Methods of Cell Formation in Group Technology: A Framework for Evaluation

Asoo J. Vakharia*

EXECUTIVE SUMMARY

Group technology is a manufacturing philosophy that attempts to provide some of the operational advantages of a line layout while maintaining some of the strategic advantages of the job shop layout. In designing a productive process that will adopt this manufacturing strategy, one of the primary problems encountered is the formation of component families and production cells. The production cell is a group of machines or processes of functionally dissimilar types that are placed together and dedicated to the manufacture of a specific range of component families.

Several researchers in operations management have proposed methods of forming production cells and component families. These methods differ in terms of information requirements and also in terms of the final cell design. Furthermore, the objectives for each method are quite different and it thus seems that the focus has been on the method rather than its appropriateness in a particular situation. This article reviews some of the most publicized methods of group formation and analyzes the type of cells that could be formed using these methods. Subsequently, an evaluative framework is presented where the relative advantages of each type of production cell are discussed in terms of several strategic and operational factors. This framework is of particular use as it highlights the fact that in implementing a cellular manufacturing system, most organizations will face a trade-off of strategic and operational "costs." Finally, the appropriateness of the cell types with respect to the degree of customer interaction is also discussed.

INTRODUCTION

Traditional approaches to organizing the manufacturing system for discrete parts manufacture all seem to focus on two extreme strategies depending on the variety of the product mix and the volume of production. In general, for organizations manufacturing a few products in large batches, the assembly line method seems to be advocated while for those companies that manufacture a large variety of products in smaller batches, the job shop configuration is adopted. In recent years, however, researchers in operations management have started to focus on a somewhat intermediate strategy that is referred to as group technology. Group technology is a manufacturing philosophy that attempts to provide some of the operational benefits of an assembly line system (higher throughput rate, lower work-in-progress, etc.) while maintaining some of the strategic advantages of a job shop (larger variety of the product mix, flexibility in operations routings, etc.). Under this mode of manufacturing, similar parts are grouped according to manufacturing and design aspects to form part families. Subsequently or simultaneously, the production equipment is also

* University of Arizona, Tucson, Arizona
grouped together to form machine groups or production cells. Usually a production cell is a group of machines or processes of functionally dissimilar types that are placed together and dedicated to the manufacture of a specific range of part families.

Group technology has, of late, been receiving greater attention by U.S. manufacturers. The increased interest in this mode of manufacturing is due to several factors. First, the advent of modern manufacturing methods (especially the flexible manufacturing system concept) is really based on the formation of manufacturing cells. Second, there exists an increasing demand for customized products, which are produced in smaller lot sizes than before. Thus, there seems to be an increased focus on finding new methods that have most of the strategic advantages of a job shop but also can provide some of the operational advantages of an assembly line. Group technology seems to be just such a method. Third, manufacturing managers are starting to realize the importance of easing the boredom and repetitive nature of the worker tasks. In using the group technology concept, multifaceted workers (workers adept at more than one task) are an essential requirement and consequently, this concept holds out some hope in motivating the work force.

Besides the reasons stated earlier, cellular manufacturing systems have also been identified as being more economical than the traditional job shops in several aspects. Almost all the researchers (e.g., Burbidge, El-Essawy, Edwards) have pointed out that a major advantage of cellular manufacturing is the reduction in setup times. Edwards gives an example from a case study where there was a reduction in setup time from $39\frac{3}{4}$ hours to $9\frac{1}{2}$ hours [5, p. 51]. Burbidge [1] goes on to discuss the several operational advantages of reduced setup times. These are an increase in available machine capacity, a reduction in tooling investment, a reduction in setup costs, and finally a total reduction in operation costs per component.

Another operational advantage of cellular manufacturing is the use of flow line layout within cells. Edwards discusses the case where one pilot cell was created to test the concept and usefulness of group technology [5, p. 54]. In the pilot cell, the following benefits were realized:

1. Speed of Throughput. Usually the conversion from raw material to the finished part took four, six, or eight weeks, but within the pilot cell it took only two, three, or four days.
2. Work-in-Progress. This decreased as throughput time decreased.
3. Materials Handling. Since special equipment could be devised for a family and group, the level of automation rises significantly.
4. Scrap. This decreases significantly as familiarity with the limited range of components is easier to achieve.
5. Production Control. This is easier as compared to a functional layout.
6. Paperwork. Flow and quantity of paperwork is much lower as the operations on each part are done in the same group.

In terms of total company savings, very few companies have published complete information. The one exception is Serck-Audco Ltd., where cellular manufacturing was considered for the whole plant. The successes of the undertaking as reported [1, p. 52; 5, p. 55] are as follows:

1. Sales increased 32%.
2. Stocks decreased 44% (£550,000).
3. Throughput time decreased from twelve to four weeks.
4. Overdue orders decreased from six weeks to less than one week.
5. Stock/Sales Ratio decreased from 52% to 25%.

Consequently, it appears that cellular manufacturing systems would benefit a company as a whole. However, it is also clear that every company would not always be able to realize all the advantages discussed. This is mainly because many of the operational earnings can be achieved if

1. Each component family is completely processed within a machine group; and
2. The manufacturing process is set up by organizing equipment in a flow-line manner within cells.

In practical situations, however, it may not always be possible to meet both of the above conditions. In fact, several researchers [3, 17] have argued that forming cells such that each component family is completely processed within a machine group is not always possible and even if it is possible, it may not always be the most economical. Furthermore, setting up the within cell manufacturing process as a flow-line shop really depends on the previous decision. This is because only if the routings of the component families manufactured within a machine group are similar can attempts be made to organize each cell as a flow shop.

The problem of cellular formation thus forms the basis of implementing a group technology system. Researchers in operations management who have studied the problem have focused on the development of a “best” method for forming groups. The methods and algorithms proposed usually focus on different objectives (i.e., machine groups formed are such that a component family is completely processed within one cell [1] as against groups formed on the basis of machine loadings and cell flexibility [17]). These would, of course, result in machine assignments being different. Furthermore, even in cases where the same basic component-machine matrix is used as a starting point [1, 2, 10], the final machine assignments are not always the same as seen in Chan and Milner’s paper [2]. It would thus seem that the focus of past research has been on the method rather than its appropriateness in a particular situation. However, as Burbidge points out, “As most batch and jobbing production factories at present use functional layout and stock control, the introduction of group technology means changes for most companies in both plant layout and production control” [1, p. 1]. Consequently, cell formation should not only be based on any one objective; rather, it should be a decision based on several objectives which are usually conflicting and, thus, have to be prioritized. Also, some of these objectives are based on corporate policies, such as the degree of flexibility required to maintain a certain market share. This leads to the decision of cell formation being based on strategic as well as operational policies.

The purpose of this article is to develop a framework within which several distinct types of methods of cell formation are evaluated. The remainder of this article is organized as follows: the second section presents a brief literature review of cell formation methodologies developed; the third section outlines the general types of cells that could be created using these different methodologies; the fourth section discusses some of the major hypothesized relationships between the types of cells formed and some major strategic and operational factors; and the fifth section discusses the implications of this framework.

**LITERATURE REVIEW**

The methods formulated to form component-machine groups in group technology can be generally classified as:
1. **Descriptive Methods**: Production Flow Analysis (PFA) [1], Flexible Production Cells (FPC) [17], Production Flow Synthesis (PFS) [3], and Component Flow Analysis (CFA) [6, 7].

2. **Block Diagonal Matrix Methods**: Rank Order Clustering Algorithm (ROC) [10], ROC 2 Algorithm [11], and the Direct Clustering Algorithm [2].

3. **Similarity Coefficient Methods**: Clustering Method [12] and the Graph-Theoretic Method [16].

4. **Other Analytical Methods**: Mathematical Programming and Set-Theoretic Techniques [13, 14, 15].

Before proceeding any further it must be noted that Edwards [5] has also identified universal component classification systems (OPITZ and VUOSO systems) and tailor-made classification systems (used by, for example, Ferranti) as possible methods to proceed to develop production cells. However, since these systems constitute only one aspect of the cell formation problem (they are mainly used to identify component families) these are not considered as methods by which production cells are formed.

**Descriptive Methods**

PFA is an evaluative technique developed by Burbidge. In using PFA, the analyst follows a four-step procedure, the second step dealing with the formation of production cells consisting of machine groups (or processing units in Burbidge’s terminology) such that each component family is completely processed within a production cell. One method used to form cells is referred to as “nuclear synthesis.” This method is based on selecting machines used by a few components as starting points for several cells or nuclei. The next machine is allocated on the basis that it has the smallest number of unassigned components. These nuclei are then added to form production cells of a “socially acceptable size.” Any exceptional components identified in forming the cells are either redesigned or rerouted.

Production Flow Synthesis (PFS), developed by DeBeer and de Witte [3], is a method that is an extension of PFA in that it also considers forming cellular subsystems for the subassembly and assembly aspects of the production process. The data requirements include, in addition to the component routings and processing times per operation, the product structure of the final products. The division into production subsystems or cells is based on the identification of operations as primary (which can be performed on one machine only), secondary (for which only a small number of machines are available), and tertiary (where the number of machines is large enough so that each machine can be allocated to every production cell). This method proceeds further in the sense that once routings are assigned to a subsystem (using a “relatie” matrix), the workloads for each subsystem are estimated and finally workflows within and between cells are also established. The PFS method does seem to produce good results in small engineering shops as illustrated by the example presented by the authors [3, pp. 391-392]. It is not clear how effective this method would be in situations where a large number of operations can be performed at a single machine or in cases where additional investment may be economically justified.

The Flexible Production Cells (FPC) method was proposed by Tilsley and Lewis [17]. This method is proposed to consider the fluctuations in demand that may be experienced for individual components. This demand variability is implicitly considered in forming the production cells by ensuring that a component family for which variability is the highest can be manufactured in almost all the cells formed. The three basic factors considered in forming the cells are as follows:
1. A component family should constitute enough work to justify the establishment of a machine group.
2. Machine utilization should not be lower after cells are formed compared to utilization before cell formation.
3. The number of machines in a cell are limited to ensure that each cell can be controlled by one direct worker.

The FPC method does seem to offer a larger degree of scheduling flexibility compared to the other methods. However, in allowing workloads to overflow from one cell to the next, flow line scheduling efficiencies within cells may not be achieved.

Component Flow Analysis (CFA) [6, 7] was first proposed by El-Essawy in 1971 as being a different method from PFA. The two approaches are, however, strikingly similar in certain aspects. CFA is a three-step procedure. At the first stage components are sorted into categories based on their manufacturing requirements. Two sorted lists are prepared, the first one in the order of machines required and the second in the smallest number of machine numbers required. At the second stage, the sorted lists are manually analyzed to obtain machine groupings which take into account various situational factors. Rough groups are formed by using the combination with the highest number of machines as “cores.” The last stage involves a detailed analysis of the flow patterns of the cells with appropriate adjustments to ensure that an acceptable design is achieved.

All of the descriptive methods reviewed require a large amount of information. Furthermore, all of the authors emphasize the importance of local factors that are not easily identified; thus, the analyst using any method must be very familiar with the production system in terms of machine incompatibility, component design specifications, as well as the materials handling equipment available.

Block Diagonal Matrix Methods

These methods proposed by King [10], King and Nakornchai [11], and Chan and Milner [2] are a direct result of the PFA technique proposed by Burbidge. In the group analysis stage of PFA, Burbidge uses nuclear synthesis to manipulate the machine-component routing matrix, and the algorithms proposed under this method all use the same matrix as the starting point.

King’s Rank Order Clustering (ROC) Algorithm [10] rearranges the rows and columns of the machine-component routing matrix by associating binary values with each row and column, and ranking the decimal equivalents in decreasing order. King also discusses some methods of identifying exceptional elements and goes on to discuss a matrix reorganization in case of bottleneck machines. However, as pointed out by Chan and Milner [3], as the number of machines and components gets to be extremely large, computing the decimal equivalents of the binary values gets to be a very time consuming task.

Consequently, King and Nakornchai [11] revised the ROC algorithm just discussed and proposed the ROC 2 Algorithm where rows and columns of the machine-component routings matrix are consecutively reordered based on the usage of a machine in the component routings.

The DCA proposed by Chan and Milner [2] is strikingly similar to the ROC 2 Algorithm discussed above. The major difference is that row and column reordering by the DCA Algorithm is based on the total number of entries in the particular rows or columns, and these entries are ranked in an ascending/descending order.

The major advantage of the block-diagonal matrix methods is that they can be easily
solved on an interactive basis and require only the use of a reasonably good sorting procedure. However, these methods do not address the specific issues of how to account for machine incompatibility, the availability of additional investment, and the improvement (or reduction) of materials flow between and within cells.

**Similarity Coefficient Methods**

McAuley [12] was among the first researchers to propose the use of clustering techniques for forming machine groups. He used Single Linkage Cluster Analysis and a similarity coefficient “distance” matrix to form machine groups. The similarity measure of machine \(i\) and machine \(j\) was computed as the total number of components visiting both machines divided by the total number visiting machine \(i\) plus the total number visiting machine \(j\). McAuley also determined the optimum number of groups from the dendogram obtained by the clustering method. This was based on evaluating all the possible solutions in terms of total movements within cells and among cells to find the solution requiring the least total movements. It is interesting to note that he considered the fact that the within cell movements decreased as the intergroup movements increased. The major criticism of McAuley’s method is based on the fact that an equal weight is placed on components visiting and not visiting a particular machine.

Rajgopalan and Batra [16] use a graph theoretic approach to design cells. They construct a graph, each vertex representing a machine. An arc between machine \(i\) and machine \(j\) represents the “strength” of the relationship between the machines. The arcs are given a value corresponding to a similarity coefficient computed as follows:

\[
S_{ij} = \frac{X_{ij}}{X_{ii} + X_{jj} - X_{ij}}
\]

where

- \(S_{ij}\) = similarity coefficient of machines \(i\) and \(j\)
- \(X_{ij}\) = number of components visiting machines \(i\) and \(j\)
- \(X_{ii}\) = total number of components visiting machine \(i\)
- \(X_{jj}\) = total number of components visiting machine \(j\)

The authors then form cliques of machines (a clique being defined as a maximal complete subgraph) and these cliques are merged into production cells such that the relationship within a cell is “strong” and intercell relationships “weak.” Once production cells are formed, a set of heuristic procedures are used to allocate components. This approach works well in case where the number of machines is small, as the number of possible cliques varies exponentially with the number of vertices in the graph. Thus, computational problems would arise when applying this method to a large manufacturing operation. Furthermore, De Beer and de Witte [3] also point out that the similarity coefficient works well when \(X_{ii} \simeq X_{jj}\), but if \(X_{ii} \gg X_{jj}\) or vice versa, the \(S_{ij}\) values could be understated (assuming \(X_{ij} > 0\)).

**Other Analytical Methods**

Purcheck [13] presented a combinatorial grouping procedure to form component (guest) families and a system of machine (host) groups. The procedure maximizes the amount of “hospitality” extended by the “host” to the “guests.” Essentially, the hospitality measure indicates that as the number of machines required for processing a component goes up, the number of cells available to process the component decreases. Thus, any component requiring fewer machines will have a greater chance of being processed more quickly. This would, of course, lead to greater scheduling flexibility and machine utilization. This procedure is very
elegant, but seems to be difficult to apply in a realistic situation, as computational problems would arise.

In a later paper, Purcheck [14] also proposed the use of a mathematical classification scheme to test the hypothesis that under a specific grouping of components there would be forecast workloads that are sufficient to keep one or more corresponding groups of manufacturing facilities busy at an economic level of utilization. The classification scheme suggested combines machine requirements and sequences by coding them in the form of letters and digits. The major drawback here is that code lengths tend to be very long and in most cases are difficult to handle effectively.

Optimization methods and mathematical programming applied to the cell formation problem would tend to restrict the scope of the solution in the sense that conflicting objectives could not be considered. Furthermore, the constraint matrices would also be extremely large and thus computational problems may arise.

**TYPES OF PRODUCTION CELLS**

Based on the methods of cell formation discussed and some practical considerations, five distinct types of production cells can be identified;

**Type A**

These are the cells formed such that each component family is completely processed within any one machine group. Thus, each cell is completely independent of any other cell and acts as a manufacturing subsystem by itself. These production cells could be formed by the PFA method [1], the CFA method [6], the block-diagonal matrix methods [2, 10, 11], and the similarity coefficients methods [12, 16]. The production cells formed here do not allow for any intercell flows and also do not have any common pieces of equipment.

**Type B**

These cells are very similar to Type A cells except that some cells share a common piece of equipment. Such cell formation could be possible if a majority of the components require processing at one type of equipment, which may be nondivisible or extremely expensive.

**Type C**

Using the FPC method [17], cells are designed so that variability in demand can be considered and scheduling flexibility achieved. The production cells formed here are such that certain component families can be processed within one or more cells. Thus, when a component needs to be manufactured, it can be routed through a different cell each time depending on the machine availability and current machine loads. In this case, we can also consider the case where a component is partly processed at one cell and is subsequently routed through another if the former cell is overloaded.

**Type D**

This type of production cell has not been clearly specified in any study. However, in cases where a large majority of the components require processing at successive stages by the same pieces of equipment, an assembly line cell system could be set up. Here cells are formed such that the output of a preceding cell is the input of the next cell. There will, of course, be a few components that are completely manufactured in any one cell formed under this type.
The single cell or job shop representation is typified by this cellular design. The machines are arranged in a functional layout and all components are routed based on their processing requirements. This type of cellular design is considered here only for comparison purposes. A schematic representation of each type of cellular system described above (Types A–D) is shown in Figure 1. It must be noted that in any existing production system, a cellular manufacturing process would usually be designed by combining several of the above types, as in practice all the cells cannot be formed so as to meet the objectives of any one design category. However, for comparison purposes, each type of cell is considered separately.

RELATIONSHIPS OF CELL STRUCTURES AND SOME MAJOR STRATEGIC AND OPERATIONAL VARIABLES

As noted earlier, researchers in group technology have focused mainly on the methods of group formation rather than the situational considerations. The purpose of this section is to hypothesize the appropriateness of a particular type of cellular design given the strategic and operational policies of an organization. Thus, the intention here is not to identify the “best” type of design but to attempt to specify the advantages of a particular type of design given a particular policy.

Strategic Considerations

The strategic variables discussed here are those that would affect the organization over a long time frame.

1. Process Flexibility. The flexibility of the manufacturing process in this context refers to the degree to which the process can be adjusted to meet variations in the demand for components. Generally, it has been hypothesized that as the production process changes from a job shop to an assembly line, the process tends to be less flexible. Thus, process flexibility is an important strategic variable since it determines the selection of the type of process that a company would prefer.

It seems obvious that the Type A, B, and D cell structures would have a lower process flexibility as compared to the other two types of structures. This can be hypothesized on the basis of the types of cells formed. Since in cell types A, B, and D, a component family is either processed completely within a cell (A and B) or sequentially by cells (D) if demand for a particular component family was to be highly variable, the production would have to be planned such that the fluctuations in demand are handled through the use of inventories. Consequently, a short-term demand variation would be better handled by the cell structures of types C and E where components can be processed in more than one cell (C) or where a job shop layout exists (E).

2. Product Customization. A generally recognized, major advantage of job shop manufacturing is that it enables a firm to fulfill a large number of customer specified orders. Thus, in cellular manufacturing where subsystems of a job shop are organized and these cells are designed as flow lines, it appears that product customization would be lower. This variable is, consequently, relatively important in analyzing the several different types of cell designs.

The potential for a high degree of product customization is extremely high in the job shop where, as long as the equipment is available, any type of customer specified
FIGURE 1
Schematic Representation of the Types of Production Cells

Type A
- C1
- C2
- C3
- C4

Type B
- C1
- C2
- C3
- C4

Type C
- C1
- C2

Type D
- C1
- C2
- C3

Key:
- CI Component family "I"
- MJ Production cell "J"
- - - - Primary routing of a component family
- --- Secondary routing of a component family

Journal of Operations Management 265
product can be manufactured. However, when forming cellular manufacturing systems, since machines are being grouped to form a more specialized manufacturing system, the cell types A and B are likely to result in a lower degree of product customization. Cell types C and D, on the other hand, would allow for a higher degree of customization than types A and B, simply because some intercell flows are allowed.

3. Requirement of Additional Capital. In creating production cells from a job shop process, it is usually the case that additional capital investment is required to make the cells completely independent. This is because certain key machines cannot be allocated to any one cell exclusively and thus an additional piece of equipment may need to be purchased. The level of investment that could be considered is, of course, a function of the capital available and this must be considered in forming cells.

The operation of a job shop would, of course, require a base amount of capital depending on the volume of work proposed to be carried out. In forming cellular subsystems, however, usually an additional capital investment is required as certain machines may be required in more than one machine group or cell. In these terms, the type A cell system would possibly require the largest additional investment as the cells created are totally independent. Cell types B, C, and D, on the other hand, would require a lower additional capital investment since either common pieces of equipment are grouped together (B), or intercell flows are allowed (C and D).

Operational Considerations

As discussed previously, Burbidge [1] and Edwards [5] have identified several operational advantages of cellular manufacturing systems. The operational considerations discussed here are as follows:

1. Setup Times and Setup Costs. This is definitely one of the major operational factors that needs to be considered since cellular manufacturing should lead to a reduction in setup times and thus setup costs. However, contemporary problem-solving approaches [9] correctly point out that an hour saved at a bottleneck machine saves one hour for the system, while an hour saved at a nonbottleneck does not affect the total system time. Consequently, the reduction in setup times (and thus costs) should only be analyzed in terms of bottleneck facilities.

One of the key operational disadvantages of a job shop is that since a large number of different products are being manufactured, setup times are unusually high. In forming cellular subsystems, Burbidge [1] comments that the saving in setup times are not entirely dependent on the introduction of group technology, but are much lower with GT than with traditional manufacturing methods. In considering the types of cells, it can be argued that the setup times would be considerably lower in cell types A and B. This is based on the assumption that in processing component families within a cell, families with setup similarities can be processed together. In cell types C and D, however, since intercell flows are allowed, the reduction in setup times may not be so high.

2. Call Layout. Since cellular manufacturing systems are proposed to take advantage of flow-line production, the layout of machines within a cell is of primary importance. Only if the machines within a cell can be arranged in a flow line sequence does the cellular system offer advantages of flow-shop manufacturing systems.
The type of layout within a cell controls, among other things, the throughput rate and the type of scheduling procedure that is to be applied. When we consider the cell types, a component routing-based machine layout (dedicated grouping) is possible in all the cell systems. In cell types A and C, a purely dedicated grouping of machines can be easily formulated since there exists a list of component families that are to be processed within such cells. In the case of cell type B, a dedicated grouping of all the individual cell equipment is possible but the common equipment may have to be functionally grouped. Cell type D is perhaps the most complex to hypothesize. However, within cells, a dedicated layout could be constructed but the intercell relationships need to be maintained as the majority of components are processed in all the cells.

3. **Materials Flow.** A simplification of the materials flow system is one of the primary advantages of cellular manufacturing. In fact, Burbidge's PFA procedure [1] outlines the use of Factory Flow Analysis (FFA) to simplify the materials flow system before creation of production cells. Furthermore, in cell systems where no intercell flows are allowed, materials handling costs should also go down and the within cell materials flow could be simplified.

The intercell materials flow is only relevant to the cell types C, D, and E. In cell type C, since intercell flows are allowed, a complex materials flow could be hypothesized for all components. A similar situation exists for cell type E (the job shop). In cell type D, however, since cells are formed such that a majority of component families are processed sequentially from cell to cell, a unidirectional materials flow would result. Looking at the within cell material flows, a unidirectional materials flow could be hypothesized. This is, of course, a result of the dedicated grouping of machines within cells.

4. **Types of Equipment.** The development of a cellular system seems to indicate that more specialized equipment may be considered. Since a production cell manufactures components from a given set of families, the equipment allocated to a cell would only be required to manufacture components that are similar and thus more specialized equipment could be a viable alternative.

Cell types A, B, and D are formed such that specified component families are either completely processed within a cell (A and B) or processed sequentially through cells; consequently, more specialized equipment would be preferred in these cases. In the cell types C and E, since intercell flows are allowed, the equipment would be more of a general purpose type.

5. **Scheduling Aspects.** Job shop scheduling has long been recognized as an extremely complex problem. Thus, when changing over from a job shop to a cellular system, simplifications in the scheduling process should occur. For example, even if each production cell is designed as a smaller job shop, the scheduling problem size is considerably reduced and consequently more "optimal" methods may be applicable.

Intercell scheduling is only relevant for cell types C, D, and E, since in such cases intercell component processing is allowed. In the case of cell type C, a particular component could be routed through two or more cells based on the machine loads within a cell. Consequently, the scheduling problem here is considerably more complex. In the case of cell type D, an assembly line balancing technique would be the most
appropriate for determining the appropriate cycle time. Cell type E represents the job shop and consequently the complex job shop scheduling problem is encountered here. For the within cell scheduling aspects, all the cell types (A, B, C, and D) will encounter the flow line scheduling problem. This depends on the dedicated machine groupings that are possible for all these types of cells.

6. Throughput Rate. The conversion of the job shop into a cellular manufacturing process has been shown to increase the rate of throughput [1, 5]. However, different types of cell designs would not necessarily increase the throughput rate equally and, consequently, in this comparative framework this variable has been included.

The rate of throughput could be thought of as a function of the type of cell layout, the materials flow, and the complexity of the scheduling procedure. In this context, since cell types A and B have a dedicated grouping of machines, a unidirectional materials flow within cells (no materials flow intercell) and can use the simple flow line scheduling procedures (no intercell scheduling required), it is hypothesized that they could offer the highest rate of throughput. Cell types C and D, however, deal with a more complex materials flow and scheduling problem and consequently would offer an intermediate rate of output. The lowest rate of output would be offered by the job shop, which groups machines on a functional basis and thus faces an extremely complex materials flow and scheduling problem.

7. Machine Utilization. Conflicting ideas regarding machine utilization in cellular manufacture have been expressed. Tilsley and Lewis [17] are of the opinion that forming cellular systems would lead to lower machine utilization as queue lengths of jobs would decrease. However, in the simulation study performed by Flynn and Jacobs [8] where a process layout (physical grouping of machines that are functionally similar) and a group technology layout (physical grouping of machines dedicated to the production of a family of similar parts) were compared, they found the utilization rate was higher in the second type of layout.

Cell types A and D are hypothesized to lead to a higher utilization as compared to the other types. In cell type A, since dedicated groupings of machines are formed, this causes queues to build up and machine utilization is higher. For the case of cell type D, where an assembly line cell structure is assumed, the machine utilization would be higher based on the premise that an assembly line schedule would attempt to fix the throughput rate to maximize efficiency and thus implicitly maximize machine utilization. In case of cell type B, the commonality of some pieces of equipment may result in such pieces having a higher utilization, but the other machine types would not necessarily have such a higher utilization and consequently the overall utilization would be lower. In cell type C, since intercell flows are allowed, the machine utilization would be lower as queues would not build up as flexible scheduling would be practiced. In the job shop (type E), however, machine utilization would be lower than in cell types A and D as more idle time exists and the average queue length is shorter.

A summary of the hypothesized relationships of the cell types and the specified variables are shown in Table 1.

**IMPLICATIONS**

1. Cell types A and B appear to be similar in terms of the strategic and operational variables. However,
### TABLE 1
Summary of the Hypothesized Relationships of Types of Cell Structures and the Strategic and Operational Variables

<table>
<thead>
<tr>
<th>Types of Cell Structures</th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
<th>Type D</th>
<th>Type E</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strategic Variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Process Flexibility</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>b) Product Customization</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>c) Additional Capital Requirements</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Operational Variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Setup Times and Setup Costs</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>b) Cell Layout</td>
<td>Dedicated Grouping</td>
<td>Dedicated &amp; Functional Grouping</td>
<td>Dedicated Grouping</td>
<td>Dedicated &amp; Intercell Related Grouping</td>
<td></td>
</tr>
<tr>
<td>c) Materials Flow Intersect Within Cells</td>
<td>NA</td>
<td>Unidirectional</td>
<td>Complex Unidirectional</td>
<td>Unidirectional</td>
<td>Complex NA General Purpose</td>
</tr>
<tr>
<td>d) Types of Equipment</td>
<td>NA</td>
<td>Unidirectional</td>
<td>Complex Unidirectional</td>
<td>NA General Purpose</td>
<td></td>
</tr>
<tr>
<td>e) Scheduling Intercell</td>
<td>NA</td>
<td>NA</td>
<td>Scheduling Based on Cell Loads</td>
<td>Assembly Line Balance</td>
<td>Complex JS Scheduling</td>
</tr>
<tr>
<td>Within Cells</td>
<td>Simple Flow Line Scheduling</td>
<td>Simple Flow Line Scheduling</td>
<td>Simple Flow Line Scheduling</td>
<td>Simple Flow Line Scheduling</td>
<td></td>
</tr>
<tr>
<td>f) Throughput Rate</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>g) Machine Utilization</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

a) Cell type B would probably require less additional investment than cell type A. This is hypothesized as being the case because in the first cell structure, common pieces of equipment are shared by some cells while in the second, the cells formed are completely independent.

b) The cell type B would probably be less productive as a manufacturing system (the commonality of equipment would lead to the creation of bottlenecks and thus a lower throughput rate) than cell type A. However, the productivity of the type B cell system would be high as compared to cell types C, D, and E. These cell types would be feasible for situations where

a) Demand forecasts for the manufactured components are fairly accurate and consequently a more rigid process flow is acceptable.

b) The customer can dictate component specifications as long as the machines required for that component are grouped into a cell.

2. Cell type C would result in a “cascade” system of production cells [4]. A manufacturing system that consists of these types of interrelated cells would probably be more productive than a job shop since work overflows into the next cell. However, in comparing this system to the one previously discussed, this work overflow would result in the
need to schedule components between cells and within cells. Consequently, the previously discussed system (cell types A and B) would be operationally more efficient than the current system. The system design in this case would be appropriate in cases where

a) The demand for complex components (i.e., those which require the use of a large number of machines) is forecasted with greater accuracy. This argument is based on the fact that cells of this type are formed such that as the routing complexity of a component goes up there are a fewer number of cells within which it can be processed.

b) The customer dictates component specifications for those which have a simpler routing.

3. The manufacturing system resulting from the formation of cells in the manner prescribed by type D would have all the advantages of the assembly line manufacturing process. In terms of productivity, the system is quite comparable to the type C system. Such system designs would apply to situations where

a) Demand forecasts for the components manufactured on the cellular designed assembly line are fairly accurate and, consequently, a rigid process flow can be considered.

b) The customer can dictate product specifications as long as the machine required for processing the component are grouped into a cell, and are located in sequential cells.

CONCLUSIONS

This article has been concerned with hypothesizing a framework for comparing different types of cells that can be formed. The variables considered in this framework have been categorized as strategic and operational. In essence, based on this hypothesized framework, it appears that implementing cellular manufacturing systems leads to a trade-off among the strategic and operational “costs.” A job shop has the advantages of a flexible process flow and of accommodating a wide variety of customer specified orders. Operationally, however, the job shop is a complex and inefficient manufacturing system. The cellular system, on the other hand, offers a step up in operational advantages but cannot offer most of the above mentioned advantages of a job shop.

In conclusion, switching over from a job shop to a cellular manufacturing system cannot always be evaluated only on operational considerations. Strategic variables also need to be considered before such an important process decision is made.

REFERENCES


