Layout Design

Some of these slides are courtesy of Professor Paul Griffin

Post Woods Apartment Complex
Hospital floor plan

Acute Hospital - First Floor

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
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>
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<tr>
<td>B</td>
<td></td>
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<td>C</td>
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<td>D</td>
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</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></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:

\[ C_j^X = \frac{\sum_{i=1}^{h} i x_i}{n} \]

\[ C_j^Y = \frac{\sum_{i=1}^{v} i y_i}{n} \]

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:
\[ C_1^x = \frac{1(1) + 2(2) + 1(3)}{4} = 2 \]
\[ C_1^y = \frac{3(1) + 1(2)}{4} = 1.25 \]

For department 2:
\[ C_2^x = \frac{3(3)}{3} = 3 \]
\[ C_2^y = \frac{1(2) + 1(3) + 1(4)}{3} = 3 \]

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>from</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>10</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.

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**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

<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

```
1 3 2
1 1 2
1 4 4
```
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 SCORE.

Example continued

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>4</td>
</tr>
</tbody>
</table>

Centroids:

<table>
<thead>
<tr>
<th>Dept.</th>
<th>CX</th>
<th>CY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.25</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>2.5</td>
<td>1</td>
</tr>
</tbody>
</table>
Centroid evaluation

Relationships

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

Rectilinear Distances

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

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

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.
- \( \text{SCORE} = \text{sum of the edge weights.} \)
- We want to maximize \( \text{SCORE} \)
Graph evaluation

Potential layout

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<td>1</td>
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<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Relationships

```
1  6  4  1
2  4
3  2
4  -10
```

SCORE = 22