Ch 18  Cellular Manufacturing

Sections:
1. Part Families
2. Parts Classification and Coding
3. Production Flow Analysis
4. Cellular Manufacturing
5. Applications in Group Technology
6. Quantitative Analysis in Cellular Manufacturing

Group Technology (GT) Defined

A manufacturing philosophy in which similar parts are identified and grouped together to take advantage of their similarities in design and production.

- Similarities among parts permit them to be classified into part families.
  - In each part family, processing steps are similar.
- The improvement is typically achieved by organizing the production facilities into manufacturing cells that specialize in production of certain part families.
Cellular Manufacturing

It is reasonable to believe that the processing of each member of a given family is similar, and this should result in manufacturing efficiencies.

The efficiencies are generally achieved by arranging the production equipment into machine groups, or cells, to facilitate work flow.

Organizing the production equipment into machine cells, where each cell specializes in the production of a part family is called **cellular manufacturing**.

Group technology and cellular manufacturing are applicable to a wide variety of manufacturing situations.

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Group Technology (GT)

GT is most appropriate under the following conditions:

- **The plant currently uses traditional batch production and a process type layout, which results in much material handling effort, high in-process inventory, and long manufacturing lead times.**

- **The parts can be grouped into part families.**
  
  *This is a necessary condition.*

Each machine cell is designed to produce a given part family or a limited collection of part families, so it must be possible to group parts made in the plant into families. Fortunately, in the typical mid-volume production plant most of the parts can be grouped into part families.
Overview of Group Technology

- Parts in the medium production quantity range are usually made in batches.
- Disadvantages of batch production:
  - Downtime for changeovers,
  - High inventory carrying costs.
- GT minimizes these disadvantages by recognizing that although the parts are different, there are groups of parts that possess similarities
Problems in Implementing GT

There are two major tasks that a company must undertake when it implements group technology.

These two tasks represent significant obstacles to the application of GT.

1. Identifying the part families.
   If the plant makes e.g. 10,000 different parts, reviewing all of the part drawings and grouping the parts into families is a substantial and time-consuming task.

2. Rearranging production machines into machine cells.
   It is time-consuming and costly to plan and accomplish this rearrangement, and the machines are not producing during the changeover.

Group Technology (GT) - Benefits

• GT promotes standardization of tooling, fixturing, and setups
• Material handling is reduced because the distances within a machine cell are much shorter than within the entire factory
• Process planning and production scheduling are simplified
• Setup times are reduced, resulting in lower manufacturing lead times
• Work-in-process is reduced
• Worker satisfaction usually improves when workers collaborate in a GT cell
• Higher quality work is accomplished using group technology.
Part Families and Cellular Manufacturing

- GT exploits the part similarities by utilizing similar processes and tooling to produce them.
- Machines are grouped into cells, each cell specializing in the production of a part family,
  - Called cellular manufacturing.
- Cellular manufacturing can be implemented by manual or automated methods.
  - When automated, the term flexible manufacturing system is often applied.

Part Family

A collection of parts that possess similarities in geometric shape and size, or in the processing steps used in their manufacture.

- Part families are a central feature of group technology
  - There are always differences among parts in a family,
  - But the similarities are close enough that the parts can be grouped into the same family.
Part Families

- Ten parts are different in size, shape, and material, but quite similar in terms of manufacturing.
- All parts are machined from cylindrical stock by turning; some parts require drilling and/or milling.
Traditional Process Layout

Each cell specializes in producing one or a limited number of part families.

Cellular Layout Based on GT
Ways to Identify Part Families

1. **Visual inspection**
   - Using best judgment to group parts into appropriate families, based on the parts or photos of the parts.

2. **Parts classification and coding**
   - Identifying similarities and differences among parts and relating them by means of a coding scheme.

3. **Production flow analysis**
   - Using information contained on operation and route sheets to classify parts.

Parts Classification and Coding

Identification of similarities among parts and relating the similarities by means of a numerical coding system.

- Most time consuming of the three methods,
- Must be customized for a given company or industry,
- Reasons for using a coding scheme:
  - **Design retrieval**,  
    A designer faced with the task of developing a new part can use a design retrieval system to determine if a similar part already exists.  
    Simply changing an existing part would take much less time than designing a whole new part from scratch.
Parts Classification and Coding – Reasons for using a coding scheme

- **Automated process planning.**
  The part code for a new part can be used to search for process plans for existing parts with identical or similar codes.

- **Machine cell design.**
  The part codes can be used to design machine cells capable of producing all members of a particular part family, using the composite part concept (Section 18.4.1).

Features of Parts Classification and Coding Systems

- Most classification and coding systems are based on one of the following:
  - Part design attributes,
  - Part manufacturing attributes,
  - Both design and manufacturing attributes.
Features of Parts Classification and Coding Systems

### TABLE 18.1 Design and Manufacturing Attributes Typically Included in a Group Technology Classification and Coding System

<table>
<thead>
<tr>
<th>Part Design Attributes</th>
<th>Part Manufacturing Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic external shape</td>
<td>Major processes</td>
</tr>
<tr>
<td>Basic internal shape</td>
<td>Minor operations</td>
</tr>
<tr>
<td>Rotational or rectangular shape</td>
<td>Operation sequence</td>
</tr>
<tr>
<td>Length-to-diameter ratio (rotational parts)</td>
<td>Major dimension</td>
</tr>
<tr>
<td>Aspect ratio (rectangular parts)</td>
<td>Surface finish</td>
</tr>
<tr>
<td>Material types</td>
<td>Machine tool</td>
</tr>
<tr>
<td>Part function</td>
<td>Production cycle time</td>
</tr>
<tr>
<td>Major dimensions</td>
<td>Batch size</td>
</tr>
<tr>
<td>Minor dimensions</td>
<td>Annual production</td>
</tr>
<tr>
<td>Tolerances</td>
<td>Fixtures required</td>
</tr>
<tr>
<td>Surface finish</td>
<td>Cutting tools used in manufacture</td>
</tr>
</tbody>
</table>

Coding Scheme Structures

1. **Hierarchical structure (monocode)**
   - Interpretation of each successive digit depends on the value of the preceding digit

2. **Chain-type structure (polycode)**
   - Interpretation of each symbol is always the same
   - No dependence on previous digits

3. **Mixed-code structure**
   - Combination of hierarchical and chain-type structures
Coding Scheme Structures

- To distinguish the hierarchical and chain-type structures, consider a two-digit code number for a part, such as 15 or 25.
- Suppose the first digit stands for the general shape of the part: 1 means the part is cylindrical (rotational), and 2 means the geometry is rectangular.
- In a hierarchical structure, the interpretation of the second digit depends on the value of the first digit.
- If preceded by 1, the 5 might indicate a length-to-diameter ratio; and if preceded by 2, the 5 might indicate an aspect ratio between the length and width dimensions of the part.

Coding Scheme Structures

- In the chain-type structure, the symbol 5 would have the same meaning whether preceded by 1 or 2. For example, it might indicate the overall length of the part.
- The advantage of the hierarchical structure is that in general more information can be included in a code of a given number of digits.
- The mixed-mode structure uses a combination of hierarchical and chain-type structures. It is the most common structure found in GT parts classification and coding systems.
The Opitz system is of interest because it was one of the first published classification and coding schemes for mechanical parts, and is still widely used.

It was developed by H. Opitz of the University of Aachen in Germany and represents one of the pioneering efforts in group technology.

It is probably the best known, if not the most frequently used, of the parts classification and coding systems.

It is intended for machined parts.

KC1, KC2, and KK1 systems are Japanese codes for machined parts.

Opitz Classification System

Uses the following digit sequence:

12345 6789 ABCD

The basic code consists of nine digits, which can be extended by adding four more digits.

The first nine are intended to convey both design and manufacturing data (Figure 18.5).

The first five digits (12345) are called the form code.

This describes the primary design attributes of the part, such as external shape (for example, rotational versus rectangular) and machined features (for example, holes, threads, gear teeth, and so forth).
Opitz Classification System

- The next four digits, 6789, constitute the supplementary code, which indicates some of the attributes that would be useful in manufacturing (for example, dimensions, work material, starting shape, and accuracy).
- The extra four digits, ABCD, are referred to as the secondary code and are intended to identify the production operation type and sequence.
- The secondary code can be designed by the user firm to serve its own particular needs.
- Opitz wrote an entire book on his system [29].


Basic Structure of Opitz System

Figure 18.5 Basic structure of the Opitz system of parts classification and coding.
**Opitz Form Code (Digits 1 through 5)**

<table>
<thead>
<tr>
<th>Digit 1</th>
<th>Digit 2</th>
<th>Digit 3</th>
<th>Digit 4</th>
<th>Digit 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part class</td>
<td>External shape, internal shape, dimension</td>
<td>Internal shape, internal shape, dimension</td>
<td>Planar surface machining</td>
<td>Auxiliary hole, angle, or tilt</td>
</tr>
<tr>
<td>L/D: 0.5</td>
<td>Smooth, simple shape</td>
<td>No hole, no breakthrough</td>
<td>No surface finishing</td>
<td>No auxiliary hole</td>
</tr>
<tr>
<td>L/D: 1</td>
<td>Smooth, simple shape</td>
<td>No hole, no breakthrough</td>
<td>No surface finishing</td>
<td>No auxiliary hole</td>
</tr>
<tr>
<td>L/D: 2</td>
<td>Functional groove</td>
<td>Thread</td>
<td>External surface machining</td>
<td>Axial, eccentric circle diameter</td>
</tr>
<tr>
<td>L/D: 3</td>
<td>No shape element</td>
<td>Functional groove</td>
<td>External surface machining</td>
<td>Axial, eccentric circle diameter</td>
</tr>
<tr>
<td>L/D: 4</td>
<td>No shape element</td>
<td>Internal groove</td>
<td>External surface machining</td>
<td>Axial and radial axis parallel to other direction</td>
</tr>
<tr>
<td>L/D: 5</td>
<td>No shape element</td>
<td>Internal groove</td>
<td>External surface machining</td>
<td>Axial and radial axis perpendicular to other direction</td>
</tr>
<tr>
<td>7</td>
<td>Functional cone</td>
<td>Functional cone</td>
<td>Internal groove</td>
<td>Bevel gear teeth</td>
</tr>
<tr>
<td>8</td>
<td>Operating thread</td>
<td>Operating thread</td>
<td>Internal and external groove, angle, and/or tilt</td>
<td>Other gear teeth</td>
</tr>
<tr>
<td>9</td>
<td>All others</td>
<td>All others</td>
<td>All others</td>
<td>All others</td>
</tr>
</tbody>
</table>

**Example: Opitz Form Code**

**EXAMPLE 18.1 Opitz Part Coding System**

Given the rotational part design in Figure 18.7, determine the form code in the Opitz parts classification and coding system.

**Solution:** With reference to Figure 18.6, the five-digit code is developed as follows:

![Figure 18.7 Part design for Example 18.1.](image)
Production Flow Analysis (PFA)

- Production flow analysis (PFA) is an approach to part family identification and machine cell formation that was pioneered by J. Burbidge.
- It is a method for identifying part families and associated machine groupings that uses the information contained on production route sheets rather than part drawings.
- Workparts with identical or similar routings are classified into part families.
- These families can then be used to form logical machine cells in a group technology layout.
Production Flow Analysis (PFA)

Since PFA uses manufacturing data rather than design data to identify part families, it can overcome two possible anomalies that can occur in parts classification and coding:

(1) Parts whose basic geometries are quite different may nevertheless require similar or even identical process routings.

(2) Parts whose geometries are quite similar may nevertheless require process routings that are quite different.

Production Flow Analysis (PFA)

The procedure in production flow analysis must begin by defining the scope of the study, which means deciding on the population of parts to be analyzed:

Should all of the parts in the shop be included in the study, or should a representative sample be selected for analysis?
Production Flow Analysis – Data collection

Once this decision is made, then the procedure in PFA consists of the following steps:

1. **Data collection**

   The minimum data needed in the analysis are the part number and operation sequence, which is contained in shop documents called **route sheets** or **operation sheets** or some similar name.

   Each operation is usually associated with a particular machine, and so determining the operation sequence also determines the machine sequence.

Production Flow Analysis – Workpiece

Matl. AISI 1340 Medium-carbon steel  
BHN \(\approx\) 200  
Threaded shaft made in quantities of 25 units.

Workpiece
### Production Flow Analysis – Operation Sheet

#### Operation Sheet

<table>
<thead>
<tr>
<th>OPER NO.</th>
<th>NAME OF OPERATION</th>
<th>MACHINE TOOL</th>
<th>CUTTING TOOL</th>
<th>CUTTING SPEED</th>
<th>FEED</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Face end of bolt</td>
<td>Engine Lathe</td>
<td></td>
<td>120</td>
<td>400</td>
<td>Hand</td>
</tr>
<tr>
<td>20</td>
<td>Counterbore end</td>
<td>Combination drill</td>
<td></td>
<td>100</td>
<td></td>
<td>Hand</td>
</tr>
<tr>
<td>30</td>
<td>Cut off to 3/4&quot;</td>
<td>Parting tool</td>
<td></td>
<td>120</td>
<td>400</td>
<td>Hand</td>
</tr>
<tr>
<td>40</td>
<td>Face to length</td>
<td>Face boring tool</td>
<td></td>
<td>120</td>
<td>400</td>
<td>Hand</td>
</tr>
<tr>
<td>50</td>
<td>Counterbore end</td>
<td>Combination drill</td>
<td></td>
<td>100</td>
<td></td>
<td>Hand</td>
</tr>
<tr>
<td>60</td>
<td>Face between centers,ream,slip,shoulder, and face shoulder</td>
<td></td>
<td></td>
<td>120</td>
<td>400</td>
<td>Hand</td>
</tr>
</tbody>
</table>

### Operation Sheet - Continuation

<table>
<thead>
<tr>
<th>OPER NO.</th>
<th>NAME OF OPERATION</th>
<th>MACHINE TOOL</th>
<th>CUTTING TOOL</th>
<th>CUTTING SPEED</th>
<th>FEED</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>Remove and replace end for end form,ST7</td>
<td>-</td>
<td></td>
<td>120</td>
<td>400</td>
<td>Hand</td>
</tr>
<tr>
<td>80</td>
<td>Produce 1/4-20 thread</td>
<td>-</td>
<td></td>
<td>120</td>
<td>400</td>
<td>Hand</td>
</tr>
<tr>
<td>90</td>
<td>Cut 1/4-20 thread</td>
<td>-</td>
<td></td>
<td>90</td>
<td>203</td>
<td>Hand</td>
</tr>
</tbody>
</table>

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2. Sortation of process routings

In this step, the parts are arranged into groups according to the similarity of their process routings. To facilitate this step, all operations or machines included in the shop are reduced to code numbers. For each part, the operation codes are listed in the order in which they are performed. A sortation procedure is then used to arrange parts into ‘packs,’ which are groups of parts with identical routings. Some packs may contain only one part number, indicating the uniqueness of the processing of that part. Other packs will contain many parts, and these will constitute a part family.
Production Flow Analysis (PFA)

3. **PFA Chart**

   The processes used for each pack are then displayed in a PFA chart. The chart is a tabulation of the process or machine code numbers for all of the part packs. In recent GT literature, the PFA chart has been referred to by the term part-machine incidence matrix. In this matrix, the entries have a value \( x_{ij} = 1 \) or 0. A value of \( x_{ij} = 1 \) indicates that the corresponding part \( i \) requires processing on machine \( j \). and \( x_{ij} = 0 \) indicates that no processing of component \( i \) is accomplished on machine \( j \). (For clarity in presenting the matrix, the 0’s are often indicated as blank (empty) entries, as in our table.)

---

<table>
<thead>
<tr>
<th>Operation or Machine</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutoff</td>
<td>01</td>
</tr>
<tr>
<td>Lathe</td>
<td>02</td>
</tr>
<tr>
<td>Turret lathe</td>
<td>03</td>
</tr>
<tr>
<td>Mill</td>
<td>04</td>
</tr>
<tr>
<td>Drill—manual</td>
<td>05</td>
</tr>
<tr>
<td>NC drill</td>
<td>06</td>
</tr>
<tr>
<td>Grind</td>
<td>07</td>
</tr>
</tbody>
</table>

From the pattern of data in the PFA chart, related groupings are identified and rearranged into a new pattern that brings together packs with similar machine sequences.

The blocks might be considered as possible machine cells.

It is often the case (but not in Table 18.4) that some packs do not fit into logical groupings.

These parts might be analyzed to see if a revised process sequence can be developed that fits into one of the groups.

If not, these parts must continue to be fabricated through a conventional process layout.
In Section 18.6.1, we examine a systematic technique called **rank order clustering** that can be used to perform the cluster analysis.

The weakness of production flow analysis is that the data used in the technique are derived from existing production route sheets.

In all likelihood, these route sheets have been prepared by different process planners, and the routings may contain operations that are nonoptimal, illogical, or unnecessary. Consequently, the final machine groupings obtained in the analysis may be suboptimal.
Production Flow Analysis

- Notwithstanding this weakness, PFA has the virtue of requiring less time than a complete parts classification and coding procedure.
- This is attractive to many firms wishing to introduce group technology into their plant operations.

Cellular Manufacturing

Whether part families have been determined by visual inspection, parts classification and coding, or production flow analysis, there is advantage in producing those parts using or machine cells rather than a traditional process-type machine layout.

When the machines are grouped, the term **cellular manufacturing** is used to describe this work organization.

**Cellular manufacturing** is an application of group technology in which dissimilar machines or processes are aggregated into cells, each of which is dedicated to the production of a part family or limited group of families.
**Cellular Manufacturing System**
(from ME 202 PPTs)

**Typical objectives**
- **Typical objectives of cellular manufacturing:**
  - To shorten manufacturing lead times by reducing setup, workpart handling, waiting times, and batch sizes.
  - To reduce Work in Process (WIP) inventory
  
  Smaller batch sizes and shorter lead times reduce work-in-process.
  
  - To improve quality
  
  Accomplished by allowing each cell to specialize in producing a smaller number of different parts.
  
  This reduces process variability.
Cellular Manufacturing – Typical objectives

- **To simplify production scheduling**
  Instead of scheduling parts through a sequence of machines in a process-type shop layout, the system simply schedules the parts through the cell.

- **To reduce setup times**
  Accomplished by using group tooling (cutting tools, jigs, and fixtures) that have been designed to process the part family rather than part tooling, which is designed for an individual part.
  This reduces the number of individual tools required as well as the time to change tooling between parts.

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Composite Part Concept

Part families are defined by the fact that their members have similar design and/or manufacturing features.

The composite part concept takes this part family definition to its logical conclusion.

The composite part for a given family is a hypothetical part that includes all of the design and manufacturing attributes of the family.

In general, an individual part in the family will have some of the features that characterize the family, but not all of them.
Composite Part Concept

Figure 18.8 Composite part concept: (a) the composite part for a family of machined rotational parts, and (b) the individual features of the composite part. See Table 18.5 for key to individual features and corresponding manufacturing operations.

Part Features and Corresponding Manufacturing Operations

<table>
<thead>
<tr>
<th>Design feature</th>
<th>Corresponding operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. External cylinder</td>
<td>Turning</td>
</tr>
<tr>
<td>2. Face of cylinder</td>
<td>Facing</td>
</tr>
<tr>
<td>3. Cylindrical step</td>
<td>Turning</td>
</tr>
<tr>
<td>4. Smooth surface</td>
<td>External cylindrical grinding</td>
</tr>
<tr>
<td>5. Axial hole</td>
<td>Drilling</td>
</tr>
<tr>
<td>6. Counter bore</td>
<td>Counterboring</td>
</tr>
<tr>
<td>7. Internal threads</td>
<td>Tapping</td>
</tr>
</tbody>
</table>

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Composite Part Concept

There is always a correlation between part design features and the production operations required to generate those features.

Round holes are made by drilling, cylindrical shapes are made by turning, flat surfaces by milling, and so on.

A production cell designed for the part family would include those machines required to make the composite part.

Such a cell would be capable of producing any member of the family, simply by omitting those operations corresponding to features not possessed by the particular part.

The cell would be designed to allow for size variations within the family as well as feature variations.

Machine Cell Designs

1. Single machine (plus supporting fixtures and tooling)
2. Group machine cell with manual handling
   - Often organized into U-shaped layout
3. Group machine cell with semi-integrated handling
4. Automated cell – automated processing and integrated handling
   - Flexible manufacturing cell
   - Flexible manufacturing system
Four Types of Part Moves in Mixed Model Production System

(1) Repeat operation

Proc Man

Proc Man

Proc Man

Proc Man

(3) By-passing move

(2) In-sequence move

(4) Backtracking move

Figure 18.11 Four types of part moves in a mixed model production system. The forward flow of work is from left to right.

Machine Cell with Manual Handling

Considered appropriate when there is variation in the work flow (e.g. by-pass) among the parts made in the cell. It also allows the multifunctional workers in the cell to move easily between machines.

Figure 18.9 Machine cell with manual handling between machines. A U-shaped machine layout is shown. (Key: “Proc” = processing operation (mill, turn, etc.), “Man” = manual operation; arrows indicate work flow.)
Cell with Semi-Integrated Handling

Cell with semi-integrated handling uses a mechanized handling system, such as a conveyor, to move parts between machines in the cell.

Loop layout allows variations in part routing between machines. When backtracking moves are needed, a loop or rectangular layout allows recirculation of parts within the cell.
Cell with Semi-Integrated Handling

Rectangular layout also allows variations in part routing and allows for return of work carriers if they are used.

When backtracking moves are needed, a loop or rectangular layout allows recirculation of parts within the cell.

Key Machine Concept

- In a GT machine cell it is desirable to spread the workload as evenly as possible among the machines in the cell.
- On the other hand, there is typically a certain machine in a cell (or perhaps more than one machine in a large cell) that is more expensive to operate than the other machines or that performs certain critical operations in the plant.
- This machine is referred to as the key machine.
- It is important that the utilization of this key machine be high, even if it means that the other machines in the cell have relatively low utilizations.
The other machines are referred to as supporting machines, and they should be organized in the cell to keep the key machine busy.

In a sense, the cell is designed so that the key machine becomes the bottleneck in the system.

The key machine concept is sometimes used to plan the GT machine cell.

The approach is to decide what parts should be processed through the key machine and then determine what supporting machines are required to complete the processing of those parts.

There are generally two measures of utilization that are of interest in a GT cell:

1. the utilization of the key machine and
2. the utilization of the overall cell.
Manufacturing Applications of Group Technology

- The most common applications of GT are in manufacturing, and the most common application in manufacturing involves the formation of cells of one kind or another.
- Not all companies rearrange machines to form cells.

There are three ways in which group technology principles can be applied in manufacturing:

1. Informal scheduling and routing of similar parts through selected machines.
   This approach achieves setup advantages, but no formal part families are defined and no physical rearrangement of equipment is undertaken.
Manufacturing Applications of Group Technology

2. **Virtual machine cells.**

   This approach involves the creation of part families and dedication of equipment to the manufacture of these part families, but without the physical rearrangement of machines into cells.

   The machines in the virtual cell remain in their original locations in the factory.

   Use of virtual cells seems to facilitate the sharing of machines with other virtual cells producing other part families.

3. **Formal machine cells.**

   This is the conventional GT approach in which a group of dissimilar machines are physically relocated into a cell that is dedicated to the production of one or a limited set of part families.

   The machines in a formal machine cell are located in close proximity to one another in order to minimize part handling, throughput time, and work-in-process.
Manufacturing Applications of Group Technology

- Other GT applications in manufacturing include process planning, family tooling, and numerical control part programs.
- Process planning of new parts can be facilitated by identifying part families.
- The new part is associated with an existing part family, and generation of the process plan for the new part follows the routing of the other members of the part family.
  
  This is done in a formalized way through the use of parts classification and coding.

- Ideally, all members of the same part family require similar setups, tooling, and fixturing.
- This generally results in a reduction in the amount of tooling and fixturing needed.
- Instead of using a special tool kit developed for each part, a GT system uses a tool kit developed for each part family.
- The concept of a modular fixture can often be exploited, in which a common base fixture that can accommodate adaptations to rapidly switch between different parts in the family.
Benefits of Group Technology in Manufacturing

- Standardization of tooling, fixtures, and setups is encouraged
- Material handling is reduced
  - Parts are moved within a machine cell rather than the entire factory
- Process planning and production scheduling are simplified
- Work-in-process and manufacturing lead time are reduced
- Improved worker satisfaction in a GT cell
- Higher quality work

Product Design Applications of Group Technology

- Design retrieval systems
  - Industry survey: For new part designs,
    - Existing part design could be used - 20%
    - Existing part design with modifications - 40%
    - New part design required - 40%
  - Simplification and standardization of design parameters such as tolerances, chamfers, hole sizes, thread sizes, etc.
    - Reduces tooling and fastener requirements in manufacturing
Quantitative Analysis in Cellular Manufacturing

- Grouping parts and machines by Rank Order Clustering
- Arranging machines in a GT Cell

Rank Order Clustering

- Determining how machines in an existing plant should be grouped into machine cells.
- The problem is the same whether the cells are virtual or formal.
- It is basically the problem of identifying part families.
- After part families have been identified, the machines to produce a given part family can be selected and grouped together.
Rank Order Clustering

- The rank order clustering technique, first proposed by King, is specifically applicable in production flow analysis.
- It is an efficient and easy-to-use algorithm for grouping machines into cells.
- In a starting part-machine incidence matrix that might be compiled to document the part routings in a machine shop (or other job shop), the occupied locations in the matrix are organized in a seemingly random fashion.
- Rank order clustering works by reducing the part-machine incidence matrix to a set of diagonalized blocks that represent part families and associated machine groups.


Starting with the initial part-machine incidence matrix, the algorithm consists of the following steps:

1. In each row of the matrix, read the series of 1’s and 0’s (blank entries = 0’s) from left to right as a binary number. Rank the rows in order of decreasing value. In case of a tie, rank the rows in the same order as they appear in the current matrix.
2. Numbering from top to bottom, is the current order of rows the same as the rank order determined in the previous step? If yes, go to step 7. If no, go to the following step.
Rank Order Clustering

3. Re-order the rows in the part-machine incidence matrix by listing them in decreasing rank order, starting from the top.

4. In each column of the matrix, read the series of 1’s and 0’s (blank entries = 0’s) from top to bottom as a binary number. Rank the columns in order of decreasing value. In case of a tie, rank the columns in the same order as they appear in the current matrix.

5. Numbering from left to right, is the current order of columns the same as the rank order determined in the previous step? If yes, go to step 7. If no, go to the following step.

6. Re-order the columns in the part-machine incidence matrix by listing them in decreasing rank order, starting with the left column. Go to step 1.

7. Stop.
Evaluating Binary Numbers

The entries in the first row of the matrix in Table 18.3 are read as 100100010.

This converts to its decimal equivalent follows:

\[(1 \times 2^8) + (0 \times 2^7) + (0 \times 2^6) + (0 \times 2^5) + (1 \times 2^4) + (0 \times 2^3) + (0 \times 2^2) + (1 \times 2^1) + (0 \times 2^0) = 256 + 32 + 2 = 290.\]

Decimal conversion becomes impractical for the large numbers of parts found in practice, so it is preferable to compare the binary numbers.

Rank Order Clustering

EXAMPLE 18.2  Rank Order Clustering Technique

Apply the rank order clustering technique to the part-machine incidence matrix in Table 18.3.

Solution: Step 1 consists of reading the series of 1’s and 0’s in each row as a binary number. We have done this in Table 18.6(a), converting the binary value for each row to its decimal equivalent. The values are then rank ordered in the far right-hand column. In step 2, we see that the row order is different from the starting matrix. We therefore reorder the rows in step 3. In step 4, we read the series of 1’s and 0’s in each column from top to bottom as a binary number (again we have converted to the decimal equivalent) and rank the columns in order of decreasing value, as shown in Table 18.6(b). In step 5, we see that the column order is different from the preceding matrix. Proceeding from step 6 back to steps 1 and 2, we see that a reordering of the columns provides a row order that is in descending value and the algorithm is concluded (step 7). The final solution is shown in Table 18.6(c). A close comparison of this solution with Table 18.4 reveals that they are the same part-machine groupings.
Rank Order Clustering

**TABLE 18.6(a)** First Iteration (Step 1) in the Rank Order Clustering Technique Applied to Example 18.2

<table>
<thead>
<tr>
<th>Binary values</th>
<th>2^8</th>
<th>2^7</th>
<th>2^6</th>
<th>2^5</th>
<th>2^4</th>
<th>2^3</th>
<th>2^2</th>
<th>2^1</th>
<th>2^0</th>
<th>Decimals</th>
<th>Equivalent</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machines</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
<td>G</td>
<td>H</td>
<td>I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>200</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>81</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>136</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>288</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>65</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>140</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

**Machine Reorder: 1 - 5 - 7 - 4 - 3 - 6 - 2**

Rank Order Clustering

**TABLE 18.6(b)** Second Iteration (Steps 3 and 4) in the Rank Order Clustering Technique Applied to Example 18.2

<table>
<thead>
<tr>
<th>Parts</th>
<th>Machines</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>Binary values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2^8</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2^7</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2^6</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2^5</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2^4</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2^3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2^2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2^1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2^0</td>
</tr>
</tbody>
</table>

**Parts Reorder: A - H - D - B - F - G - I - C - E**
Rank Order Clustering

In the example problem, it was possible to divide the parts and machines into three mutually exclusive part-machine groups.

This represents the ideal case because the part families and associated machine cells are completely segregated.

However, it is not uncommon for an overlap in processing requirements to exist between machine groups.

That is, a given part type needs to be processed by more than one machine group.

One way of dealing with the overlap is simply to duplicate the machine that is used by more than one part family, placing the same machine type in both cells.

TABLE 18.6(c)  Solution of Example 18.2

<table>
<thead>
<tr>
<th>Parts</th>
<th>A</th>
<th>H</th>
<th>D</th>
<th>B</th>
<th>F</th>
<th>G</th>
<th>I</th>
<th>C</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machines</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Rank Order Clustering

Other approaches, attributed to Burbidge, include:

1. changing the routing so that all processing can be accomplished in the primary machine group,
2. redesigning the part to eliminate the processing requirement outside the primary machine group, and
3. purchasing the parts from an outside supplier.

Arranging Machines in a GT Cell

After part-machine groupings have been identified, the next problem is to organize the machines into the most logical sequence.

Let us describe a simple yet effective method suggested by Hollier, that uses data contained in From/To Charts (Section 10.3.1) and is intended to place the machines in an order that maximizes the proportion of in-sequence moves within the cell.

The method is based on the use of From/To ratios determined by summing the total flow from and to each machine in the cell.
Arranging Machines in a GT Cell – From/To Charts

The algorithm can be reduced to three steps:

1. **Develop the From/To chart**
   
   The data contained in the chart indicate numbers of part moves between the machines (or workstations) in the cell. Moves into and out of the cell are not included in the chart.

2. **Determine the “From/To ratio” for each machine**
   
   This is accomplished by summing all of the “From” trips and “To” trips for each machine (or operation).
   
   The “From” sum for a machine is determined by adding the entries in the corresponding row, and the “To” sum is determined by adding the entries in the corresponding column.
   
   For each machine, the “From/To ratio” is calculated by taking the “From” sum for each machine and dividing by the respective “To” sum.
Arranging Machines in a GT Cell – From/To Charts

3. **Arrange machines in order of decreasing From/To ratio**

Machines with a high From/To ratio distribute more work to other machines in the cell but receive less work from other machines. Conversely, machines with a low From/To ratio receive more work than they distribute. Therefore, machines are arranged in order of descending From/To ratio; that is, machines with high ratios are placed at the beginning of the work flow, and machines with low ratios are placed at the end of the work flow. In case of a tie, the machine with the higher “From” value is placed ahead of the machine with a lower value.

---

**EXAMPLE 18.3 Group Technology Machine Sequence Using Hollier Method 2**

Suppose that four machines, 1, 2, 3, and 4, belong to a GT machine cell. An analysis of 50 parts processed on these machines has been summarized in the From/To chart shown in Table 18.7. Additional information is that 50 parts enter the machine grouping at machine 3, 20 parts leave after processing at machine 1, and 30 parts leave after machine 4. Determine the most logical machine sequence using the Hollier method.

![Table 18.7](image)

- Hollier [19] introduces six heuristic approaches to solving the machine arrangement problem, of which we describe only 08. He presents a comparison of the six methods in his paper.
Arranging Machines in a GT Cell – From/To Charts

TABLE 18.8 From/To Sums and From/To Ratios for Example 18.3

<table>
<thead>
<tr>
<th>To</th>
<th>From</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>&quot;From&quot; sums</th>
<th>From/To ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>25</td>
<td>30</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>45</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>∞</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>&quot;To&quot; sums</td>
<td>50</td>
<td>45</td>
<td>0</td>
<td>40</td>
<td>135</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Solution: Summing the From trips and To trips for each machine yields the “From” and “To” sums in Table 18.8. The From/To ratios are listed in the last column on the right. Arranging the machines in order of descending From/To ratio, the machines in the cell should be sequenced as follows:

3 → 2 → 1 → 4

Arranging Machines in a GT Cell – Network Diagrams

- It is helpful to use a graphical technique, such as the network diagram (Section 10.3.1; Read), to conceptualize the work flow in the cell.

- The network diagram for the machine arrangement in Example 18.3 is presented in Figure 18.12. The flow is mostly in-line: however, there is some bypassing and backtracking of parts that must be considered in the design of any material handling system that might be used in the cell.

- A powered conveyor would be appropriate for the forward flow between machines, with manual handling for the back flow.
EXAMPLE 18.4 Performance Measures for Machine Sequences in a GT Cell

Compute (a) the percentage of in-sequence moves, (b) the percentage of bypassing moves, and (c) the percentage of backtracking moves for the solution in Example 18.3.

Solution: From Figure 18.12, the number of in-sequence moves = 40 + 30 + 25 = 95, the number of bypassing moves = 10 + 15 = 25, and the number of backtracking moves = 5 + 10 = 15. The total number of moves = 135 (totaling either the “From” sums or the “To” sums). Thus,

(a) Percentage of in-sequence moves = \( \frac{95}{135} = 0.704 = 70.4\% \)

(b) Percentage of bypassing moves = \( \frac{25}{135} = 0.185 = 18.5\% \)

(c) Percentage of backtracking moves = \( \frac{15}{135} = 0.111 = 11.1\% \)
Three performance measures can be defined to rate solutions to the machine sequencing problem:

1. percentage of in-sequence moves,
2. percentage of bypassing moves, and
3. percentage of backtracking moves.

Each measure is computed by adding all of the values representing that type of move and dividing by the total number of moves.

It is desirable for the percentage of in-sequence moves to be high, and for the percentage of backtracking moves to be low.

The Hollier method is designed to achieve these goals.

Bypassing moves are less desirable than in-sequence moves, but certainly better than backtracking.