Layout Design

Some of these slides are courtesy of Professor Paul Griffin

Post Woods Apartment Complex
Hospital floor plan

Guildcrest Homes – Factory floor plan
Furniture parts warehouse

Cross-dock layout

Issues in facilities design

- What equipment should be purchased?
- How facilities should be organized?
  - Finding the locations of departments within some specified boundary
- Where facilities should be located?

Why is this important?
- 8% of the U.S. gross national product has been spent on new facilities annually since 1955
- 20-50% of total operating expenses in manufacturing are attributed to material handling costs

Layout

- Definition - How to best locate a facility's resources with respect to each other in order to maximize the firm's objectives.
Possible Objectives

- Efficient flow of people/materials/goods
- Minimize costs
  - materials handling
  - capital
  - maintenance
- Improved utilization (people, equipment, space, energy)
- Flexibility (process, volume, routing, product)
- Maximize throughput
- etc

Possible Constraints

- Financial
- Space
- Legal/Regulations
- Safety
- Historical/Cultural
- Physical (noise, dust, vibration)
Types of layouts

- Fixed position layout
  - Ships, aircraft, rockets, etc.

- Product layout
  - Machines are organized to conform to the sequence of operations
  - High volume, standardized/mass production
Types of layouts

- **Process layout**
  - Group similar machines, having similar functions
  - Common for small-to-medium volume manufacturers, e.g., job-shop
  - Effective when there is a variation in the product mix

![Diagram of a process layout](image)

Wyman-Gordon job-shop layout
Types of layouts

- Group technology layout
  - Machines are grouped into machine cells
  - Each cell corresponds to a “family” (or a small group of families) of parts
  - Appropriate for large firms producing a wide variety of parts in moderate to high volumes
Types of layouts

- Group technology layout

**Benefits**
- Reduced WIP
- Reduced setup times
- Reduced material handling costs
- Better scheduling

**Drawbacks**
- How to identify suitable part families?
- Possible duplication of some machines
- Response to the change in product mix, design, and demand patterns
Flow analysis

- It is important for a layout designer to have an understanding of the (required) flow within the facility
  - Horizontal flow
  - Vertical flow

From-To-Chart

- Used to describe the flow between departments for an “existing” layout
  - Distances between departments
  - Number of material handling trips per day
  - Total cost of material handling trips per day

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>from</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Connectedness-Tile Adjacencies

- 4-adjacent
- 8-adjacent

Connectedness-Definitions

- Departments are **4-connected** if a path exists between any two tiles in the department using 4-adjacencies.
- Departments are **8-connected** if a path exists between any two tiles in the department using 8-adjacencies.
- **Note:** It is usually required for departments to be 4-connected.
Example

Suppose the departmental areas are:

<table>
<thead>
<tr>
<th>Department</th>
<th>Area (sq.ft.)</th>
<th>Tiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8,000</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>6,000</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>8,000</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>4,000</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>6,000</td>
<td>3</td>
</tr>
</tbody>
</table>

Assume

• each tile is 2000 sq. ft.
• facility is 4x4 tiles (32,000 sq.ft.)

Two possible 4-connected alternatives

Which of these two alternatives is better?
Evaluation Techniques

- In order to pick the “best” set of alternatives, we must have an evaluation strategy. Some popular methods are:
  - Centroid Method
  - Graph Method
  - Adjacency Method
- Let SCORE denote the objective function value

Evaluation using the centroid method

- Objective: Minimize total travel (material handling) cost
- We need to fill the from-to charts for
  - Distance
  - Number of trips per period
  - Cost to move each unit of flow per unit distance
Calculating the Distance Between Departments

What is the distance between departments 1 and 2?

Idea: find the “center” or “centroid”, i.e., an (x,y) coordinate for each department.

Centroid

- The centroid for department \( j \) is computed from:

\[
C_j^X = \frac{\sum_{i=1}^{h} ix_i}{n} \quad C_j^Y = \frac{\sum_{i=1}^{v} iy_i}{n}
\]

where
- \( x_i \) is the number of tiles allocated to the department in horizontal position \( i \)
- \( y_i \) is the number of tiles allocated to the department in vertical position \( i \)
- \( h \) is the horizontal width
- \( v \) is the vertical height
- \( n \) is the number of tiles for the department
Centroid Example

For department 1:
\[ C^x_1 = \frac{1(1) + 2(2) + 1(3)}{4} = 2 \]
\[ C^y_1 = \frac{3(1) + 1(2)}{4} = 1.25 \]

For department 2:
\[ C^x_2 = \frac{3(3)}{3} = 3 \]
\[ C^y_2 = \frac{1(2) + 1(3) + 1(4)}{3} = 3 \]

Distance Metrics

- Euclidean \[ D_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \]
- Rectilinear \[ D_{ij} = |x_i - x_j| + |y_i - y_j| \]
- Tchebyshev \[ D_{ij} = \max \{ |x_i - x_j|, |y_i - y_j| \} \]
- Choice of metric depends on the application
Example: Distance between 1 and 2

- Euclidean
  \[ D_{12} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} = \sqrt{(2 - 3)^2 + (1.25 - 3)^2} = 2.016 \]

- Rectilinear
  \[ D_{12} = |x_1 - x_2| + |y_1 - y_2| = |2 - 3| + |1.25 - 3| = 2.75 \]

- Tchebyshev
  \[ D_{12} = \max\{|x_1 - x_2|, |y_1 - y_2|\} = \max\{|2 - 3|, |1.25 - 3|\} = 1.75 \]

From-To-Chart: Number of trips per day (flow)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>from</td>
<td>1</td>
<td>X</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>X</td>
<td>20</td>
<td>-</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>30</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>-</td>
<td>2</td>
<td>X</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>20</td>
<td>-</td>
<td>10</td>
<td>X</td>
</tr>
</tbody>
</table>

Using the distance between any pair of departments, and the flow, we can compute the total distance traveled per day
From-To-Chart: Cost of traveling one unit of distance between the departments

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>X</td>
<td>5</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>-</td>
<td>1</td>
<td>X</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>4</td>
<td>-</td>
<td>5</td>
<td>X</td>
</tr>
</tbody>
</table>

Using the total distance traveled per day and the cost of traveling one unit of distance, we can compute the daily total cost of traveling (material handling) between the departments.

Activity relationship chart

The activity relationship chart is constructed/modified by considering qualitative information:

- A - absolutely necessary (< 5%)
- E - especially important (< 10%)
- I - important (<15%)
- O - ordinary importance (<20%)
- U - unimportant (> 50%)
- X - not desirable (< 5%)
Example

### Relationships

<table>
<thead>
<tr>
<th>Dept.</th>
<th>Space (sqft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40,000</td>
</tr>
<tr>
<td>2</td>
<td>20,000</td>
</tr>
<tr>
<td>3</td>
<td>10,000</td>
</tr>
<tr>
<td>4</td>
<td>20,000</td>
</tr>
</tbody>
</table>

*Assume:* facility is square, is 90,000 sq.ft., departments must be 4-connected, rectilinear metric, A=6, E=4, I=2, O=1, U=0, X=-10 (e.g., Rel(1,2)=6, Rel(2,4)=4)

Example continued

### Potential layout

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
Centroid Method

- Compute the centroid for each department.
- Compute distance between each pair of departments \((D(i,j))\).
- Compute SCORE as
  \[
  \text{SCORE} = 0; \\
  \text{for } i = 1 \text{ to } \# \text{ of departments do} \\
  \text{for } j = (i+1) \text{ to } \# \text{ of departments do} \\
  \text{SCORE} = \text{SCORE} + D(i,j) \times \text{Rel}(i,j);
  \]
- In this case we want to minimize \( \text{SCORE} \).

Example continued

<table>
<thead>
<tr>
<th>Potential layout</th>
<th>Centroids:</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Potential layout" /></td>
<td>Dept.</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Centroid evaluation

Relationships

\[
\begin{array}{cccc}
1 & 6 & 2 & -10 \\
2 & 4 & 1 & \\
3 & 2 & 4 & \\
4 & & & \\
\end{array}
\]

Rectilinear Distances

\[
\begin{array}{cccc}
1 & 2.25 & 2.5 & \\
2 & 1.75 & 2 & \\
3 & 1.5 & 2 & \\
4 & & 2.25 & \\
\end{array}
\]

\[
SCORE = 6(2.25)+4(1.75)+1(2.25)+2(1.5)+4(2)-10(2.5) = 8.75
\]

Graph Method

- Construct a graph where each node corresponds to a department
- Draw an edge between two nodes if they are adjacent in the layout.
- Weight each edge by the number of 4 (or 8) adjacencies times the relationship for that edge.
- \( SCORE = \) sum of the edge weights.
- We want to maximize \( SCORE \)
Graph evaluation

Potential layout

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>3</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Relationships

1 2 3 4

6 4 2 1

-10

SCORE = 22

Creating a Layout From Scratch
Creating a Layout from Scratch

- Determine importance levels
- Prepare activity relationship chart
- Create a layout using ALDEP or CORELAP (or other approach)
- Determine a score for the layout
- Repeat several times to generate alternative layouts and pick the one with the highest score

Burger Queen - Activity Relationship Chart

- A - absolutely necessary (< 5%) 6
- E - especially important (< 10%) 5
- I - important (<15%) 4
- O - ordinary importance (<20%) 3
- U - unimportant (> 50%) 2
- X - not desirable (< 5%) 1

1. Cooking burgers
2. Cooking fries
3. Packing/storing
4. Drink dispensers
5. Counter service

Rel chart
Creating a layout from scratch: ALDEP (Automated layout design program)

- Select a department at random and place it to the upper-left corner of the layout
- Place a department with a high closeness rating next to the first department
- Continue the process every time selecting a department with the highest closest rating to an already placed department
- Compute the “score” for the layout using a numeric scale attached to the closeness ratings
- Repeat the process several times and choose the layout with the highest score

Creating a layout from scratch: CORELAP (Computerized relationship layout program)

- Similar to ALDEP, but does not select the initial placement at random
- Compute the Total closeness rating (TCR) for each department (sum of the absolute values of the relations):
  - Cooking fries: $X, I, U, U = 9$
  - Packaging and storing: $I, I, O, E = 16$
  - Drink dispensers: $U, U, O, E = 12$
  - Counter service: $A, E, U, U = 17$
- Select the department with the highest TCR in the center of the facility. In case of a tie, give priority to the department with the largest area or with the highest number of A’s.
CORELAP (Cont.)

- The second department is the one with an A relationship with the first one. If a tie exists, choose the one with the greatest TCR value.

- The third department picked should have the highest combined relationships with the two already placed. Again use tie-breaking rule if needed.

- Continue until all departments placed.

Procedure to Place Departments

- Consider the figure on the right. Assume that a department is placed in the middle (position 0). Then, if another department is placed in position 1, 3, 5 or 7, it is "fully adjacent" with the first one. It is placed in position 2, 4, 6 or 8, it is "partially adjacent".

- For each position, Weighted Placement (WP) is the sum of the numerical values for all pairs of adjacent departments.

- The placement of departments is based on the following steps:
  1. The first department selected is placed in the middle.
  2. The placement of a department is determined by evaluating all possible locations around the current layout in counterclockwise order beginning at the "western edge".
  3. The new department is located based on the greatest WP value.
Example

1. Receiving
2. Shipping
3. Raw Materials Storage
4. Finished Goods Storage
5. Manufacturing
6. Work-In-Process Storage
7. Assembly
8. Offices
9. Maintenance

CV values:
V(A) = 125
V(E) = 25
V(I) = 5
V(O) = 1
V(U) = 0
V(X) = -125

Partial adjacency:
\( \alpha = 0.5 \)

Table of Total Closeness Rating (TCR) Values

<table>
<thead>
<tr>
<th>Dept.</th>
<th>Department</th>
<th>Summary</th>
<th>TCR</th>
<th>Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>- A A E O U U A O</td>
<td>3 1 0 2 2 0</td>
<td>402</td>
<td>(5)</td>
</tr>
<tr>
<td>2</td>
<td>A - E A U O U E A</td>
<td>2 2 0 1 3 0</td>
<td>301</td>
<td>(7)</td>
</tr>
<tr>
<td>3</td>
<td>A E - E A U U E A</td>
<td>3 3 0 0 2 0</td>
<td>450</td>
<td>(4)</td>
</tr>
<tr>
<td>4</td>
<td>E A E - E O A E U</td>
<td>2 4 0 1 1 0</td>
<td>351</td>
<td>(6)</td>
</tr>
<tr>
<td>5</td>
<td>U O A E - A A O A</td>
<td>4 1 0 2 1 0</td>
<td>527</td>
<td>(2)</td>
</tr>
<tr>
<td>6</td>
<td>U O U O A - A O O</td>
<td>2 0 0 4 2 0</td>
<td>254</td>
<td>(8)</td>
</tr>
<tr>
<td>7</td>
<td>U U U A A A - X A</td>
<td>4 0 0 0 3 1</td>
<td>625</td>
<td>(1)</td>
</tr>
<tr>
<td>8</td>
<td>A E E E O O X - X</td>
<td>1 3 0 2 0 2</td>
<td>452</td>
<td>(9)</td>
</tr>
<tr>
<td>9</td>
<td>O U A U A O A X -</td>
<td>3 0 0 2 2 1</td>
<td>502</td>
<td>(3)</td>
</tr>
</tbody>
</table>

For Dept. 1: 3(125)+1(25)+2(1)+2(0)=402
**Example (cont.)**

Relationship between 7 and 5 is A, and 5 is ranked (2)

Relationship between 9 and 5 is A, and 9 is ranked (3)

Relationship between 3 and 5 is A, and 3 is ranked (4)

**Example (cont.)**
Example (cont.)

Improving an Existing Layout
Improving an Existing Layout

1. Evaluate the layout.
2. Generate a new layout satisfying connectedness by 2-opting or 3-opting.
3. Evaluate the new layout based on from-to chart for total material handling cost. If the interchange results in an improvement, keep the change. Otherwise don’t keep the change.
4. Repeat steps 2 and 3 until no further improvement is possible.

Improving an existing layout by pairwise interchange: 2-opt

- 2-opting involves the switching of two departments. It is performed by:
  - If department i and j are the same size, then the tiles in i and exchanged for the tiles in j.
  - If they are different sizes, then the departments must be adjacent in the layout for the interchange (though the interchange is performed the same way).
  - Keep the change if it improves the objective function
- In both cases, 4 (or 8) - connectedness must be preserved
Example

2-way interchange of A and B

Note: This is discussed under CRAFT in your book

Improving an existing layout by 3-opt

- 3-opting involves the switching of three departments. It is performed by:
  - For departments i, j and k: i is switched with j, j is switched with k and k is switched with i.
  - Size and or adjacency must be maintained (as in the case of 2-opting)
- Again, the departments must maintain 4 (or 8) connectedness
Example: 3-opt

3-way interchange of A, B and D

A → B → D → A

---

Summary

- Layout is complicated by multiple often competing objectives such as
  - minimize investment in equipment
  - minimize overall production time
  - provide for employee/customer convenience
  - maintain flexibility of arrangement/operation
  - minimize material handling cost
  - utilize existing space most efficiently
- Can have a huge effect on productivity