using the heuristic model(Problem 2)

Components

Cell	Machines	1	2	8	10	5	6	7	9	3	4
Cell 1	1	1									
	2		1	1	1						
	3		1								
	5		2	1	1						
Cell 2	1					1	1				
	2					1	1	1	1		
	3							1			
Cell 3	1									1	1
	3									1	
	4										1

Total Cost to produce all patrs =631875.10

Table 5.26: Final machine component chart showing the formation of cells using the heuristic model(Problem 3)

		Components									
		3	6	8	2	5	7	9	1	4	10
	1	1	1	1							
	2		1	1							
	3	1									
		Cell 1									
Machines	2					1	1	1			
	4				1	1					
	5				1		1	1			
					Cell 2						
	2								1		1
	3								1	1	1
	5									1	
									Cell 3		

Total Cost to produce all parts= 78964.00

The probabilities of occurrence for the product mixes are assumed as 0.40 for the product mix associated with machine-component chart in Table 5.24 and 0.30 for each of the other two cases. The next step is the selection of one of these three cases.

For the first machine cell arrangement the total cost to produce all parts is 485025.90. If this type of part-machine cell arrangement is used for the of second product-mixes, obviously the part-machine cell arrangement will not be optimum. The lowest cost associated with second product-mix when cellulized as the part-machine cell arrangement associated with first product-mix is 701395.20 and that for third product-mix is 809523.10. If the intercellular movement is permitted then this cost can be kept as low as to the optimum value i.e., 672691.00 but in that case the cost of intercellular movement must be considered. The optimum value for the third product-mix is 784532.31. The cost of intercellular movement than can be calculated as follows:

$$IMC_t = \sum_{k=1}^{n} \sum_{k'=1}^{n} \sum_{i=1}^{e} M_{ikk'} C_{kk'} \qquad k \neq k'$$

Where IMC_t = intercellular material handling cost
n = number of cells
e = number of exceptional parts, ie.,the parts that move from one cell to another
$M_{ikk'}$ = number of moves generated by part type i between machine cell k and k'
$C_{kk'}$ = transportation cost between cells k and k'

For example, if the intercellular material handling cost for the second and third product mixes are IMC_1 and IMC_2 then expected total cost associated with part-machine arrangement for the first cellular structure is

$$Ez_1 = (485025.90)(0.40)+(672691.00+IMC_1)(0.30) + (784532.31+IMC_2)(0.30)$$

The expected total cost for the second and third product mixes Ez_2 and Ez_3 can then be calculated and based on the above results the machine cell arrangement with the lowest expected cost can be selected as the best solution.

Chapter - 6

DISCUSSION AND SCOPE OF FUTURE WORK

CHAPTER-6

DISCUSSION AND SCOPE OF FUTURE WORK

6.1 Discussion

Understanding the concept of Cellular Manufacturing System the older system of manufacturing that placed like machines together to create a production department is to be discarded. With the newer system, parts are grouped together and processed on different machines needed which are placed together to form cellular environment. In terms of its facilities, component range and personnel, a cell is a part of larger manufacturing shop and is responsible for undertaking a sequence of functionally dissimilar operations on its batches.

The manufacturing sector in the country only yields 8% of the GDP. Though the batch manufacturing is almost 90%, but the most neglected in the country is the small lot manufacturing system. Under this setting of the manufacturing sector in the country, it is becoming urgent to build a sensible and sound base of export oriented manufacturing sector. This sector must have the ability to produce high quality products at low cost. In todays world, high performance is required first to qualify for the starting line. It is now documented that cellular manufracturing have several advantages including the capability to produce high quality products at low cost. In the country where the capital accumulation is a very crucial problem work cell type implementation in manufacturing company should be encouraged. Cellular manufacturing type automation would be suitable in the country for that it represents a justifiable, low risk, automation project.

On this philosophy the present work was initiated. Thus developing the cellular manufacturing with the economic factor such as cost minimization in cell formation was integrated. Three distinct stages were identified in successfully implementing the cellular manufacturing. The most vital and important stage is the part-machine goruping problem. A mathematical model which is in effect to a zero-one integer programming model, has been formulated to solve effectively the above problem. In the mode economic factors such as processing costs, tool costs, and machine amortization costs were considered; the other sources of cost such as setup cost, labour cost, overhead cost could have been incorporated in the model. The model is flexible and it can consider alternative machines and machine available times. The MRP computer file structure should be designed(or modified) to accept the information on each item's alternate routings and the cell to which it belongs. Moreover, the model can also incorporate other objective, such as overall cell balance. The model can also be used to a expert system. The input data of a problem concerned obtained from the user could be stored in a database system like data files as discussed earlier. The expert system then would activate the model and can selects the appropriate cellular structure for the problem. The expert system would only obtain knowledge pertinent to the machine grouping using the solution model.

It is observed that the proposed mixed integer linear model for machine part grouping has (p.r.m.n. + p.n) 0-1 integer variables and r integer variables. Unlike linear programming where very large problems have been successfully solved in a resonable amount of time, the performance of integer algorithms has been erratic. Thus for a reasonably large problem to be solved, the model would take a considerable amount of CPU time. This is, indeed, a gross disadvantage of the model. However, the part-machine grouping problem is not a frequently encountered problem; once a part-machine grouping is established it is retained for many future uses. Also the sensitivity analysis of the model provides additional information to managers to effectively utilize resources. The model uses a typical FMS data file such as part program file, routing file, part production file, station tool file and tool life file. The systems reports is a typical for flexible manufacturing system for a good overall supervisory computer control.

The proposed heuristic model shows a very good accord with the exact mathematical model. The heuristic model provides the management a type of flexibility to resist the value of cut off level. Lowering the cut off level can decrease the number of cells and as the cut off level is increased, it will increase the cell number. It is possible to conduct a separate study to determine the various cellular structure at different cut-off points. The proposed model for machine layout and machine cell layout with the machine grouping problems can form a complete expert system. The logic could be stored as the knowledge base and an appropriate interference engine. The model is also good for any type of associated deterministic uncertainity. Different types of objective can be set such as operator walking pattern with the proposed model.

6.2 Recommendations for Future Work:

Future works on this area may include both the study of analytical approaches and heuristic approaches dealing with more complicated production problems which may be associated with stochastic nature. Some of the recommendations are given below.

i. To associate the cellular manufacturing model with dynamic production planning, multiple objective decision model can be used.

ii. The cellular model may incorporate in designing an effective production and inventory(P&I) control system for production planning problem considering the inventory, demand at different time etc. After the cellular is formed a hierarchical planning procedure can also be designed considering labour costs, overtime costs, setup costs, inventory holding costs etc.

iii. The cell structure problem can incorporate with operator walking pattern. This will consider the jobs of operator such as load parts, unload parts and transport parts between machine stations.

iv. Response of the part-machine cells to changes in production plan can be analyzed for the proposed cellular model.

iv. Simulation can be used to solve the problem of design of cellular structure. Several simulation software packages are well known such as SIMAN, SLAM, GPSS, SIMSCRIPT. Performance of the manufacturing cells may fluctuate under different conditions and due to several factors. To determine the effects of these parameter on the cellular model, the stochiastic parameters in particular, a simulation run can be performed. System behaviuour can also be examined, when new parts enter into a cell.

REFERENCES

AND

BIBLOGRAPHY

REFERENCES

1. Adarns N.; *A low volume manufacturing unit realizes the advantages of FMS through innovative technique*, Industrial Engineering, pp 21-27, November, 1988

2. Burbidge J. L.; *The Introduction of group technology*, Heinemann, London, 1975.

3. Choobineh F.; *Optimum loading for GT/MRP manufacturing systems*, Computers and Industrial Engineering, Vol 8, No. 3, pp 197-206, 1984.

4. *Computers in Manufacturing*, edited by American Machinist, McGraw Hill Book Co.,Newyork,1983.

5. *Computer Integrated Manufacturing Handbook*, McGraw Hill Inc, New York, 1987.

6. Chan H. M., and Milner D. A.; *Direct clustering algorithm for group formation in cellular manufacture*, Journal of Manufacturing System, Vol 1, No. 1, pp 64-76, 1982.

7. Chow W. and Hawaleshka O.; *An efficient algorithm for solving the machine chaining problem in cellular manufac-turing*, Computers and Industrial Engineering, Vol. 22, No. 1, pp 95-100, 1992.

8. Carrie A. S.; *Numerical taxonomy applied to group technology and plant layout*, International Journal of Production Research, Vol 11, No. 4, pp-399-416, 1973.

9. Chandrasekeran M. P., and Rajagopalan R.; *An ideal seed non-hierarchial clustering for cellular manufacturing*, International Journal of Production Research, Vol 24, No. 2, pp 451-464, 1986.

10. Dutta, S. P., Lashkari R. S., Nadoli G., and Ravi T.; *A heuristic procedure for determining manufacturing families from design-based grouping for flexible manufac-turing systems*, Computer and Industrial Engineering, Vol 10, No.3, pp 193-201, 1986.

11. Gupta T.; *Production Data based Similarity Coefficient in the design of a Cellular Manufacturing Systems*, Proceddings of International Industrial Engineering Conference, pp 213-218, 1989.

12. Groover, M.P; Automation, *Production System and Computer Integrated Manufacturing*, Printice Hall, International Editions, 1987.

13. Gunnsingh K. R.,and Lashkari R. S.; *The cell formation problems in cellular manufacturing systems- a sequential modelling approach*,Computer and Industrial Engineering, Vol. 16, No. 4, pp 469-476, 1989.

14. Heragu S. S.; *A group technology approach to machine layout*, International Industrial Engineering Conference and Societies Manufacturing and Productivity Symposium Proceedings, pp 207-212, 1989.

15. Hitomi K., and Ham I.; *Group scheduling technique for multiproduct, multistage manufacturing systems*,Journal of Engineering and Industry, Vol 99, pp 756-765, 1977.

16. Hitomi K., Ham I., Nakamura N., and Yoshida K.; *Optimal group scheduling and Machining-speed decision under due-date constraints*,Journal of Engineering and Industry, Vol 101, pp 128-134, 1979.

17. Hitomi K., and Ham I.; *Machine loading and product-mix analysis for group technology*, Journal of Engineering and Industry, Vol 100, pp 370-374, 1978.

18. King J. R.; *Machine-component grouping in production flow analysis:an approach using rank order clustering algorithm*,International Journal of Production Research, Vol 18, No. 1, pp 213-232, 1980.

19. Kondo Y, *Quality Control Activities in Japanese Industries*, The Association for Overseas Technical Scholarship, 1988.

20. Kusiak A.; *Group technology in design of manufacturing facilities: a modular perspective*, Proceedings of International Industrial Engineering Conference , pp 219-224, 1989.

21. King J. R. and Nakornchai V.; *Machine-component group formation in group technology:review and extension*, Inter- national Journal of Production Research, Vol 20, No. 2, pp 117-133,1982.

22. Khator S. K., and Irani S. A.; *Cell formation in GT: A new approach*, Computer and Industrial Engineering, Vol 12, No. 2, pp 131-142, 1987.

23. McCormick W. T., Schweitzer P. J., and White, T. W ; *Production decomposition and data recognition by a clustering technique*, Operations Research, Vol 20, No. 5, pp 993-1009, 1972.

24. McAuley J.; *Machine grouping for efficient production*, Production Engineering, vol 52, pp 53-57, February 1972.

25. Oba F., Kato K., Yasuda K., and Tsumura T.; *Review and extension of cell formation problems in flexible manufacturing systems*, International Conference on Computer Applications in Production and Engineering, Copenhagen, 1986.

26. Ozden M., Egbelu P. J., and Ananthanarayanan V. I.; *Job scheduling in a group technology environment for a single facility*, Computers & Industrial Engineering, Vol 9, No. 1, pp 67-72, 1985.

27. Rajagopalan R., and Batra J. L.; *Design of cellular production systems: a graph theoretic approach*, International Journal of Production Research, Vol 13, No. 6, pp 567-579, 1975.

28. Rasaratnam L.; *Effect of the identification of key machines in the cell formation problem of cellular manufacturing systems*, Computers and Industrial Engineering, Vol 20, No. 4, pp 439-449, 1991.

29. Richardson K., Taboun S.M., and Bhole S.; *Design and Evaluation of Cellular Manufacturing Systems*, International Industrial Engineering Conference and Societies Manufacturing and Productivity Symposium Proceedings, pp 630-636, 1989.

30. Rembold U., Blume C., and Dillman R.; *Computer-Integrated Manufacturing Technology and Systems*, Marcel Dekker Inc., NewYork,1987.

31. Siddique M.H.; *Technology in Engineering Industry of Bangladesh*, Investment Adving Centre of Bangladesh, 1985.

32. Sule, R.D.; *A Systematic Approach for Machine Grouping in cellular Manufacturing*, Proceedings of International Industrial Engineering Conference , pp 619-624, 1989.

33. Seifoddini, H.; *Comparison between the Similarity by Coefficient Method and Machine Compnent group analysis in group technology applications*, Proceeding of the 11th Annual Conference on Computers and Industrial Engineering, pp 609-613, Pergamon Press Ltd., 1989.

34. Sharif, M.N.; *Technology Policy Formulation and Planning, A Reference Manual*, Asian and Pacific Centre for Transfer of Technology, Bangalore, India, 1986.

35. Seifoddini H. K.; *Single Linkage versus average linkage clustering in machine cells formation applications*, Computer & Industrial Engineering, Vol 16, No. 3, pp 419-426,1989.

36. Steudel H. J., and Ballakar A.; *A dynamic programming based heuristic for machine grouping in manufacturing cell formation*, Computer and Industrial Engineering, Vol 12, No. 3, pp 215-222, 1987.

37. Slagle J. R., Chang C. L., and Heller S. R.; *A clustering and data recognition algorithm*, IEEE Transactions, System Manufacturing and Cybernetics, Vol 5, No. 1, pp 125-128, 1975.

38. White, L.B.; *The Technology Assessment Process*, Quorum Books, New York, 1988.

Bibliography

1. Bedworth D.D., and Bailey E.J.; Integrated Production Control Systems, John Wiley & Sons,1987.

2. Culbreth, C.T., and Pollpeter, D.L.; A Flexible Manufac-turing Cell for Furniture Part Production, Industrial Engineering, pp 28-34, November, 1988.

3. Crawford H.B., and Fleck G.H.; Computer Integrated Manufacturing Handbook, McGraw Hill Inc., New York, 1987.

4. Computer Applications in Production and Engineering, Proceedings of the Second International IFIP Conferences, edited by Eslensen L., Falster P., and Warman A.E.; Elseveir Science Publishers B.V., Netharland,1987.

5. Choobineh F.; A framework for the design of cellular manufacturing systems, International Journal of Production Research, Vol 26, No. 7, pp 1161-1172,1988.

6. Gentiti E.; Flexibility and JIT, a new advantage for FMS, Proceedings of the International Conference on Computer Integrated Manufacturing, ICCIM, Singapore, pp 311-314, 1991.

7. Guide to Quality Control and Company Standardization, Japanese Standard Association, 1984.

8. Harrington J. J.; Understanding the manufacturing process, key to successful CAD/CAM implementation, Marcel Dekker, New York, 1989.

9. Ismael D.J.; Back to Basis; Just what is Involved in Implementing a Flexible Manufacturing System, Industrial Engineering, April, pp 43-45, 1991.

10. Koren E., Clark P.E.; Cell Control : The missing link to Factory Integration, International Industrial Engineering Conference and Societies Manufacturing and Productivity Symposium Proceedings, pp 641-646, 1989.

11. Koren Y.; Computer Control of Manufacturing Systems, McGraw Hill book Co.,Singapore,1983.

12. Luong, L.H.S.; A group technology approach to cellular manufacturing design, Proceedings of the International Conference on Computer Integrated Manufacturing, ICCIM, pp 272-275, 1991.

13. Logendram R.; Effect of the identification of key machines in the cell formation problem of cellular manufacturing systems, Computers and Industrial Engineering, Vol 20, No. 4, pp 439-449, 1991.

14. McDermott K.; and Kamisetty K.V., Developing a FMS Using IE Tools and Principles, Industrial Engineering, December, pp 28-32, 1991.

15. Nagarkar S.; and Bennett D., Flexible Manufacturing System Lets small manufacturer of Mainframes Compete with Giants, Industrial Engineering, November, pp 42-46, 1988.

16. Porter A.L., Rossini F.A., and Carpenter S.R.; A guide book for Technology Assessment and Impact Analysis, series volume-4, North-Holland, New York, 1980.

17. Rembold U., Armbruster K., and Ulzmann W.; Interface Technology for Computer-Controlled Manufacturing Processes, Marcel Dekker, Inc., New York, 1983.

18. Rembold U., Armbruster K., and Ulzmann W.; Interface Technology for Computer-Controlled Manufacturing Processes, Marcel Dekker Inc.,NewYork,1983.

19. Seal M. G.; 1990's- Years of promise, years of peril for U.S. Manufacturers, Industrial Engineering, January, pp 18- 21, 1990.

20. Syan, C.S. and Dunford A.; A Modular Approach to Low-cost Flexible Manufacturing, Proceedings of the International Conference on Computer Integrated Manufacturing, ICCIM, Singapore, pp 307-310, 1991.

21. Samli, A.C.; Technology Transfer - Geographic, Economic and Cultural and Technical Dimensions, Qurom Books, 1985.

22. Salam, A.A.; A review of Industrial Policies of Bangladesh, IAT, BUET, 1988.

23. Seifoddini, H.; A Probabilistic Approach to Machine Cell Formation in group technology, Internation Industrial Engineering Conference and Societies Manufacturing and Productivity Symposium Proceedings, pp 625-629, 1989.

24. Seifoddini H. K., and Djassemi M.; The production data based similarity coefficient versus Jaccard's similarity coefficient, Computers and Industrial Engineering, Vol 21, No. 4, pp 263-266, 1991.

25. Taboun S.M., Dutta S.P., and Richardson, K.; Comparison and Evaluation of Cellular Manufacturing Techniques, Proceedings of the 11th Annaul Conference on Computer and Industrial Engineering, pp 603-608, Pergamon Press Ltd., 1989.

26. Taboun S.M., Sankaran S., and Bhole S.; Comparison and Evaluation of Similarity Measures in group technology, Computers and Industrial Engineering, vol.20, no.3, pp 343-353, 1991.

27. Taha, H.A.; Integer Programming, Theory, Applications and Computations, Academic Press inc., Florida, 1975.

28. UN-ESCAP, A Framework for Technology Based Development, Technology Atlas Project, Tokyo Program on Technology for Development in Asia and the Pacific, APCTT, Bangalore, India, 1989.

29. Walke A. H., and Overbreeke J.; Cellular Manufacturing: A good technique for implementing Just-in-Time and Total Quality Control, Industrial Engineering, November, pp 36-41, 1988.

30. Wild R.; Production and operations management principles and techniques, 3rd edition, ELBS, 1986.

APPENDIX

The detail computer output for the problem 2 is given below. Results are also taken for some intermediate steps.

INTERCELL MOVEMENT IS ALLOWED

TOTAL MACHINE TIME REQUIRED IN MINUTE FOR MINIMUM COST MACHINE PART MATRIX

```
TMTR(          1)         404000.0000000
TMTR(          2)         961800.0000000
TMTR(          3)         360100.0000000
TMTR(          4)         476500.0000000
TMTR(          5)          97500.0000000
```

TOTAL COST TO PRODUCE A PART

```
P(          1)=          96165.9800000
P(          2)=          87998.5800000
P(          3)=          58062.7400000
P(          4)=          91841.2700000
P(          5)=          51280.0000000
P(          6)=          73514.7500000
P(          7)=          73143.0300000
P(          8)=          60445.7100000
P(          9)=          37319.7000000
P(         10)=          42919.2300000
```

MACHINE REQUIRED TO PRODUCE A PART FOR MINIMUM COST MACHINE PART MATRIX

```
       p m m m

TPMIN( 1 3 5 4)=  96165.98
TPMIN( 2 3 2 4)=  87998.58
TPMIN( 3 4 3 *)=  58062.74
TPMIN( 4 4 4 1)=  91841.27
TPMIN( 5 1 2 *)=  51280.00
TPMIN( 6 2 2 2)=  73514.75
TPMIN( 7 2 3 2)=  73143.03
TPMIN( 8 1 2 *)=  60445.71
```

TPMIN(9 2 2 *)= 37319.70
TPMIN(10 2 1 *)= 42919.23

INITIAL PART SIMILARITY DIAGONAL MATRIX

SP(	1	2)=	0.5000000
SP(	1	3)=	0.5714286
SP(	1	4)=	0.4545455
SP(	1	5)=	0.3125000
SP(	1	6)=	0.2500000
SP(	1	7)=	0.2500000
SP(	1	8)=	0.2068966
SP(	1	9)=	0.1818182
SP(	1	10)=	0.1578947
SP(	2	3)=	0.6666667
SP(	2	4)=	0.4285714
SP(	2	5)=	0.3636364
SP(	2	6)=	0.3571429
SP(	2	7)=	0.4117647
SP(	2	8)=	0.3809524
SP(	2	9)=	0.3750000
SP(	2	10)=	0.3571429
SP(	3	4)=	0.3333333
SP(	3	5)=	0.1428571
SP(	3	6)=	0.1000000
SP(	3	7)=	0.1538462
SP(	3	8)=	0.1176471
SP(	3	9)=	0.1000000
SP(	3	10)=	0.0833333
SP(	4	5)=	0.3333333
SP(	4	6)=	0.1666667
SP(	4	7)=	0.1000000
SP(	4	8)=	0.1538462
SP(	4	9)=	0.1250000
SP(	4	10)=	0.1578947
SP(	5	6)=	0.5000000
SP(	5	7)=	0.4000000
SP(	5	8)=	0.5714286
SP(	5	9)=	0.5555556
SP(	5	10)=	0.6363636
SP(	6	7)=	0.5000000
SP(	6	8)=	0.5000000
SP(	6	9)=	0.6000000
SP(	6	10)=	0.5714286
SP(	7	8)=	0.3333333
SP(	7	9)=	0.4000000
SP(	7	10)=	0.3750000
SP(	8	9)=	0.5000000
SP(	8	10)=	0.7500000
SP(	9	10)=	0.5000000

PART SIMILARITY MATRIX AFTER TWO PARTS JOIN TO FORM A CELL

SP(	1	2)=	0.5000000
SP(	1	3)=	0.5714286
SP(	1	4)=	0.4545455
SP(	1	5)=	0.3125000
SP(	1	6)=	0.2500000
SP(	1	7)=	0.2500000
SP(	1	8)=	0.0000000
SP(	1	9)=	0.1818182
SP(	1	10)=	0.0000000
SP(	1	11)=	0.1823956
SP(	1	12)=	0.0000000
SP(	1	13)=	0.0000000
SP(	2	3)=	0.6666667
SP(	2	4)=	0.4285714
SP(	2	5)=	0.3636364
SP(	2	6)=	0.3571429
SP(	2	7)=	0.4117647
SP(	2	8)=	0.0000000
SP(	2	9)=	0.3750000
SP(	2	10)=	0.0000000
SP(	2	11)=	0.3690476
SP(	2	12)=	0.0000000
SP(	2	13)=	0.0000000
SP(	3	4)=	0.3333333
SP(	3	5)=	0.1428571
SP(	3	6)=	0.1000000
SP(	3	7)=	0.1538462
SP(	3	8)=	0.0000000
SP(	3	9)=	0.1000000
SP(	3	10)=	0.0000000
SP(	3	11)=	0.1004902
SP(	3	12)=	0.0000000
SP(	3	13)=	0.0000000
SP(	4	5)=	0.3333333
SP(	4	6)=	0.1666667
SP(	4	7)=	0.1000000
SP(	4	8)=	0.0000000
SP(	4	9)=	0.1250000
SP(	4	10)=	0.0000000
SP(	4	11)=	0.1558704
SP(	4	12)=	0.0000000
SP(	4	13)=	0.0000000
SP(	5	6)=	0.5000000

SP(	5	7)=	0.4000000
SP(	5	8)=	0.0000000
SP(	5	9)=	0.5555556
SP(	5	10)=	0.0000000
SP(	5	11)=	0.6038961
SP(	5	12)=	0.0000000
SP(	5	13)=	0.0000000
SP(	6	7)=	0.5000000
SP(	6	8)=	0.0000000
SP(	6	9)=	0.6000000
SP(	6	10)=	0.0000000
SP(	6	11)=	0.5357143
SP(	6	12)=	0.0000000
SP(	6	13)=	0.0000000
SP(	7	8)=	0.0000000
SP(	7	9)=	0.4000000
SP(	7	10)=	0.0000000
SP(	7	11)=	0.3541667
SP(	7	12)=	0.0000000
SP(	7	13)=	0.0000000
SP(	8	9)=	0.0000000
SP(	8	10)=	0.0000000
SP(	8	11)=	0.0000000
SP(	8	12)=	0.0000000
SP(	8	13)=	0.0000000
SP(	9	10)=	0.0000000
SP(	9	11)=	0.5000000
SP(	9	12)=	0.0000000
SP(	9	13)=	0.0000000

PART SIMILARITY MATRIX AFTER THIRD STEP

SP(	1	2)=	0.0000000
SP(	1	3)=	0.0000000
SP(	1	4)=	0.4545455
SP(	1	5)=	0.0000000
SP(	1	6)=	0.2500000
SP(	1	7)=	0.2500000
SP(	1	8)=	0.0000000
SP(	1	9)=	0.1818182
SP(	1	10)=	0.0000000
SP(	1	11)=	0.2474478
SP(	1	12)=	0.5357143
SP(	1	13)=	0.0000000
SP(	2	3)=	0.0000000
SP(	2	4)=	0.0000000
SP(	2	5)=	0.0000000

SP(	2	6)=	0.0000000
SP(	2	7)=	0.0000000
SP(	2	8)=	0.0000000
SP(	2	9)=	0.0000000
SP(	2	10)=	0.0000000
SP(	2	11)=	0.0000000
SP(	2	12)=	0.0000000
SP(	2	13)=	0.0000000
SP(	3	4)=	0.0000000
SP(	3	5)=	0.0000000
SP(	3	6)=	0.0000000
SP(	3	7)=	0.0000000
SP(	3	8)=	0.0000000
SP(	3	9)=	0.0000000
SP(	3	10)=	0.0000000
SP(	3	11)=	0.0000000
SP(	3	12)=	0.0000000
SP(	3	13)=	0.0000000
SP(	4	5)=	0.0000000
SP(	4	6)=	0.1666667
SP(	4	7)=	0.1000000
SP(	4	8)=	0.0000000
SP(	4	9)=	0.1250000
SP(	4	10)=	0.0000000
SP(	4	11)=	0.2446019
SP(	4	12)=	0.3809524
SP(	4	13)=	0.0000000
SP(	5	6)=	0.0000000
SP(	5	7)=	0.0000000
SP(	5	8)=	0.0000000
SP(	5	9)=	0.0000000
SP(	5	10)=	0.0000000
SP(	5	11)=	0.0000000
SP(	5	12)=	0.0000000
SP(	5	13)=	0.0000000
SP(	6	7)=	0.5000000
SP(	6	8)=	0.0000000
SP(	6	9)=	0.6000000
SP(	6	10)=	0.0000000
SP(	6	11)=	0.5178571
SP(	6	12)=	0.2285714
SP(	6	13)=	0.0000000
SP(	7	8)=	0.0000000
SP(	7	9)=	0.4000000
SP(	7	10)=	0.0000000
SP(	7	11)=	0.3770834
SP(	7	12)=	0.2828054
SP(	7	13)=	0.0000000
SP(	8	9)=	0.0000000
SP(	8	10)=	0.0000000
SP(	8	11)=	0.0000000
SP(	8	12)=	0.0000000

SP(	8	13)=	0.0000000
SP(	9	10)=	0.0000000
SP(	9	11)=	0.5277778
SP(	9	12)=	0.2375000
SP(	9	13)=	0.0000000

CELLULAR STRUCTURE AFTER SOLVING THE HEURISTIC LOGIC WITH INTERCELL MOVEMENT

TOTAL ITERATION NEEDED 3

PARTS	MACHINE REQUIRED		
1	3	5	4
2	3	2	4
3	4	3	
4	4	4	1
5	1	2	
6	2	2	2
7	2	3	2
8	1	2	
9	2	2	
10	2	1	

CONSTRUCTION OF CELL 1

PARTS

8
10
5

MACHINE REQUIRED

MACHINE TYPE	NO OF MACHINE	TOT. MACHINE TIME
1	1.	204000.0
2	1.	288000.0

CONSTRUCTION OF CELL 2

PARTS

2
3
1
4

MACHINE REQUIRED

MACHINE TYPE	NO OF MACHINE	TOT. MACHINE TIME
1	1.	112000.0
2	1.	104000.0
3	1.	254500.0
4	1.	396500.0
5	1.	97500.0

CONSTRUCTION OF CELL 3

PARTS

6
9
7

MACHINE REQUIRED

MACHINE TYPE	NO OF MACHINE	TOT. MACHINE TIME
2	2.	569800.0
3	1.	105600.0

TOTAL NO OF MACHINE REQUIRED

MACHINE TYPE	NO OF MACHINE
1	2.
2	4.
3	2.
4	1.

5 1.

MINIMIZED OBJECTIVE VALUE= 672691.00

WITHOUT INTERCELL MOVEMENT

TOTAL COST TO PRODUCE A PART

P(	1)=	96165.9800000
P(	2)=	91043.3400000
P(	3)=	58062.7400000
P(	4)=	91841.2700000
P(	5)=	51280.0000000
P(	6)=	73514.7500000
P(	7)=	73143.0300000
P(	8)=	60445.7100000
P(	9)=	37319.7000000
P(	10)=	42919.2300000

MACHINE REQUIRED TO PRODUCE PART

	p	m	m	m	
TPMIN(	1	3	5	4)=	96165.98
TPMIN(	2	3	5	4)=	91043.34
TPMIN(	3	4	3	*)=	58062.74
TPMIN(	4	4	4	1)=	91841.27
TPMIN(	5	1	2	*)=	51280.00
TPMIN(	6	2	2	2)=	73514.75
TPMIN(	7	2	3	2)=	73143.03
TPMIN(	8	1	2	*)=	60445.71
TPMIN(	9	2	2	*)=	37319.70
TPMIN(	10	2	1	*)=	42919.23

INITIAL PART SIMILARITY DIAGONAL MATRIX

SP(	1	2)=	1.0000000
SP(	1	3)=	0.8333333
SP(	1	4)=	0.6000000
SP(	1	5)=	0.4000000
SP(	1	6)=	0.3157895
SP(	1	7)=	0.3043478
SP(	1	8)=	0.2500000
SP(	1	9)=	0.2187500
SP(	1	10)=	0.1891892
SP(	2	3)=	0.6666667
SP(	2	4)=	0.4285714
SP(	2	5)=	0.2500000
SP(	2	6)=	0.1875000
SP(	2	7)=	0.2000000
SP(	2	8)=	0.1600000
SP(	2	9)=	0.1379310
SP(	2	10)=	0.1176471
SP(	3	4)=	0.3333333
SP(	3	5)=	0.1428571
SP(	3	6)=	0.1000000
SP(	3	7)=	0.1538462
SP(	3	8)=	0.1176471
SP(	3	9)=	0.1000000
SP(	3	10)=	0.0833333
SP(	4	5)=	0.3333333
SP(	4	6)=	0.1666667
SP(	4	7)=	0.1000000
SP(	4	8)=	0.1538462
SP(	4	9)=	0.1250000
SP(	4	10)=	0.1578947
SP(	5	6)=	0.5000000
SP(	5	7)=	0.4000000
SP(	5	8)=	0.5714286
SP(	5	9)=	0.5555556
SP(	5	10)=	0.6363636
SP(	6	7)=	0.5000000
SP(	6	8)=	0.5000000
SP(	6	9)=	0.6000000
SP(	6	10)=	0.5714286
SP(	7	8)=	0.3333333
SP(	7	9)=	0.4000000
SP(	7	10)=	0.3750000
SP(	8	9)=	0.5000000
SP(	8	10)=	0.7500000
SP(	9	10)=	0.5000000

TOTAL ITERATION NEEDED 6

PARTS	MACHINE REQUIRED		
1	3	5	4
2	3	2	4
2	3	5	4
3	4	3	
4	4	4	1
5	1	2	
6	2	2	2
7	2	3	2
8	1	2	
9	2	2	
10	2	1	

CONSTRUCTION OF CELL 1

PARTS

1
2
3
4

MACHINE REQUIRED

MACHINE TYPE	NO OF MACHINE	TOT. MACHINE TIME
1	1.	112000.0
3	1.	254500.0
4	1.	396500.0
5	1.	217500.0

CONSTRUCTION OF CELL 2

PARTS

8
10
5

P

MACHINE REQUIRED

MACHINE TYPE	NO OF MACHINE	TOT. MACHINE TIME
1	1.	204000.0
2	1.	288000.0

CONSTRUCTION OF CELL 3

PARTS

6
9
7

MACHINE REQUIRED

MACHINE TYPE	NO OF MACHINE	TOT. MACHINE TIME
2	2.	569800.0
3	1.	105600.0

TOTAL NO OF MACHINE REQUIRED

MACHINE TYPE	NO OF MACHINE
1	2.
2	3.
3	2.
4	1.
5	1.

MINIMIZED OBJECTIVE VALUE= 675735.80