Group technology and cellular manufacturing systems: an introduction

Angel A. Cedeño
Professor
Department of Industrial Engineering, PUPR

Abstract

Global market competition is changing the nature of the present and future marketplace to a highly dynamic environment. Product variety is high and individual product demands are low. Also, customer's demand for faster responses and for products of lower costs and higher quality increases everyday. Under these circumstances, companies are forced to search for new ways to improve the productivity of their manufacturing operations. Group technology, and its application to the manufacturing environment called cellular manufacturing, arises as a new manufacturing philosophy that will play a key roll helping companies meet their objectives. The use of group technology and cellular manufacturing concepts will allow small batches of high variety and mixed quantity production with the benefits and economic advantages of mass production. This paper presents an explanation of the fundamental concepts and definitions related to group technology and cellular manufacturing. It also addresses some relevant issues related to the design and control of cellular manufacturing systems from a production management view.

Sinopsis

La libre competencia a nivel mundial está tornando los mercados actuales y futuros en unos muy dinámicos. La diversidad de los productos en demanda es alta, pero las demandas individuales de productos tienden a disminuir. Mas aún, los requerimientos de los clientes de la distribución inmediata de los productos y artículos de alta calidad y costos bajos son cada vez más altos. Estas circunstancias fuerzan a las compañías a buscar nuevas formas de mejorar la productividad de sus procesos de manufactura. La tecnología de grupo, y su aplicación al ambiente de manufactura llamada manufactura celular, emerge como una nueva filosofía de produción que tendrá una importancia capital como medio para que las compañías consigan sus objetivos. El uso de los conceptos de la tecnología de grupo y la manufactura celular permitirá la produción de lotes pequeños de una gran variedad de productos aprovechando los beneficios de la produción en masa. En este artículo explicaremos los conceptos fundamentales y definiciones relacionados con la tecnología de grupo y la manufactura celular. También se presentarán algunos conceptos relacionados con el diseño y control de los sistemas de manfactura celular desde el punto de vista de la gerencia de operaciones.

Introduction

The fierce competition among manufacturing companies has forced many of them to find new ways to simplify and improve their manufacturing processes in order to survive in a global market. The need to use resources in the most efficient way to reduce waste and costs and, at the same time, to improve production and service quality to increase customer satisfaction has set the ground for the rise of new and better manufacturing philosophies and techniques. Just-in-time (JIT), world class manufacturing (WCM), total quality management (TQM) and group technology (GT) are some of those techniques and philosophies that are used to develop methodologies for the efficient use of resources, elimination of waste and continuous improvement of activities.

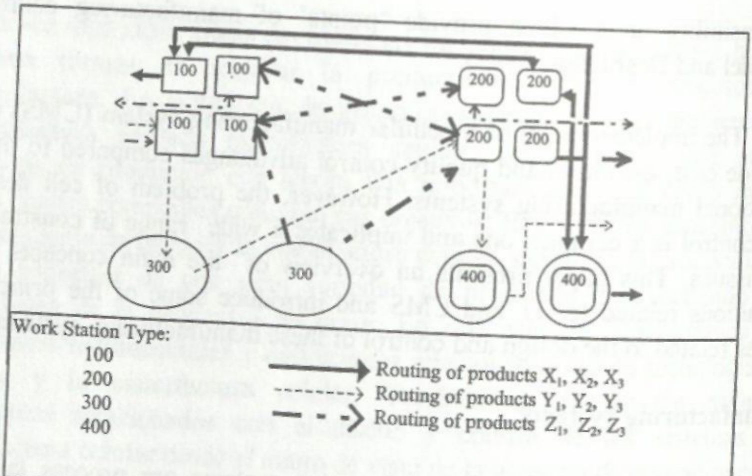
Group technology is one of the most widely accepted management philosophies for the organization of manufacturing systems. Cellular manufacturing (CM) is an application of GT to manufacturing. CM involves the design of clusters of machines or operations (cells). The objective of these clusters is to process the groups of similar products (product families) to "create concentrated mini-processing and responsibility units which provide 'points' of manufacturing control" (Steudel and Desruelles, 1992).

The implementation of a cellular manufacturing system (CMS) can provide cost, operation and quality control advantages compared to other traditional manufacturing systems. However, the problem of cell design and control is a complex one and implicates a wide range of constraints and issues. This paper presents an overview of the main concepts and definitions related to GT and CMS and introduce some of the principal issues related to the design and control of these manufacturing systems.

Manufacturing systems

The four best known manufacturing systems are process layout, product layout, project planning and continuous process. The first three systems are applied to the production of discrete items such as automobiles, machine tools, electrical and electronic products, house appliances, industrial machinery and apparel. The fourth is common to the chemical industry for the production of non-discrete nature items such as plastics, drugs, soaps, petroleum, metal products, food and beverages and paper goods.

In a process layout manufacturing system, also known as job shop (fig. 1), operations and machines with similar functional type are grouped together. Each group is considered as a department. This system is common in batch production because it is very flexible to cope with a myriad of different product job orders. In fact, batch manufacturing accounts for 60 to 80 percent of all manufacturing activity in the world. Job shop is used in cases where product demand is low and variety of products is high. Among its major disadvantages are high work-in-process inventory, long setup times, long leadtimes and slow response to the market place.



ROUTERS					
Product	1st Operation	2nd Operation	3rd Operation	4th Operation	5th Operation
X_1	100	200	400		
X_2	400	200	100		
X_3	200	100	400		
Z_1	200	100	300	200	100
Z_2	200	100	300	200	100
Z_3	100	200	300	100	200
Y_1	100	300	200	400	
Y_2	100	300	200	400	
Y_3	100	300	200	400	

Figure 1. Process layout manufacturing system

In a product layout manufacturing system, also known as flow shop (fig. 2), different operations and specialized machines are arranged in such a way that products flow continuously through a specific sequence of transformation processes. Usually, this arrangement of operations and more specialized machines involves the configuration of a production line where no back flow is allowed. This system is used in mass production environments where demand for products is high and variety of products is low. Its major drawback is the low flexibility to process different product job orders because of the product line specialization. As a consequence, production batches are large, production runs are long, end product inventories are large and conversions to another product take a lot of time.

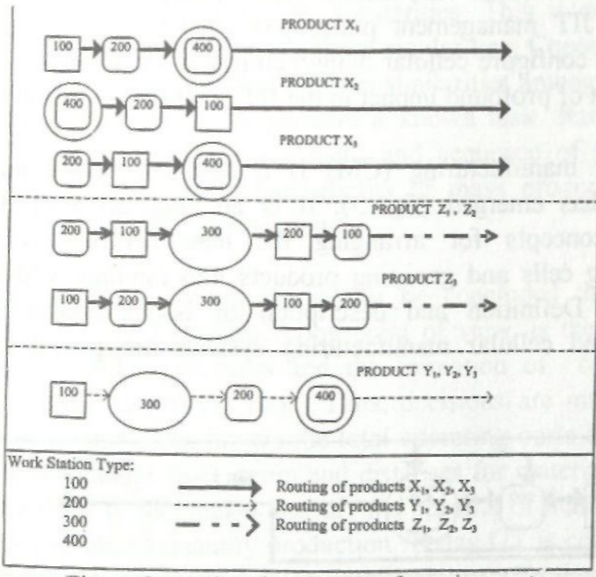


Figure 2. product layout manufacturing system

Project planning is a system used for large projects involving the production of long lead time products and services. In those systems the primary focus is the efficient management of time. Related to time is cost. The project is usually supported by job shop and flow shop systems that supply components and subassemblies that are later assembled and processed in the project site.

The continuous process systems are typical of the chemical industry and consist in the flow of products, generally gases, liquids, powders or slurries, through a series of continuous connected processes. Given the non-discrete manufacturing nature of the continuous process systems, it will not be considered for further description in this article. However, it must be pointed out that, from a production management point of view, the operations planning control of these systems are easier and simpler. Therefore, the continuous process systems constitute the ideal vision of the successful Japanese JIT manufacturing systems in which the flow of discrete products should run, ideally, like a liquid through a continuous system. The JIT management philosophy uses the rationale of group technology to configure cellular manufacturing systems, which constitute a core element of profound impact in the JIT manufacturing environment.

Cellular manufacturing (CM) is a new kind of manufacturing system that has emerged (fig. 3). It is an application of the group technology concepts for arranging the manufacturing system into manufacturing cells and grouping products into families; CM job shop environment. Definition and description of issues related to group technology and cellular manufacturing systems are provided in later sections.

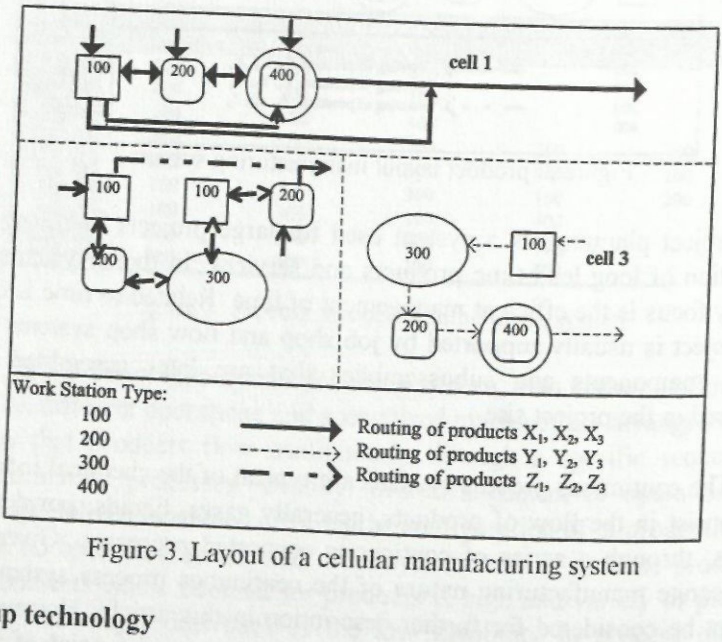


Figure 3. Layout of a cellular manufacturing system

Group technology

Some definitions of GT by some researchers are as follows: Shunk (1985) said that it is an approach to identify things by their attributes in order to establish similarities between them. Then, families are formed, grouping those things based on the similarities. This is done with the purpose of taking the advantages of those similarities. Choobineh (1988) outlined GT as a philosophy that uses the similarities among attributes of given objects or situations to perform a known task. Ranson (1972) defined GT as a logical arrangement and sequence of all facets of company operations to bring the benefits of mass production to high variety and mixed quantity production.

Regarding those definitions, it can be concluded that the basic concept of GT, from a manufacturing point of view, is the grouping of products with similar processes and the formation of cells with the required machines to process them. Thus, decisions are made based on those formed groups. This lowers the total operating costs as a result of the reduction in change-over, setup and distances for material movement. At the same time, it also makes use of the benefits of mass production, high variety and mixed quantity production. Today GT is considered as a manufacturing philosophy with broad applicability affecting all areas of manufacturing environment.

Cellular manufacturing

Cellular manufacturing is the application of the GT philosophy to a manufacturing environment. The result of this application is the partitioning of the manufacturing system into cells and part families. Therefore, CM can be described as a manufacturing process that produces families of products in designated manufacturing cells. Product families are formed based on the similarities of manufacturing processes among products. The manufacturing cells are formed by those machines capable of processing all of the products in a family. However, in some cases, manufacturing cells might process products from different families to introduce more flexibility to the system. The manufacturing cells may follow defined shapes (S, U, C, etc.) and can be classified in two types (Steudel and Desruelle, 1992):

1. Job shop cell layouts, where machines in a cell cannot be arranged in a unidirectional flow of work and, as a result, backtracking is allowed (fig. 4a);

2. Flow shop cell layouts, where machines are arranged in an unidirectional flow of work and backtracking is eliminated (fig. 4b). In the figures, M*i* represents the machine of type *i*.

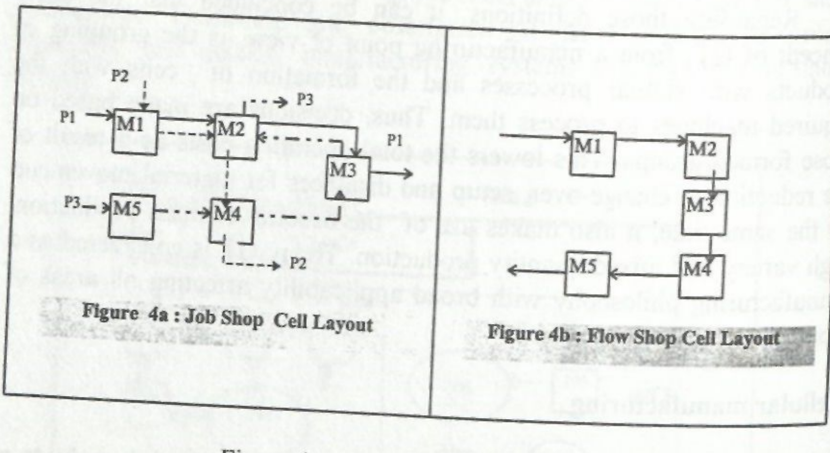


Figure 4a : Job Shop Cell Layout

Figure 4b: Flow Shop Cell Layout

Figure 4. types of manufacturing cells

Design of manufacturing cells

The main objective of the design of a CMS is the identification of part families that are to be processed in suitable manufacturing cells. While doing so, a number of strategic structural and operational issues, with broad implications for the organization, have to be considered (Wemmerlov and Hyer, 1987).

Operational issues include:

Design of jobs

Organization of supervisory and support personnel in the cellular system

- Maintenance and inspection procedures

- Consideration of planning and control issues such as flexibility, demand variability, production volumes, product mix, number of cells, cell layouts, investment cost, tardiness-related cost, cell loading and scheduling, etc.

- Monitory procedures (in terms of work flow and information)

Structural issues include:

- Product families formation

- Selection of machines and process for cell formation

- Selection of tools, fixtures and pallets

- Selection of material handling equipment

- Cell layout

The design of cellular manufacturing systems is a complex task. It is not possible to outline a specific sequence of decisions related to the cell design. However, because of the complexity of the various dimensions of the manufacturing realities inherent to the design of a CMS, comprehensive methodologies are needed. These methodologies should consider the operational and structural issues in an integrated manner for the effective design of cellular manufacturing systems.

Cell formation

When designing a cellular manufacturing system, the process of forming the manufacturing cells is very important. There are two main issues in forming cells, namely,

1. forming product families
2. forming cells to process them.

A number of papers on CMS design focus only on techniques and approaches for forming product families and machine cells. There are various classifications of those cell forming techniques and approaches and most of them can be grouped in the following categories depending on the inputs they use: visual methods, GT classification codes, production flow analysis and cluster analysis.

The techniques and approaches most complete are those that fall into the cluster analysis category. Those techniques stand for a formal method of grouping products and machines. They include some mathematical analysis and use data such as demand, processing time and sequence of operations in the design process. Most of the work on cluster analysis focuses only on the identification of manufacturing cells and product families. Those clustering techniques are primarily concerned with the rearrangement of the rows and columns of a "binary product-machine* processing matrix" such as the one shown in figure 5. The objective is to identify a block diagonal structure as shown in Figure 6. The binary product-machine processing matrix is based on product routers. Typically, it consists of 0/1 entries, where a "1" entry means that the machine in row "*i*" can process the product in column "*j*". A "0" entry means that the machine does not process the corresponding product.

* The term "operation" is more appropriate; however, the term "machine" is used instead of "operation". This is done to agree with the terminology used in the published related literature .

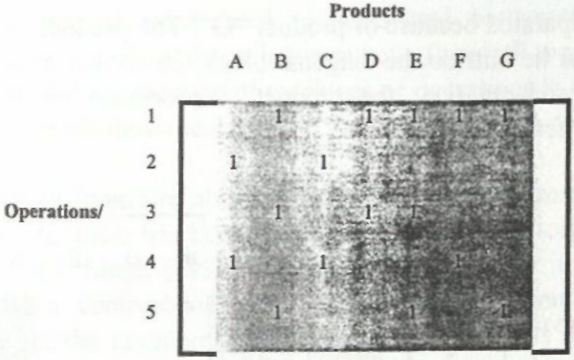


Figure 5. Binary product-machine processing matrix

There are two categories of "binary product-machine processing matrix": mutually separable clusters and partially separable clusters. Figure 6 shows a mutually separable cluster, where the clusters of 1's around the diagonal of the matrix indicate two product families {PF-1 and PF-2 } and their corresponding cells {MC-1 and MC-2}.

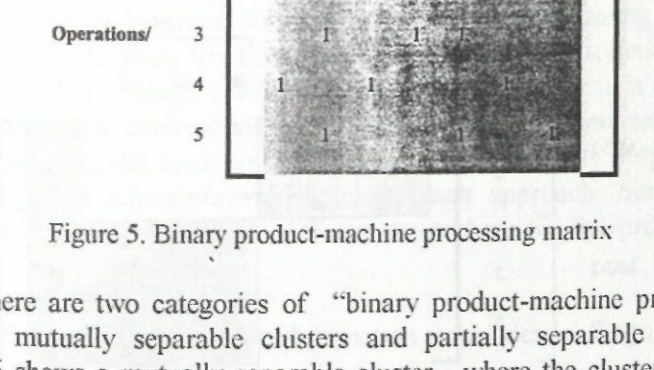


Figure 6. Mutually separable clusters binary product-machine processing matrix

However, not all matrices can be rearranged to fit a block diagonal form such that no 1s lie outside one of the clusters. Figure 7 shows a partially separable cluster matrix, where two disjointed separable clusters cannot be separated because of product "G." The products corresponding to the 1s that lie outside the diagonal block are known as exceptional or bottleneck products (i.e., the product is processed on machines that pertain to different cells).

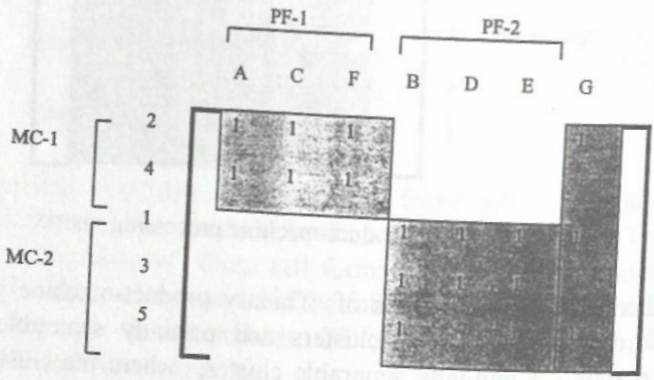


Figure 7. Mutually separable clusters binary product-machine processing matrix – exceptional product case

Also, similar to the bottleneck product, the machines corresponding to the 1s that lie outside the diagonal block can be defined as bottleneck machines (machine "5" in figure 8). A bottleneck machine is one that processes products pertaining to different families.

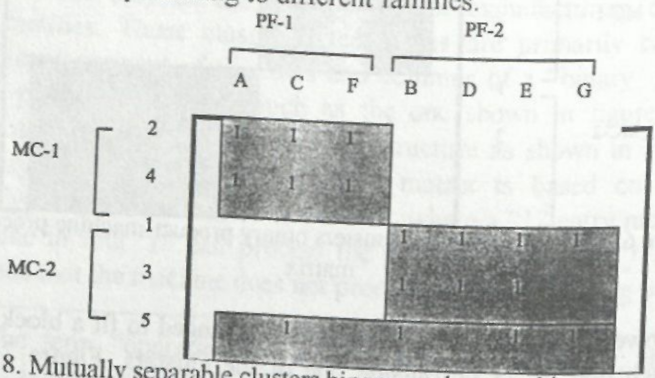


Figure 8. Mutually separable clusters binary product-machine processing matrix – bottleneck machine case

The presence of exceptional products and bottleneck machines suggests the handling of products between cells (intercell movements) or the duplication of the same type of machines or operations to minimize or eliminate the intercell movements.

The existing literature about cell formation and clustering methods is vast. Therefore, there has been a need to classify those techniques into taxonomic groups. Singh (1993) classified those methods in a series of approaches for a comprehensive review of cell formation techniques. Table 1 presents the taxonomy of different approaches as proposed by him along with representative studies of each approach. Some other taxonomic classifications due to different researchers are also presented in table 2.

Table 1 Taxonomy of cell formation techniques by Singh.

Taxonomy	Related studies
Coding and classification	Hyer and Wemmerlov, 1985
Machine-component group analysis	King (1980), Chandrasekaran and Rajagopalan
Similarity coefficient	Seifoddini and Hsu (1994), Suer and Ortega
Knowledge-based	Kusiak (1988)
Mathematical programming	Co and Araar (1988)
Fuzzy clustering	Chu and Hayya (1991)
Neural networks	Chung and Kusiak (1994), Rao and Gu (1993)
Heuristics	Vohra et al. (1990)

Control in cellular manufacturing

When controlling a cellular manufacturing system, there are two tasks that must be performed: cell loading and cell scheduling. Cell loading refers to the task of assigning the products of a family to feasible cells, determining how many units should be produced and in what order. This assignment should pursue three objectives according to Saiz (1992)

1. balance the loads among cells;
2. balance the loads within each cell;
3. balance the proportion of jobs with large processing time and jobs with small processing time among cells

The cell loading problem is a complex one. Therefore, most cell loading problems will fall into the category of NP-complete problems. Nevertheless, the need to consider cell loading issues while designing CMS is strongly acknowledged. If the number of jobs assigned to a cell is relatively low, then finding reasonably good solutions (and even optimal ones) for the cell loading problem may not be impossible.

Cell scheduling deals with the determination of start times and completion times of operations and the determination of lot sizes and transfer sizes through several workstations once a product has been loaded to a particular cell. Like the cell loading problem, the cell scheduling problem is also a complex issue in which most scheduling problems fall in the category of NP-complete problems. Depending of the type of manufacturing cells and the performance measures to be optimized, different heuristic procedures and loading rules might be used to schedule operations in each cell. However, as a result of the cell loading task, the dimension of the scheduling problem is decreased because of the reduced number of jobs and product operations in each cell. Hence, the amount of computations involved in the scheduling task is dramatically reduced and might even allow the use of optimizing techniques. Therefore, the use of cellular systems contributes to the easiness of the control and scheduling task in the manufacturing environment.

Table 2 Taxonomies of cell formation techniques of different researchers

Author	Taxonomic Classification
Offodile et al.(1995):	1. Visual Method 2. Parts Coding Analysis: Monocode (Hierarchical) Polycode (Chain-Type) Hybrid (Mixed) 3 Production Flow Analysis: Matrix Formulation: Similarity Coefficient Array-Based Method Graph Theory Mathematical Formulation Integer Programming Linear Programming Dynamic Programming 3. Other Structures Systems Simulation Expert Systems Neural Networks Fuzzy Sets Theory
Wemmerlov and Hyer (1989):	Methods that identify: 1. Part Families without Routings 2. Machine Groups 3. Part Families with Routings 4. Part and Machine Groups Simultaneously
Ballakur and Steudel (1987)	Techniques Based on: 1. Part Family Grouping 2. Machine Grouping 3. Machine-Part Grouping

Implementation of cellular manufacturing

Cellular manufacturing systems are still being implemented in the United States. Studies in different scenarios and how CM compares to other manufacturing systems still need to be conducted to evaluate the performance of CMS. A survey of a number of U.S. companies that are using cellular manufacturing systems showed, among other benefits, the following (Wemmerlov and Hyer, 1987):

- Reduction in throughput time by 45.6 percent.

- Reduction in work in process inventory by 41.4 percent.
- Reduction in material handling by 39.3 percent
- Reduction in setup time by 32.0 percent
- Improvement in quality by 29.6 percent

Cellular manufacturing is good for the production of small-to medium-sized batch of products with medium to high variety and mixed quantity production (fig. 9). Cellular systems are likely to be more effective and offer operating advantages when setup times are longer, demand is predictable, the flow of jobs through machine centers is uni-directional and move time is substantial.

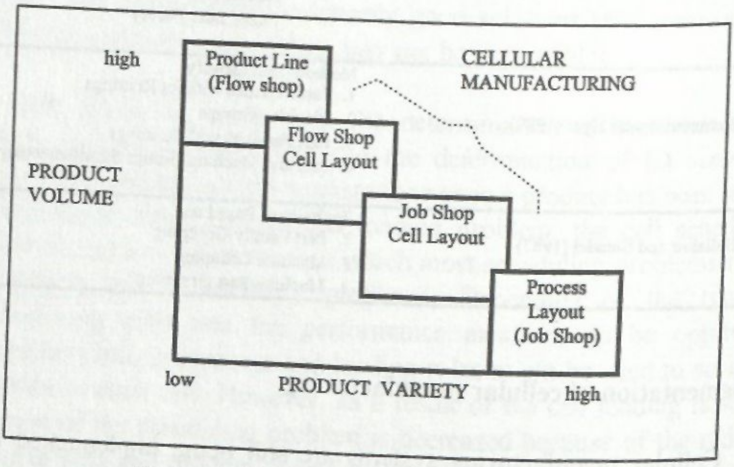


Figure 9. Different manufacturing systems

Among the advantages that cellular systems offer are:

- Reduction of setup times because of similarities between products in a family.

- Reduction in material handling.

- Easy implementation of changes in production such as different production schedules, cell setups, implementation of new products manufacture, new product routings, etc..

- Shorter leadtimes.

- Lower work-in-process inventory.

- Savings in floor space.

- Improved visual control of shops.

- Improvement of intangible factors like worker's satisfaction, maintenance, quality control and customer satisfaction.

Two major disadvantages of cellular manufacturing are:

- the lower machine utilization that may result because of the increased number of machines;

- the reduced flexibility of the system, which is due to dedicating machines to certain cells and dedicating cells to certain product families.

Conclusion

Global market competition makes present and future marketplaces a highly dynamic environment. The manufacturing activity, to survive in this environment, has to be able to satisfy the requirements of a market characterized by an every day increasing high variety of products, hence, lower individual product demands. This task has to be accomplished in an environment where requirements for faster responses, low cost and high quality products, as well as competition are increasing. The impact of this environment in manufacturing operations is high investment in equipment, large set up times, high quality control costs, complex manufacturing planning and control activities at all levels, excessive scrap, high tooling costs, etc.

Under the circumstances previously explained, the need to improve the productivity of batch manufacturing systems is essential. The adoption of group technology and cellular manufacturing concepts, along with just-in-time manufacturing and an integrated engineering environment from product design to product manufacturing, will provide the strategy for success in the twenty-first century. Cellular manufacturing permits the production of small to medium-sized batches of products with high variety and mixed quantity production and, at the same time, retains the benefits and economic advantages of mass production. Therefore, GT and CM provide the competitive advantages to help companies meet their objectives of increasing market share and profitability. This paper provides a conceptual explanation and definition of some important issues related to the design, planning and control of cellular manufacturing systems.

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