CELLULAR MANUFACTURING - CURRENT IMPLEMENTATION PRACTICES AND FUTURE DIRECTIONS

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Abstract

This paper presents the views of the authors on current implementation issues relating to the design, training, performance and control of Cellular Manufacturing Systems (CMS). Specific examples are drawn from company implementations.

Cellular Manufacturing is a generally accepted method to improve productivity and throughput in discrete manufacturing systems. Traditionally the method has been applied in medium volume and medium variety production situations with a cost minimization focus. Now, with the market demand for smaller volumes and increased product varieties, CMS is being implemented in more demanding manufacturing situations. The authors have worked with companies to achieve improvements by coupling elements of CMS with traditional high volume line layouts. The authors have also implemented CMS in focused factories for short-run time products, small batch size products and speciality products.

This paper highlights the critical success factors for the implementation of CMS in new manufacturing situations. The paper also discusses potential future directions for integrating cellular manufacturing systems with synchronous manufacturing and agile manufacturing practices.

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I. Introduction and Background

Cellular Manufacturing is generally accepted as a methodology to improve both productivity and throughput in discrete manufacturing systems. Traditionally the method has been applied in medium volume and medium variety production situations with a cost minimization focus.

In Cellular Manufacturing Systems, machines are grouped into cells and components (or parts) are grouped into families such that most, if not all, parts within a family are produced within one manufacturing cell. These systems have the advantages of reduced throughput times, shorter material travel, reduced changeover times, improved quality and improved worker morale.

Cellular Manufacturing Systems (CMS) have been applied to a variety of production situations in organizations making different products and parts. One of the earliest applications cited was over thirty years ago in the United Kingdom. Burbidge, one of the pioneers in this area is of the view that potentially every process type layout can be successfully changed into a cellular layout (Burbidge, 1992).

However, a 1989 survey indicated that even after 25 years of research and development, relatively few companies choose to implement the technique and commonly did not have a high percentage of cellularization (Wemmerlov and Hyer, 1989). A more recent survey on implementation experiences and performance improvements of cellular manufacturing systems in the United States was published in 1997. This survey indicates that there are several reasons for companies to implement this technique (Wemmerlov and Johnson, 1997). Forty-six user plants indicated eleven reasons for implementing CMS. The first six justification points included reducing throughput times, reducing work-in-progress, improving part quality, reducing customer lead time, reducing material travel distance and bringing flexibility into the system.

With the market demand for smaller volumes and increased product varieties, CMS is being implemented with a broader strategic focus. This paper highlights critical success factors for the implementation of CMS in current manufacturing environments. The paper also provides future directions for integrating cellular manufacturing systems with synchronous manufacturing and agile manufacturing practices.

II. Implementation Issues

Based on the authors' experience in implementing CMS in a variety of manufacturing organizations, the below listed are some of the critical implementation issues. Companies successfully implementing cellular techniques have given careful attention to the following factors:

- Rapid response to market changes
- Empowerment of employees
- Use of appropriate cell designs
- Demonstration of success with a pilot cell
- Effective management of cell operations
- Integration of support functions and tools

1. Rapid response to market changes

Customer response times and customization of products are increasingly becoming key factors of competitive advantage in today's global economy. Often manufacturing companies are unable to meet these goals with traditional production management practices. Cellular Manufacturing Systems enable an organization to improve response time and customer enrichment through quick changeover, elimination of waste, smaller batch sizes, shorter lead times and improved quality. For example, the authors have worked with a sheet metal fabrication company to reduce work-in-process, improve delivery performance and improve productivity. In addition to these benefits customer needs were better understood as empowered employees worked proactively with customers. This resulted in rapid implementation of engineering changes and development of new products.

Though early efforts of CMS implementation focused on cost reduction, the authors have experienced that current implementations are more strategic than tactical. Hence it is necessary for the organizations to identify and prioritize strategic advantages while defining the scope of CMS implementation. For example, the authors have helped an organization to offer "fabrication solutions" to diverse customers rather than selling "products" in a high volume mass production set up. This strategic shift required reengineering of business processes and was facilitated by using cellular manufacturing as a tactical tool. This transition enabled the company to effectively meet customer expectations.

2. Empowerment of employees

Typically improvement efforts in organizations are targeted towards a narrow departmental focus. For CMS to be fully successful, employees often need to understand and adapt an enterprise wide perspective. As the scope of CMS implementation extends from tactical to include strategic, organizations need to emphasize the required cultural change. The cultural shift can be achieved through appropriate training programs covering the following elements:

- Marketplace challenges and the need for change
- Strategic thinking toward corporate goals
- Cross functional training to promote coordination
- Best practices and benchmarking studies
- Issues related to Cellular Manufacturing (Design, Operations and Strategies)
- Role of support functions (Marketing, Information Services, Sales and Maintenance)

Training enhances the ability of employees to work together in teams toward a common goal and contributes toward the improvement process. Since the output from the CMS depends more on team performance and less on individual efficiencies, the synergy and power of teamwork, cooperation, and coordination are essential. It is the author's experience that knowledge of the strategic and systems thinking, acquired through training, helps in the smooth and successful implementation of CMS.

3. Use of appropriate cell designs

There are two different approaches to cell design. They are **product based cells** and **process based cells.** In **product based cells**, the problem of cell formation is relatively easy because all

the machines required to make the product can be organized in a sequential manner. This design strives to provide the benefits of continuous production in batch manufacturing. This approach to CMS is recommended if the volume of the product family is sufficient to justify such a system. When the physical size of the product is not a limitation for single piece transfer, this system is ideal. The challenges are likely to be in cycle time determination and line balancing. In some cases, limited additional capacity and resources need to be planned in the cell to anticipate and respond to the changes and uncertainties of the market. The authors were involved in the design

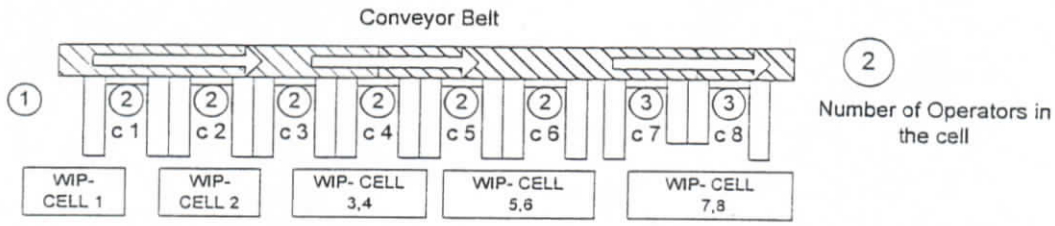

Figure 1-Cellular Manufacturing System based on product type

of an assembly line for a sheet-metal fabrication company to manage significant variations in the volume and variety of the products (Figure 1). This design demonstrates coupling of a traditional product line with elements of a cellular system. In this system multiple operators in each cell work on the same product without moving the part between them and finally feeding the part to the main line. Inventory for different operations is stored near the point of use. The number of employees in each cell is calculated from the product demand and processing time. All the cells were active for some products, while some were inactive for a few products depending on the parts. This design provided the necessary capacity and flexibility to meet the variations in product volume and variety.

In **process based cell** design, part families and machine cells are formed such that all parts within a family undergo processing in the assigned cell. The important issue is in the identification of part families and machine cells. The authors have developed and used algorithms to group machines and parts using machine component incidence matrices primarily as a starting point. The groups are formed based on maximizing similarities or minimizing dissimilarities of parts and machines. These are further equated to a mathematical distance that is computed using the zero-one incidence data. Commonly used measures of similarities and distances between machines are given below:

$$s_{ij} = \sum_k a_{ikj} x_j \, a_{jk}, \qquad d_{ij} = |a_{ik} - a_{jk}|$$

Where s_{ij} represents the similarity coefficient between machines i and j, d_{ij} represents the distance between machines i and j (dissimilarity index) and $a_{jk}=1$, if part j requires processing on machine k and $a_{jk} = 0$ otherwise.

A typical mathematical programming formulation attempts to minimize the sum of distances or dissimilarities. The decision variable $x_{ij} = 1$ if machine i is allocated to a cell with nucleus machine (or median) j, otherwise $x_{ij} = 0$. The problem is to

$$Minimize \sum_i \sum_j d_{ij} x_{ij}$$

$$x_{ij} \le x_{jj}, -- \sum_j x_{ij} = 1, -- \sum_j x_{jj} = p, -- x_{ij} = 0,1$$

The authors have observed that in practical applications, it is necessary to adapt the theoretical solutions on a case by case basis. Often this is because the computed machine distances do not correspond to the material distance covered and also do not represent the dissimilarity in the process sequence of the products. In most of the cases the algorithm optimizes a single objective without concentrating on other issues such as operator manning and line balancing. For example, for a machine shop fabricating small volume aerospace components, the solutions found from a clustering algorithm had to be modified by considering issues such as cost of adding machines, operator skills, sharing machines and utilities among the business units, and safety.

Figure 2 illustrates a typical CMS based on the process type approach where manufacturing cells make a set of parts completely. This layout was developed for a focused factory manufacturing sheet metal enclosures. This layout shows final assembly sequences with six operators and three packaging operators. The layout demonstrates feeding processes and subassemblies coupled with the final assembly. The crossed boxes indicate strategic inventory stored at the point of use. This design serves six different parts in a product family. The product life cycle of these products is short (less than one year). The equipment and supporting utilities were engineered such that with slight variations in the layout, it was possible to rapidly respond to significant product changes. For the same company a focussed factory was setup for small lot production with short lead times to serve different customers.

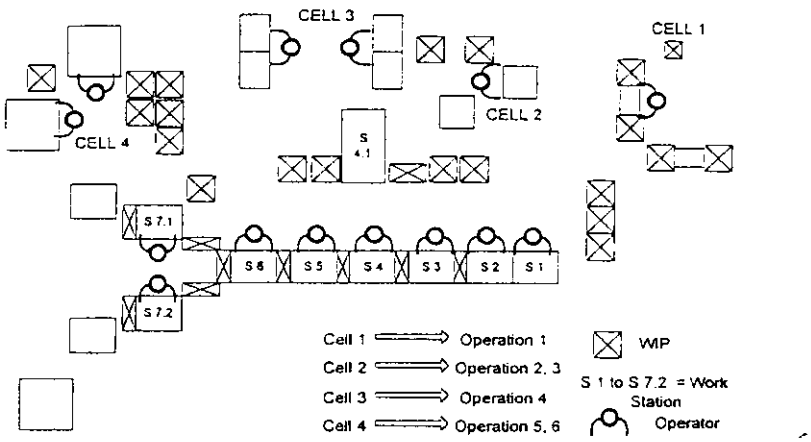

Figure 2 - Cellular Manufacturing System based on the Process type Cell Design

In the process type cell design, the challenges are likely to be in capacity determination and equipment duplication. It is sometimes observed that the most critical machines turn out to be the bottlenecks that cannot be duplicated. To overcome this, it is necessary to offload some of the work to slower machines without increasing the product cycle times.

The authors have encountered several variations of the process type layout for cell design. There are instances where companies have grouped 60% of machines into cells and retained the rest of the machines as a separate shop where parts are processed in the assigned cell and also in the common facility.

An exploratory study for cell design was done by one of the authors for a firm manufacturing machinery, where among the alternatives, this was considered. For another exploratory study V shaped cells were considered. In a V cell machines are arranged in a big V shape and several Vs

are created from this. In this case, several lines share common equipment and there is ownership and responsibility for the product and not for the cell. There are instances where star type layouts have been considered where only one piece of equipment is shared by many cells.

4. Demonstration of success with a pilot cell

The authors have found that CMS implementation is more successful if there is a demonstrated success through a pilot cell implementation. During the CMS implementation productivity should not be sacrificed. If analysis and redesign of cells is performed in mainstream production, operation efficiency may suffer because of skepticism. The authors have experienced that by demonstration with pilot cells, issues such as project planning, safety concerns, labor relations can be effectively addressed. Pilot cells also provide an opportunity for feedback from operators to refine the cell design. The factory wide implementation should immediately follow the success of the pilot cell.

5. Effective management of cell operations.

Product type cells are normally designed for a single piece transfer. Sometimes, the line is split into several modules or cells for operational control. This system should be ideally designed for a single piece production batch size to achieve maximum benefits. These systems can be easily integrated with just-in-time philosophy of eliminating waste and reducing lead times. This system offers the flexibility in designing product throughput by proper operator allocation and manning.

There are situations where the operators move with the parts in the cell and complete the operations in one trip. This results in ownership and responsibility for the product. In some cases the operators welcome this compared to the monotony of repeating the same assembly operation. These have been used by some organizations in both manufacturing and assembly (Black, 1991).

Cell scheduling is relatively complicated in the process type when there are inter cell moves. The scheduling problems are similar to that of a job shop except that the problem size is reduced. In these cases, there is a need to match the assembly requirements and plan the production in the cells ensuring that bottleneck machines for the products are not idle.

6. Integration of support functions and tools

With a proper cell implementation, lead times decrease and hence it is necessary to track the inventory only at the input and exit points of each cell. Traditional MRP based material control systems are often found to be inadequate to meet the needs of CMS since they traditionally do not aid decisions on operator allocation and manning. It may be necessary to customize these aspects for CMS.

In CMS material control is relatively straightforward. It is necessary that each cell have clearly defined purchasing and materials control functions so that they meet the specific requirements of the cell. The material storage is usually as close to the point of use as possible. As organizations couple participation of their vendors in CMS systems, it is becoming a common practice to receive purchased components in kits ready to be used on the final assembly.

III. Future Directions and Practices

1) Integrating with Synchronous Manufacturing (SM)

Synchronous manufacturing is a methodology that helps to improve operations by identifying the bottlenecks and constraints in the system. Organizations have limited resources, time, and people. They need to utilize their scarce resources to focus on the opportunities that provide high returns on investment. Cellular manufacturing implemented on its own may result in a series of local optimizations. The synchronous manufacturing perspective provides CMS implementation with priorities for improving the effectiveness of the overall organization. For example, the results of capacity analysis and process flow charting were used in the CMS design to identify buffer sizes and strategic location of buffers for a company that supplies machined parts to the aerospace industry.

Another benefit of integrating synchronous manufacturing with CMS is the ability to make provisions for the dynamic changes in constraint location. With the changes in the product mix and volume fluctuations a fixed constraint resource approach is not sufficient. During the design of the CMS it is critical to design strategic buffers by anticipating where the constraints will move.

2) Agile Manufacturing

Agility is a relatively new business philosophy and strategy that enables organizations to thrive in a changing and uncertain environment. Agility is built around the following four important characteristics: enriching customers, cooperating to enhance competitiveness, organizing to master change and uncertainty, and leveraging the impact of people and information. The Cellular approach fits well with these characteristics.

Organizations are moving from arms-length transactions to collaborations and partnering. With increased connectivity and trust, companies are opening their business processes to suppliers and customers. Considerable success has been reported in substantially reducing the WIP inventories, as the production schedules of customers became transparent to suppliers. In addition, companies have been able to setup virtual organizations between customers, suppliers and the transportation providers. This resulted in delivery of "just-in-time shipments" to the cells twice a day at the point of use. Organizations have been successful in coupling these and similar strategic benefits of agile business practices with broadened scope of cellular manufacturing techniques to improve the profitability of manufacturing businesses.

It is the author's belief that agility approach can help provide a strategic perspective for CMS implementations. The flexibility of CMS has the potential to help organizations become agile and hence CMS is becoming a tactical tool for agility implementations.

IV. Summary

In summary, this paper has presented some of the critical factors for successful implementation of CMS. These include rapid response to market changes, empowerment of employees, use of appropriate cell design, demonstration of success with a pilot cell, effective management of cell operations, and integration of support functions and tools. Specific examples are drawn from the experiences of the writers to support the views expressed in the paper. Finally, in the opinion of

the authors, integration of CMS with synchronous manufacturing and agile manufacturing practices will better enable organizations to meet changing market uncertainties.

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Author Biographies

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