Chapter 7

Capacity and Facilities Design

Russell and Taylor
Operations and Supply Chain Management,
8th Edition
Lecture Outline

- **Capacity Planning** – Slide 4
- **Basic Layouts** – Slide 12
- **Designing Process Layouts** – Slide 19
- **Designing Service Layouts** – Slide 31
- **Designing Product Layouts** – Slide 33
- **Hybrid Layouts** – Slide 47
Learning Objectives

• Evaluate different strategies for capacity expansion

• Explain the concepts of economies of scale, best operating level, and cycle time

• Describe the advantages and disadvantages of different types of layouts in both manufacturing and service settings

• Visualize work flow and utilize algorithmic problem solving to lay out a facility

• Create and evaluate hybrid layouts and hybrid solutions to problems
Capacity Planning

• Capacity
  • maximum capability to produce

• Capacity planning
  • establishes overall level of productive resources for a firm

• Capacity expansion strategy in relation to steady growth in demand
  • lead
  • lag
  • average
Capacity Expansion Strategies

(a) Capacity lead strategy

(b) Capacity lag strategy

(c) Average capacity strategy

(d) Incremental versus one-step expansion
Capacity Expansion

• Capacity increase depends on
  • volume and certainty of anticipated demand
  • strategic objectives
  • costs of expansion and operation

• Best operating level
  • % of capacity utilization that minimizes unit costs

• Capacity cushion
  • % of capacity held in reserve for unexpected occurrences
Economies of Scale

- Unit cost decreases as output volume increases
- Fixed costs can be spread over a larger number of units
- Production or operating costs do not increase linearly with output levels
- Quantity discounts are available for material purchases
- Operating efficiency increases as workers gain experience
Operating Level

- Best operating level
  - percent of capacity utilization that minimizes unit cost

- Capacity cushion
  - percent of capacity held in reserve for unexpected occurrences

- Diseconomies of scale
  - higher levels of output cost more per unit to produce
Best Operating Level for a Hotel

![Graph showing economies of scale and diseconomies of scale for hotel operating levels.](image)

- **Economies of scale**: When the average cost per room decreases as the number of rooms in the hotel increases.
- **Diseconomies of scale**: When the average cost per room increases as the number of rooms in the hotel increases.
- **Best operating level**: The point where the average cost per room is at its lowest.

Number of rooms in hotel

- 250
- 500
- 1000

Average cost per room

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Objectives of Facility Layout

• Minimize material-handling costs
• Utilize space efficiently
• Utilize labor efficiently
• Eliminate bottlenecks
• Facilitate communication and interaction
• Reduce manufacturing cycle time
• Reduce customer service time
• Eliminate wasted or redundant movement
Objectives of Facility Layout

- Facilitate entry, exit, and placement of material, products, and people
- Incorporate safety and security measures
- Promote product and service quality
- Encourage proper maintenance activities
- Provide a visual control of activities
- Provide flexibility to adapt to changing conditions
- Increase capacity
Basic Layouts

• Process layouts
  • group similar activities together according to process or function they perform

• Product layouts
  • arrange activities in line according to sequence of operations for a particular product or service

• Fixed-position layouts
  • are used for projects in which product cannot be moved
## Process Layout in Services

<table>
<thead>
<tr>
<th>Women’s lingerie</th>
<th>Shoes</th>
<th>Housewares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women’s dresses</td>
<td>Cosmetics and jewelry</td>
<td>Children’s department</td>
</tr>
<tr>
<td>Women’s sportswear</td>
<td>Entry and display area</td>
<td>Men’s department</td>
</tr>
</tbody>
</table>
Manufacturing Process Layout

[Diagram showing various departments such as Lathe, Milling, Drilling, Grinding, Painting, and Assembly with flow arrows connecting them]
A Product Layout
Comparison of Product and Process Layouts

<table>
<thead>
<tr>
<th>Description</th>
<th>Type of process</th>
<th>Product</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Sequential arrangement of activities</td>
<td>• Functional grouping of activities</td>
<td>• Continuous, mass production, mainly assembly</td>
<td>• Intermittent, job shop, batch production, mainly fabrication</td>
</tr>
<tr>
<td>• Standardized, made to stock</td>
<td>• Varied, made to order</td>
<td>• Stable</td>
<td>• Fluctuating</td>
</tr>
<tr>
<td>• High</td>
<td>• Low</td>
<td>• Special purpose</td>
<td>• General purpose</td>
</tr>
<tr>
<td>• Special purpose</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Comparison of Product and Process Layouts

<table>
<thead>
<tr>
<th>Product</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Workers</td>
<td>• Varied skills</td>
</tr>
<tr>
<td>• Inventory</td>
<td>• High in-process, low</td>
</tr>
<tr>
<td>• Storage space</td>
<td>finished goods</td>
</tr>
<tr>
<td>• Material handling</td>
<td>• Large</td>
</tr>
<tr>
<td>• Aisles</td>
<td>• Variable path (forklift)</td>
</tr>
<tr>
<td>• Scheduling</td>
<td>• Wide</td>
</tr>
<tr>
<td>• Layout decision</td>
<td>• Dynamic</td>
</tr>
<tr>
<td>• Goal</td>
<td>• Machine location</td>
</tr>
<tr>
<td>• Advantage</td>
<td>• Minimize material</td>
</tr>
<tr>
<td>• Limited skills</td>
<td>handling cost</td>
</tr>
<tr>
<td>• Low in-process, high</td>
<td>• Flexibility</td>
</tr>
<tr>
<td>finished goods</td>
<td></td>
</tr>
<tr>
<td>• Small</td>
<td></td>
</tr>
<tr>
<td>• Fixed path (conveyor)</td>
<td></td>
</tr>
<tr>
<td>• Narrow</td>
<td></td>
</tr>
<tr>
<td>• Part of balancing</td>
<td></td>
</tr>
<tr>
<td>• Line balancing</td>
<td></td>
</tr>
<tr>
<td>• Equalize work at each</td>
<td></td>
</tr>
<tr>
<td>station</td>
<td></td>
</tr>
<tr>
<td>• Efficiency</td>
<td></td>
</tr>
</tbody>
</table>

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Fixed-Position Layouts

- Typical of projects
- Fragile, bulky, heavy items
- Equipment, workers & materials brought to site
- Low equipment utilization
- Highly skilled labor
- Typically low fixed cost
- Often high variable costs
Designing Process Layouts

- Goal: minimize material handling costs
- Block Diagramming
  - minimize nonadjacent loads
  - use when quantitative data is available
- Relationship Diagramming
  - based on location preference between areas
  - use when quantitative data is not available
Block Diagramming

• Unit load
  • quantity in which material is normally moved

• Nonadjacent load
  • distance farther than the next block

• Steps
  • create load summary chart
  • calculate composite (two way) movements
  • develop trial layouts minimizing number of nonadjacent loads
Block Diagramming: Example

Load Summary Chart

<table>
<thead>
<tr>
<th>FROM/TO</th>
<th>DEPARTMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
</tr>
</tbody>
</table>
Block Diagramming: Example

| Nonadjacent Loads | 110+40=150 |

Grid 1

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### Block Diagramming: Example

<table>
<thead>
<tr>
<th>Edge</th>
<th>Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 ↔ 3</td>
<td>200</td>
</tr>
<tr>
<td>2 ↔ 4</td>
<td>150</td>
</tr>
<tr>
<td>1 ↔ 3</td>
<td>110</td>
</tr>
<tr>
<td>1 ↔ 2</td>
<td>100</td>
</tr>
<tr>
<td>4 ↔ 5</td>
<td>60</td>
</tr>
<tr>
<td>3 ↔ 5</td>
<td>50</td>
</tr>
<tr>
<td>2 ↔ 5</td>
<td>50</td>
</tr>
<tr>
<td>3 ↔ 4</td>
<td>40</td>
</tr>
<tr>
<td>1 ↔ 4</td>
<td>0</td>
</tr>
<tr>
<td>1 ↔ 5</td>
<td>0</td>
</tr>
</tbody>
</table>

Nonadjacent Loads: 0

Grid 2
Block Diagramming: Example

- Block Diagram
  - type of schematic layout diagram; includes space requirements

(a) Initial block diagram

(b) Final block diagram
Input load summary chart and trial layout

Try different layout configurations

Excel will calculate composite movements and nonadjacent loads

Example 7.1 - Process Layout

Load Summary Chart

<table>
<thead>
<tr>
<th>From \ To</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td></td>
<td>40</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>40</td>
<td></td>
<td></td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>

Composite Movements

<table>
<thead>
<tr>
<th>From \ To</th>
<th>Loads</th>
<th>1&lt;&gt;3</th>
<th>1&lt;&gt;6</th>
<th>3&lt;&gt;4</th>
<th>4&lt;&gt;6</th>
<th>Layout Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>110</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>150</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Output: Nonadjacent loads = 150
Relationship Diagramming

- Schematic diagram that uses weighted lines to denote location preference
- Muther’s grid format for displaying manager preferences for department locations
Relationship Diagramming

Key:
- **A** Absolutely necessary
- **E** Especially important
- **I** Important
- **O** Okay
- **U** Unimportant
- **X** Undesirable

Diagram:

- Production
- Offices
- Stockroom
- Shipping and receiving
- Locker room
- Toolroom

Diagram depicts relationships and importance levels for various areas.
(a) Relationship diagram of original layout
(b) Relationship diagram of revised layout
Computerized Layout Solutions

- CRAFT
  - Computerized Relative Allocation of Facilities Technique
- CORELAP
  - Computerized Relationship Layout Planning
- PROMODEL and EXTEND
  - visual feedback
  - allow user to quickly test a variety of scenarios
- Three-D modeling and CAD
  - integrated layout analysis
  - available in VisFactory and similar software
Designing Service Layouts

• Must be both attractive and functional

• Free flow layouts
  • encourage browsing, increase impulse purchasing, are flexible and visually appealing

• Grid layouts
  • encourage customer familiarity, are low cost, easy to clean and secure, and good for repeat customers

• Loop and Spine layouts
  • both increase customer sightlines and exposure to products, while encouraging customer to circulate through the entire store
Types of Store Layouts

- Freeflow Layout
- Grid Layout
- Spine Layout
- Loop Layout
Designing Product Layouts

• Objective
  • Balance the assembly line

• Line balancing
  • tries to equalize the amount of work at each workstation

• Precedence requirements
  • physical restrictions on the order in which operations are performed

• Cycle time
  • maximum amount of time a product is allowed to spend at each workstation
Cycle Time Example

Produce 120 units in an 8-hour day

\[
C_d = \frac{\text{production time available}}{\text{desired units of output}}
\]

\[
C_d = \frac{8 \text{ hours}}{120 \text{ units}}
\]
Cycle Time Example

Produce 120 units in an 8-hour day

\[ C_d = \frac{\text{production time available}}{\text{desired units of output}} \]

\[ C_d = \frac{(8 \text{ hours} \times 60 \text{ minutes / hour})}{120 \text{ units}} \]

\[ C_d = \frac{480}{120} = 4 \text{ minutes} \]
Flow Time vs Cycle Time

- Cycle time = max time spent at any station
- Flow time = time to complete all stations

Flow time = 4 + 4 + 4 = 12 minutes
Cycle time = max (4, 4, 4) = 4 minutes
Efficiency of Line and Balance Delay

**Efficiency**

\[
E = \frac{\sum_{i=1}^{j} t_i}{nC_a}
\]

**Min# of workstations**

\[
N = \frac{\sum_{i=1}^{j} t_i}{C_d}
\]

where

- \(t_i\) = completion time for element \(i\)
- \(j\) = number of work elements
- \(n\) = actual number of workstations
- \(C_a\) = actual cycle time
- \(C_d\) = desired cycle time

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Line Balancing Procedure

1. Draw and label a precedence diagram
2. Calculate desired cycle time required for line
3. Calculate theoretical minimum number of workstations
4. Group elements into workstations, recognizing cycle time and precedence constraints
5. Calculate efficiency of line
6. Determine if theoretical minimum number of workstations or an acceptable efficiency level has been reached. If not, go back to step 4.
# Line Balancing

<table>
<thead>
<tr>
<th>Work Element</th>
<th>Precedence</th>
<th>Time (Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A  Press out sheet of fruit</td>
<td>—</td>
<td>0.1</td>
</tr>
<tr>
<td>B  Cut into strips</td>
<td>A</td>
<td>0.2</td>
</tr>
<tr>
<td>C  Outline fun shapes</td>
<td>A</td>
<td>0.4</td>
</tr>
<tr>
<td>D  Roll up and package</td>
<td>B, C</td>
<td>0.3</td>
</tr>
</tbody>
</table>

![Diagram](https://via.placeholder.com/150)
## Line Balancing

<table>
<thead>
<tr>
<th>Work Element</th>
<th>Precedence</th>
<th>Time (Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press out sheet of fruit</td>
<td>—</td>
<td>0.1</td>
</tr>
<tr>
<td>Cut into strips</td>
<td>A</td>
<td>0.2</td>
</tr>
<tr>
<td>Outline fun shapes</td>
<td>A</td>
<td>0.4</td>
</tr>
<tr>
<td>Roll up and package</td>
<td>B, C</td>
<td>0.3</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
C_d &= \quad \\
N &= \quad 
\end{align*}
\]
Line Balancing

<table>
<thead>
<tr>
<th>Work Element</th>
<th>Precedence</th>
<th>Time (Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Press out sheet of fruit</td>
<td>—</td>
<td>0.1</td>
</tr>
<tr>
<td>B Cut into strips</td>
<td>A</td>
<td>0.2</td>
</tr>
<tr>
<td>C Outline fun shapes</td>
<td>A</td>
<td>0.4</td>
</tr>
<tr>
<td>D Roll up and package</td>
<td>B, C</td>
<td>0.3</td>
</tr>
</tbody>
</table>

\[
C_d = \frac{40 \text{ hours} \times 60 \text{ minutes} / \text{hour}}{6,000 \text{ units}} = \frac{2400}{6000} = 0.4 \text{ minute}
\]

\[
N = \frac{0.1 + 0.2 + 0.3 + 0.4}{0.4} = \frac{1.0}{0.4} = 2.5 \Rightarrow 3 \text{ workstations}
\]
## Line Balancing

<table>
<thead>
<tr>
<th>Workstation</th>
<th>Element</th>
<th>Remaining Time</th>
<th>Remaining Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Diagram](image)
Line Balancing

<table>
<thead>
<tr>
<th>Workstation</th>
<th>Element</th>
<th>Remaining Time</th>
<th>Remaining Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>0.3</td>
<td>B, C</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>0.1</td>
<td>C, D</td>
</tr>
<tr>
<td>2</td>
<td>C</td>
<td>0.0</td>
<td>D</td>
</tr>
<tr>
<td>3</td>
<td>D</td>
<td>0.1</td>
<td>none</td>
</tr>
</tbody>
</table>

$C_d = 0.4$

$N = 2.5$
Line Balancing

Work station 1  Work station 2  Work station 3

A, B  C  D

0.3 minute  0.4 minute  0.3 minute

\[ C_d = 0.4 \]
\[ N = 2.5 \]

\[ E = \]
Line Balancing

\[ C_d = 0.4 \]
\[ N = 2.5 \]

\[ E = \frac{0.1 + 0.2 + 0.3 + 0.4}{3(0.4)} = \frac{1.0}{1.2} = 0.833 = 83.3\% \]
Computerized Line Balancing

- Use heuristics to assign tasks to workstations
  - Longest operation time
  - Shortest operation time
  - Most number of following tasks
  - Least number of following tasks
  - Ranked positional weight
Hybrid Layouts

• Cellular layouts
  • group dissimilar machines into work centers (called cells) that process families of parts with similar shapes or processing requirements

• Production flow analysis (PFA)
  • reorders part routing matrices to identify families of parts with similar processing requirements

• Flexible manufacturing system
  • automated machining and material handling systems which can produce an enormous variety of items

• Mixed-model assembly line
  • processes more than one product model in one line
Cellular Layouts

1. Identify families of parts with similar flow paths
2. Group machines into cells based on part families
3. Arrange cells so material movement is minimized
4. Locate large shared machines at point of use
Parts Families

A family of similar parts

A family of related grocery items

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Original Process Layout
## Part Routing Matrix

<table>
<thead>
<tr>
<th>Parts</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
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Revised Cellular Layout
Reordered Routing Matrix

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<th>Parts</th>
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Direction of part movement within cell

Key:
S = Saw
L = Lathe
HM = Horizontal milling machine
VM = Vertical milling machine
G = Grinder

- - - Paths of three workers moving within cell
----- Material movement

Worker 1
Worker 2
Worker 3

Final inspection
Finished part

In
Out
Cellular Layouts

• Advantages
  • Reduced material handling and transit time
  • Reduced setup time
  • Reduced work-in-process inventory
  • Better use of human resources
  • Easier to control
  • Easier to automate

• Disadvantages
  • Inadequate part families
  • Poorly balanced cells
  • Expanded training and scheduling of workers
  • Increased capital investment
Automated Manufacturing Cell
Flexible Manufacturing Systems (FMS)

- Consists of
  - programmable machine tools
  - automated tool changing
  - automated material handling system
  - controlled by computer network
- Combines flexibility with efficiency
- Layouts differ based on
  - variety of parts the system can process
  - size of parts processed
  - average processing time required for part completion
Fully-Implemented FMS
Mixed Model Assembly Lines

• Produce multiple models in any order on one assembly line

• Factors in mixed model lines
  • Line balancing
  • U-shaped lines
  • Flexible workforce
  • Model sequencing
Balancing U-Shaped Lines

(a) Balanced for a straight line

A, B → C, D → E
9 min 12 min 3 min

Efficiency = \frac{24}{3(12)} = \frac{24}{36} = 0.6666 = 66.7%

(b) Balanced for a U-shaped line

A, B → C, D

12 min

Efficiency = \frac{24}{2(12)} = \frac{24}{24} = 100%