# Facilities planning

## Systematic Layout Plan

# Systematic Layout Planning (SLP)

- Developed by Richard Muther, 1961
- The best-known, most widely used and best-coordinated methodology for layout planning
- Step 0:Input data and activities
  - Data on product (what is to be produced) quantity (volume to be produced), routing (how it is to be produced), support services (with what will we produce), timing/transport (when will we produce and how will we move parts in and out)

# Systematic Layout Planning (SLP)

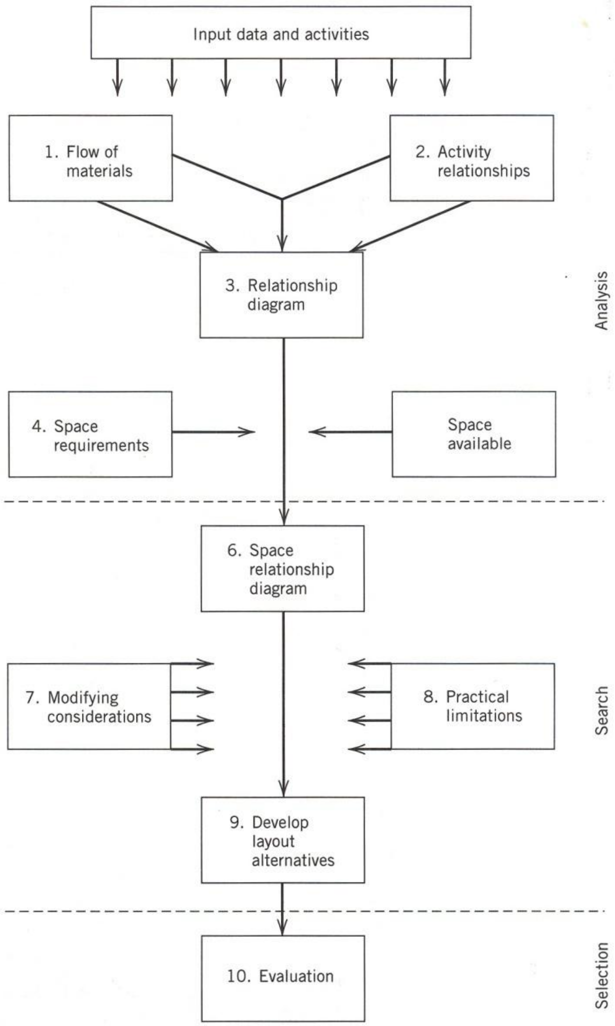



**Figure 6.3** Systematic layout planning (SLP) procedure.

# Flow of materials

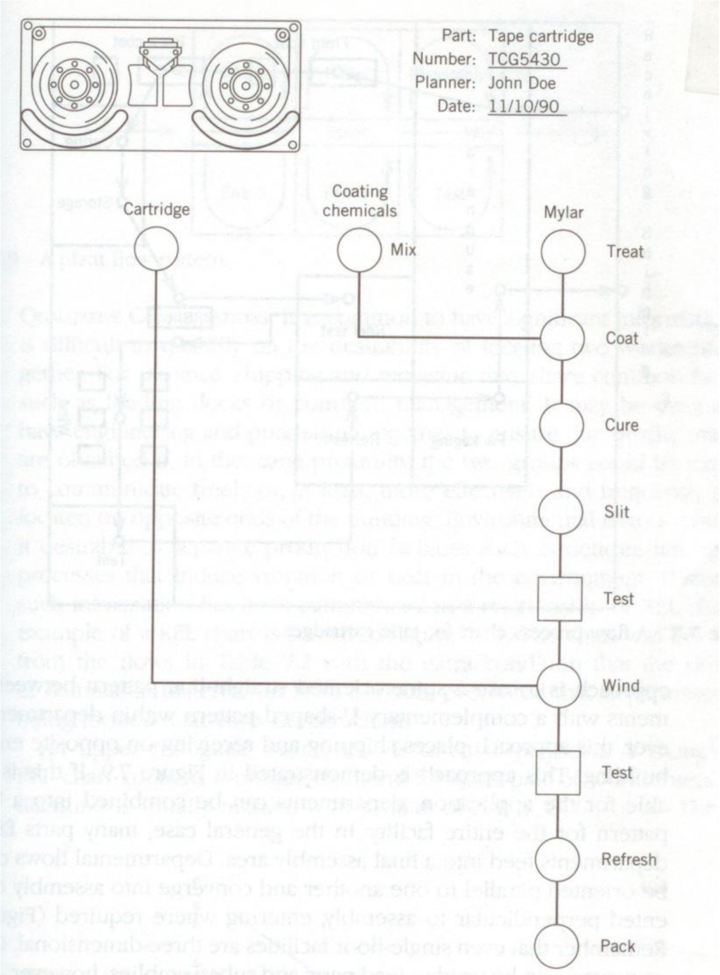
- Step 2: Flow of materials
  - Flow volumes and flow patterns must be established
  - Flow volumes can be summarized with From-To chart.
  - Flow patterns can be illustrated by operation chart and flow process chart
  - Distance based flow cost is determined by the flow volumes and the flow patterns.

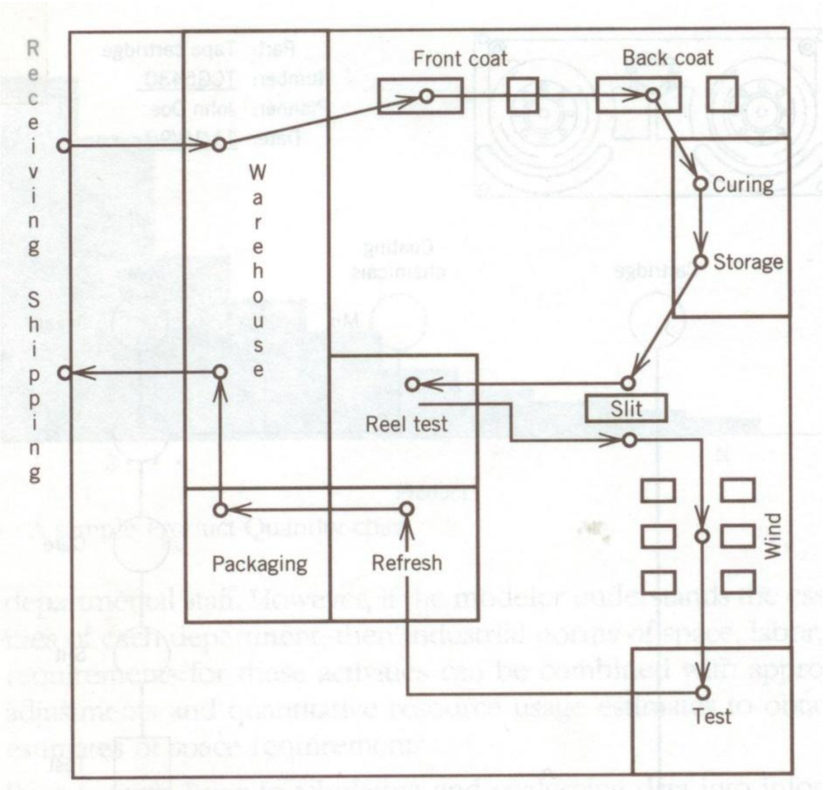
•Distance based objective: From-To chart is needed.

$$\min z = \sum_{i=1}^{m} \sum_{j=1}^{m} w_{ij} d_{ij}$$

# Flow of materials

- Operation chart and flow process chart



# Activity relationships

- Activity relationships
  - Organizational relationships influenced by span of control and reporting relationships.
    - Formal relationship can be expressed by an organization chart.
    - Informal relationship should be considered also.
  - Flow relationships including the flow of materials, people, equipment, information and money.
  - Environmental relationships including safety considerations and temperature, noise, fumes, humidity and dust.
  - Process relationships other than those considered above such as floor loadings, requirements for water treatment, chemical processing and special services

# Activity relationships

- Closeness relationship values

| Closeness | Relationship | Value |
|---|---|---|
| Absolutely necessary | A | 64 |
| Especially important | E | 16 |
| Important | I | 4 |
| Ordinary closeness okay | O | 1 |
| Unimportant | U | 0 |
| Undesirable | X | −1024 |

- Adjacency based objective: relationship chart is needed

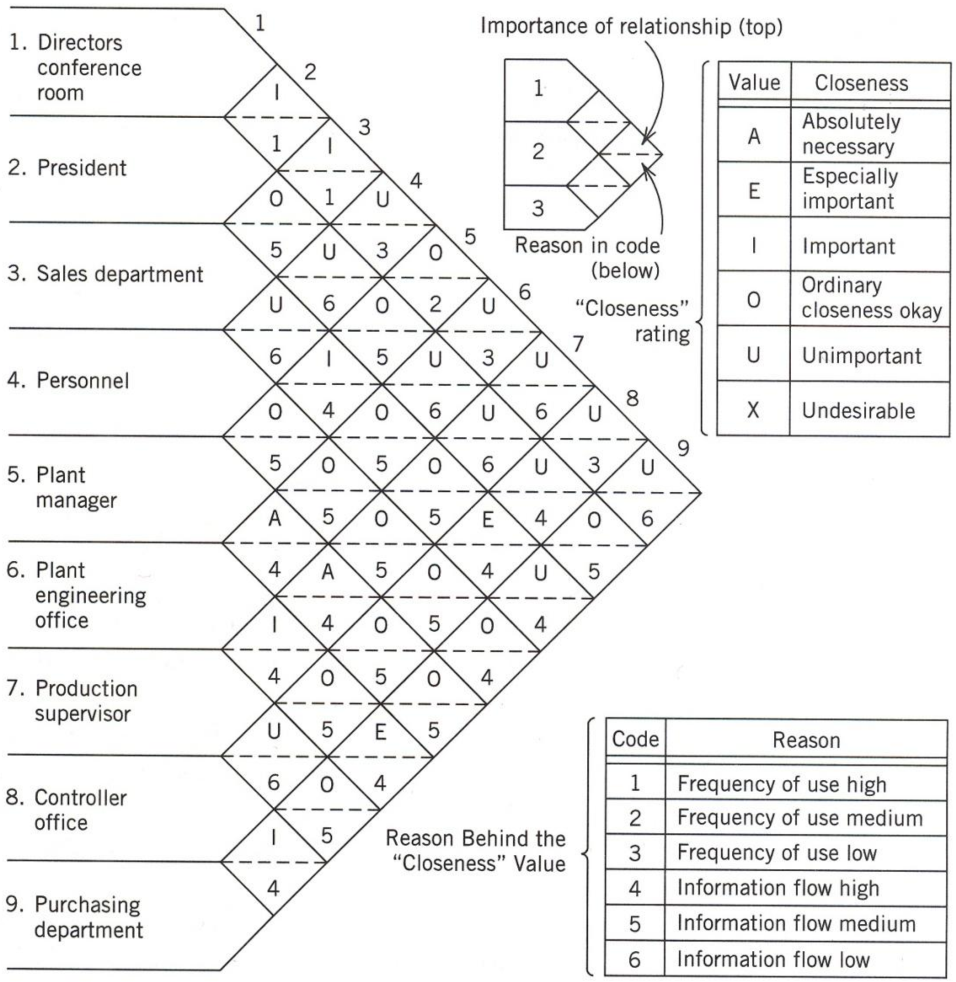
Let $x_{ij}$ be 1 if department i and j are adjacent and 0 otherwise.

$f_{ij}$ denote the relationship values in this case.

$$\max z = \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} x_{ij}$$

# Activity relationships

- Relationship chart




| Value | Closeness |
|---|---|
| A | Absolutely necessary |
| E | Especially important |
| I | Important |
| O | Ordinary closeness okay |
| U | Unimportant |
| X | Undesirable |

| Code | Reason |
|---|---|
| 1 | Frequency of use high |
| 2 | Frequency of use medium |
| 3 | Frequency of use low |
| 4 | Information flow high |
| 5 | Information flow medium |
| 6 | Information flow low |

**Figure 3.34** Relationship chart.

# Relationship diagram

- Relationship diagram combines quantitative and qualitative relationship data to initiate the determination of the relative location of facilities.
- Initial relationship diagram
  - Calculate the total closeness of departments and place departments in nonincreasing order of the total closeness
  - Place the first department in the center  and iteratively add the next department to the periphery of the layout. Always place the newly added department to the location that maximizes the sum of the closeness with adjacent departments.

# Relationship diagram

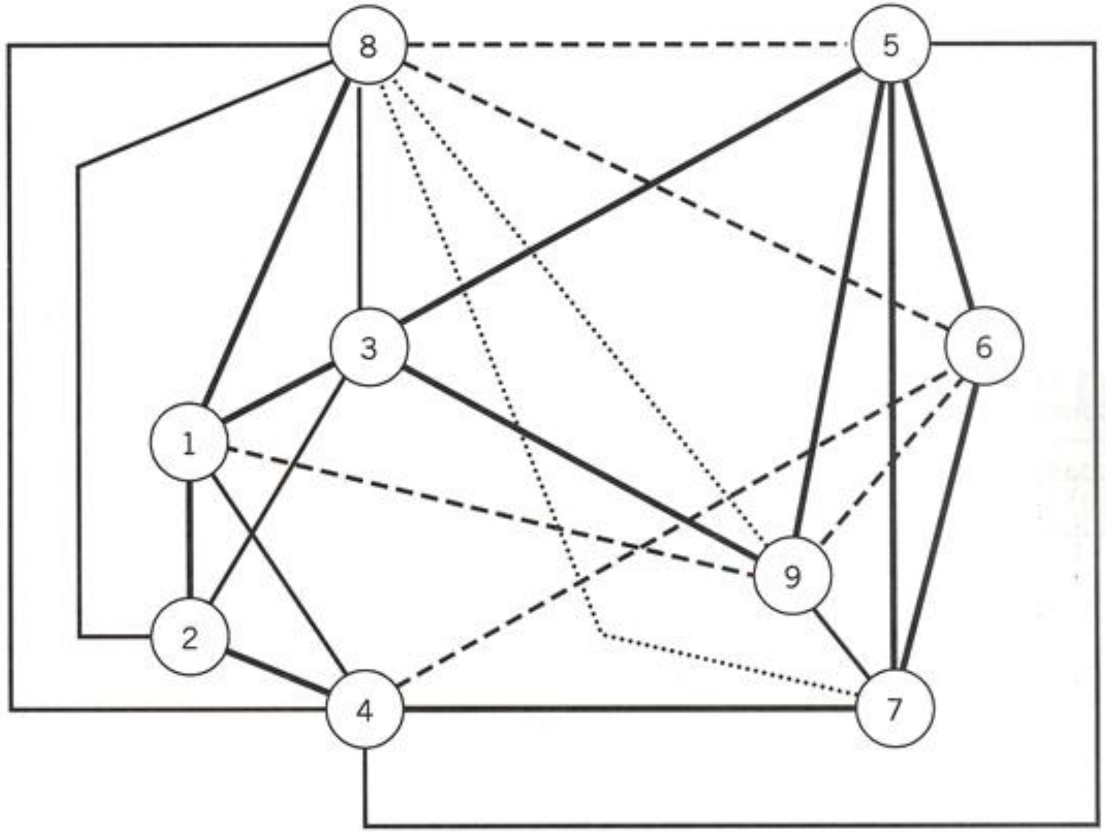



Figure 6.5 Relationship diagram.

# Example

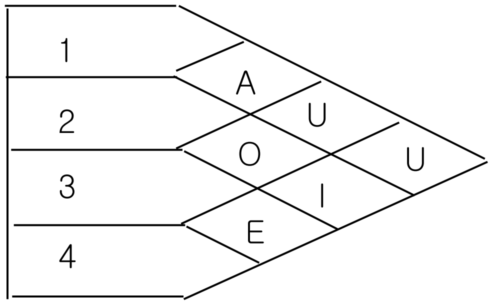
- A factory has four planning departments (1,2,3,4). Product A is manufactured according to the sequence 1–2–3–4 and product B according to the sequence 3–4–2–1–2. The daily production volumes of products A and B are 10 and 20 parts, respectively. Both products A and B have similar sizes, shapes and material handling requirements
- 2)Develop a relationship chart following these rules: “A” for any two departments with a total number of trips (including both directions) equal to 40 or more; “E” for 30 or more but less than 40; “I” for 20 or more but less than 30; “O” for 10 or more but less than 20; “U” for less than 10.
- 3)Construct a relationship diagram.

# Example

2)

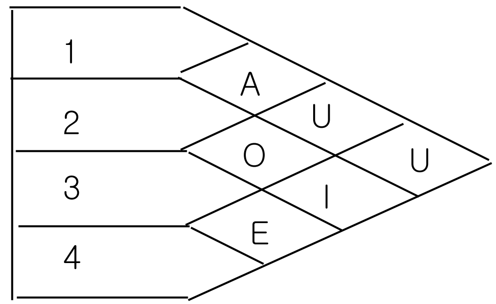
| From-to | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | – | 30 | – | – |
| 2 | 20 | – | 10 | – |
| 3 | – | – | – | 30 |
| 4 | – | 20 | – | – |

| trips | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | – | 50 | – | – |
| 2 | | – | 10 | 20 |
| 3 | | | – | 30 |
| 4 | | | | – |

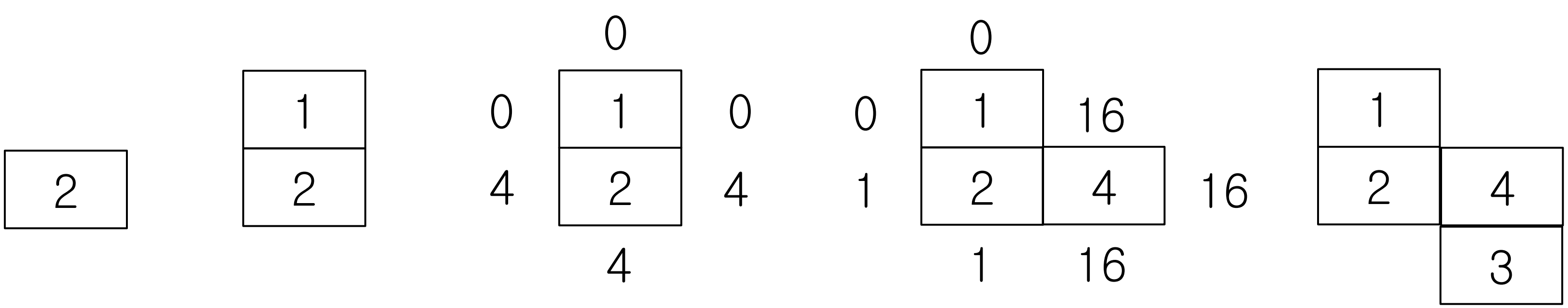


# Example

3)

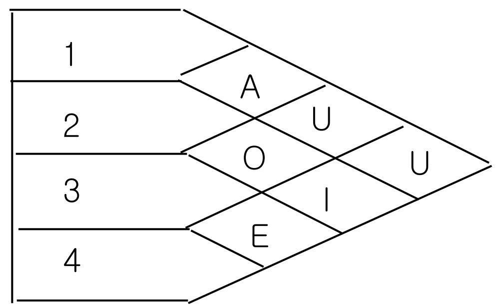


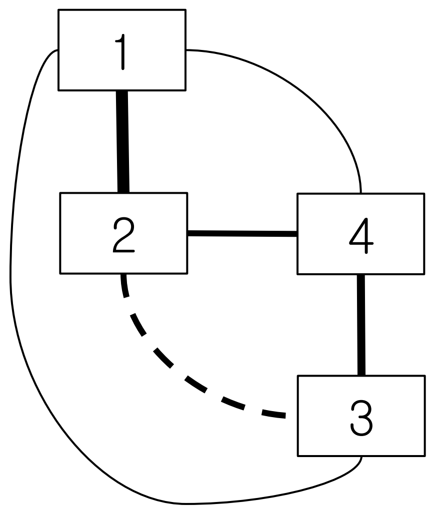

TC1=64+0+0=64, TC2=64+1+4=69, TC3=0+1+16=17, TC4=0+4+16=20



# Example

3)



# Space requirement and space availability

- Estimation of space requirement:
  - Estimation by the space requirement per unit of resource
  - Estimation by the rough sketches of workplaces
  - Estimation by the scaling up and down of similar existing layout
  - Estimation by the square feet per unit produced
- Space availability
  - Space availability is limited by the existing facility and the financial limitation.

# Space relationship diagram

- Relationship diagram assumes that all departments are of equal size
- Space relationship diagram replaces the equal sized templates with templates proportional in size to departmental space requirements

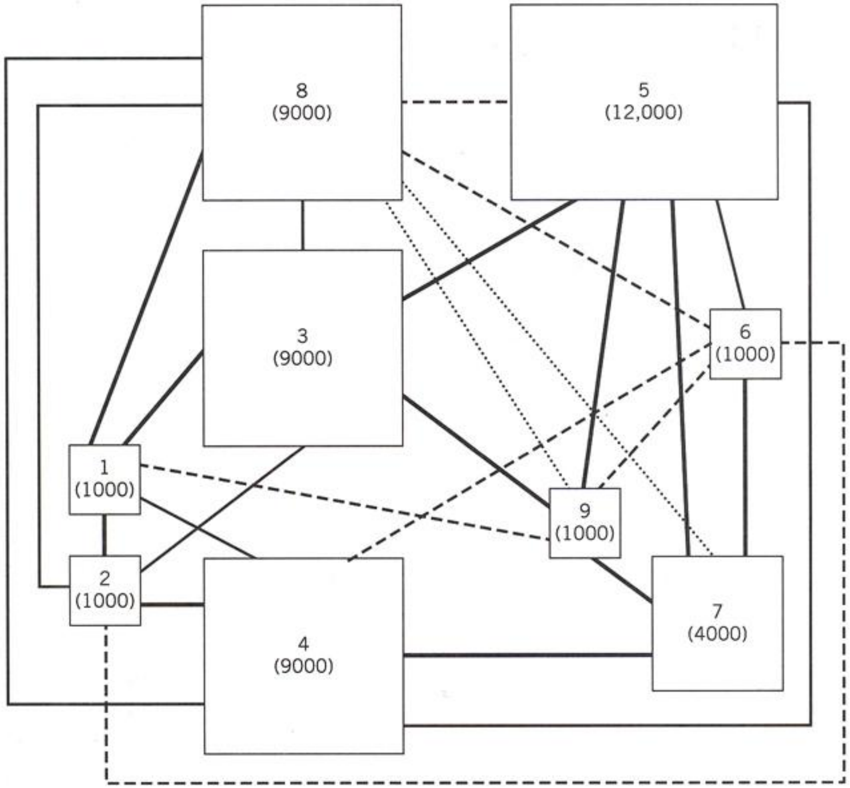



Figure 6.6 Space relationship diagram.

# Space relationship diagram

- Departmental switching to improve the layout is not simple for relationship diagram.
- Block layouts: Individual departments are represented as a grid by a number of grid squares proportional to departmental space needs.

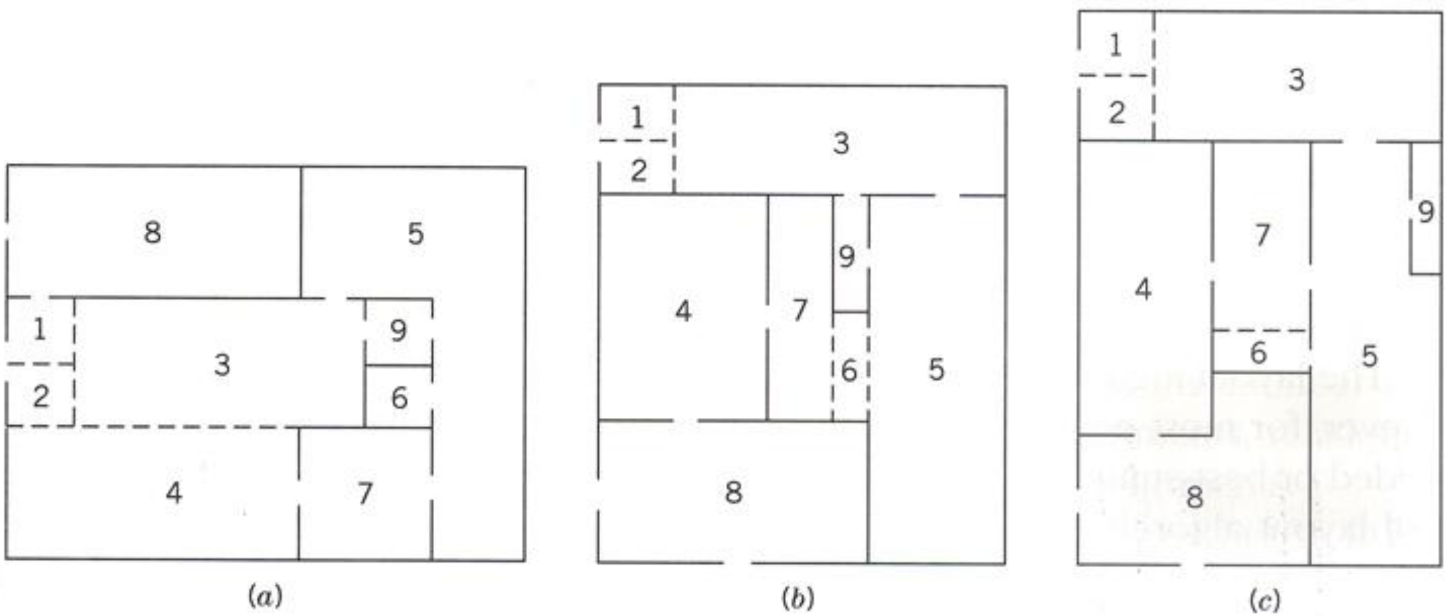



Figure 6.7 Alternative block layouts.

# Net layout

- Once the basic block plan is formulated, detail flow patterns (aisle and departmental P/D point) must be established

$l_{xi}, u_{xi}$ : lower and upper bounds on x-axis length of department i

$l_{yi}, u_{yi}$ : lower and upper bounds on y-axis length of department i

$P_{li}, P_{ui}$ : lower and upper bounds of perimeter of department i

$X_i, Y_i$ :P/D point for department i(decision variable)

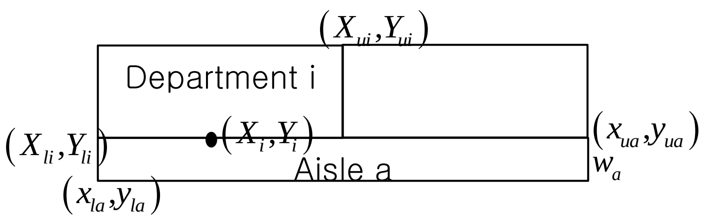
$X_{li}, Y_{li}$ :lower left corner of department i(decision variable)

$X_{ui}, Y_{ui}$:upper right corner of department i(decision variable)

$x_{la}, y_{la}$ :lower left corner of aisle segment a(decision variable)

$x_{ua}, y_{ua}$:upper right corner of aisle segment a(decision variable)

$w_a$ :required width for aisle segment a



# Net layout

$$\text{minimie} \sum_{i=1}^{M-1} \sum_{j>i} w_{ij} \left( X_{ij}^{+} + X_{ij}^{-} + Y_{ij}^{+} + Y_{ij}^{-} \right)$$

$$st$$

$$X_i - X_j = X_{ij}^{+} - X_{ij}^{-}, \forall i, j$$

$$Y_i - Y_j = Y_{ij}^{+} - Y_{ij}^{-}, \forall i, j$$

$$l_{xi} \le X_{ui} - X_{li} \le u_{xi}, \forall i$$

$$l_{yi} \le Y_{ui} - Y_{li} \le u_{yi}, \forall i$$

$$P_{li} \le 2\left( X_{ui} - X_{li} + Y_{ui} - Y_{li} \right) \le P_{ui}, \forall i$$

$$X_{li} \le X_i \le X_{ui}, \forall i$$

$$Y_{li} \le Y_i \le Y_{ui}, \forall i$$

$$x_{ua} \ge x_{la}, \forall a$$

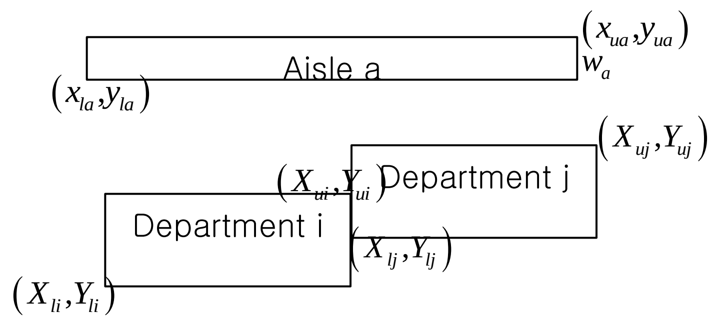
$$y_{ua} \ge y_{la}, \forall a$$

$$y_{ua} - y_{la} = w_a, \forall \text{horizontal aisle a}$$

$$x_{ua} - x_{la} = w_a, \forall \text{vertical aisle a}$$

$$Y_{ui} \le Y_{lj}, \forall \text{vertical adjacency between i and j}$$

$$X_{ui} \le X_{lj}, \forall \text{horizontal adjacency between i and j}$$



# Modifying considerations and practical limitation, Develop layout alternatives, Evaluation

- Modifying considerations and practical limitation
  - Consideration of site-specific and operations-specific conditions may require adjustment to the layout.
  - Example) The location of external transportation system may restrict the location of shipping and receiving. The load-bearing capacity of floor. The limitation on access to utilities.
- Develop layout alternatives
- Evaluation
  - At this point several reasonable alternatives exist.
  - A list of advantages and disadvantages of each layout can be made.
  - A rating should be assigned for each qualitative factor (flexibility, maintainability, expandability, safety, operational ease) for each layout alternative.

# Algorithmic approaches

Layout algorithms

- Distance based objective: from to chart is needed.

$$\min z = \sum_{i=1}^{m} \sum_{j=1}^{m} w_{ij} d_{ij}$$

- Adjacency based objective: relationship chart is needed

Let $x_{ij}$ be 1 if department i and j are adjacent and 0 otherwise.

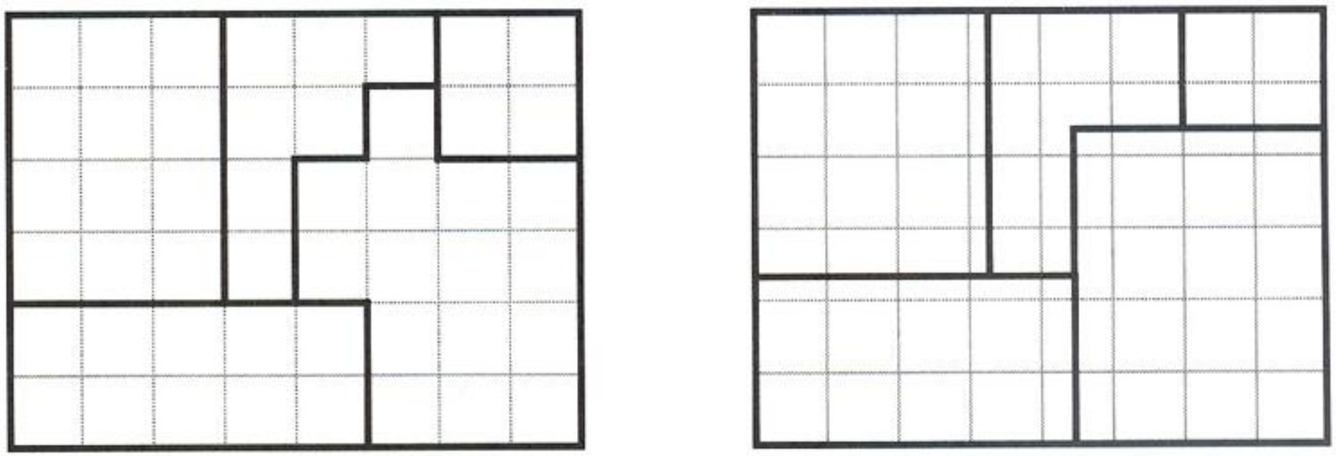
$f_{ij}$ denote the relationship values in this case.

$$\max z = \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} x_{ij}$$

# Algorithmic approaches

- Layout algorithms
  - Discrete layout algorithm
    - The area of each department is rounded off to the nearest integer number of grids.
    - A smaller grid size yields a finer resolution which allows more flexibility in department shapes. However this will increase computational burden.
  - Continuous layout algorithm
    - It is more flexible than discrete algorithm.
    - It is difficult to implement on a computer.
    - Present computerized layout algorithm that use the continuous representation are restricted to rectangular building and rectangular department shapes.

# Algorithmic approaches



(a) (b)

**Figure 6.8** Discrete versus continuous layout representation. (*Adapted from* [16])

# Algorithmic approaches

- Department shapes
  - Unsplit department
    - Two grids are adjacent only if they share a border of positive length.
    - A dot can move only from one grid to an adjacent grid.
    - We say that department i is not split if a dot can start at any grid assigned to department i and travel to any other grid assigned to department without visiting any grid that has not been assigned to department i.

# Algorithmic approaches

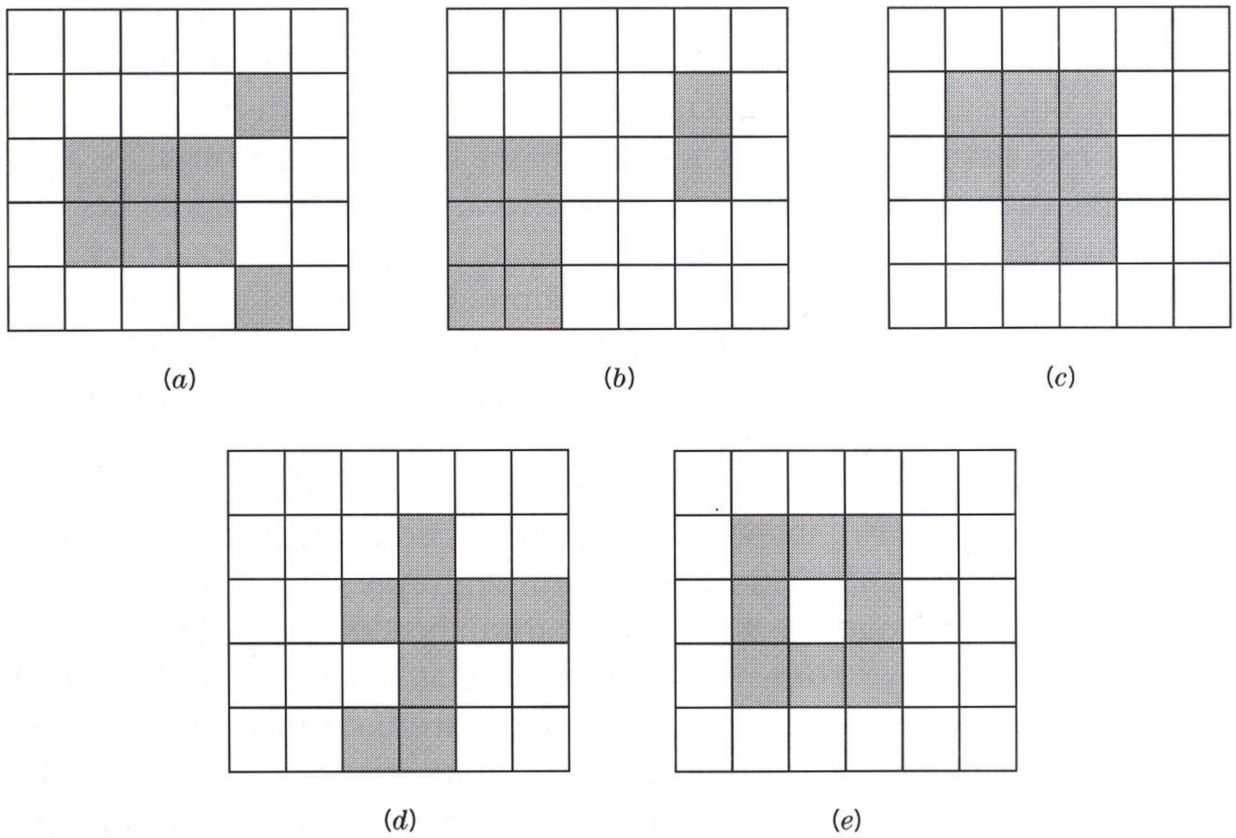



**Figure 6.9** Examples of split and unsplit departments.

# Algorithmic approaches

- Layout algorithms
  - Improvement algorithm
    - It starts with an initial layout and seek to improve the objective function through incremental changes in the layout.
  - Construction algorithm
    - It develops a layout from scratch.
    - Building dimensions may be given or may not.

# Pairwise exchange method

- Characteristics and assumptions
  - Improvement layout algorithm
  - Adequate for distance based objective
  - Assume equal-area departments
- Example
  - Initial layout

| | | | |
|---|---|---|---|
| 1 | 2 | 3 | 4 |

  - From-to chart

**Table 6.2** *Material Flow Matrix*

| From Department \ To Department | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | — | 10 | 15 | 20 |
| 2 | | — | 10 | 5 |
| 3 | | | — | 5 |
| 4 | | | | — |

  - Distance

**Table 6.3** *Distance Matrix Based on Existing Layout*

| From Department \ To Department | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | — | 1 | 2 | 3 |
| 2 | | — | 1 | 2 |
| 3 | | | — | 1 |
| 4 | | | | — |

  - $TC_{1234}=10(1)+15(2)+20(3)+10(1)+5(2)+5(1)=125$

# Pairwise exchange method

- Iteration 1
  - $TC_{2134}(1-2) = 10(1)+15(1)+20(2)+10(2)+5(3)+5(1)=105$
  - $TC_{3214}(1-3) = 10(1)+15(2)+20(1)+10(1)+5(2)+5(3)=95$
  - $TC_{4231}(1-4) = 10(2)+15(1)+20(3)+10(1)+5(1)+5(2)=120$
  - $TC_{1324}(2-3) = 10(2)+15(1)+20(3)+10(1)+5(1)+5(2)=120$
  - $TC_{1432}(2-4) = 10(3)+15(2)+20(1)+10(1)+5(2)+5(1)=105$
  - $TC_{1243}(3-4) = 10(1)+15(3)+20(2)+10(2)+5(1)+5(1)=125$
  - Select the pair 1–3 and perform the exchange in the layout

| | | | |
|---|---|---|---|
| 3 | 2 | 1 | 4 |

- Iteration 2
  - $TC_{2314}(2-3) = 10(2)+15(1)+20(1)+10(1)+5(3)+5(2)=90$

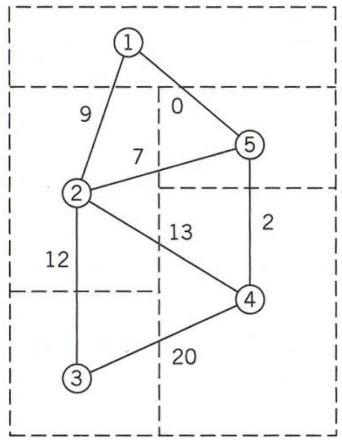
| | | | |
|---|---|---|---|
| 2 | 3 | 1 | 4 |

- Iteration 3: the lowest total cost is worse than 90. Stop

# Graph-based procedure

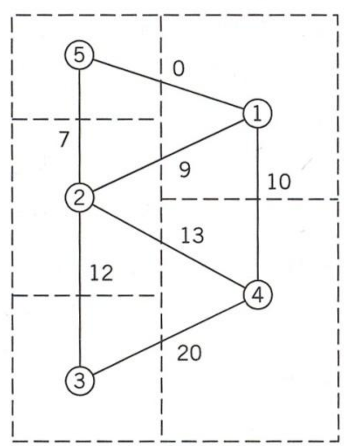
- Characteristics and assumptions
  - Construction algorithm
  - Adjacency-based objective
  - Dimensional specifications of departments are not considered.
  - The arcs do not intersect: this property of graphs is called planarity. We note that the graph obtained from the relationship diagram is usually a nonplanar graph.

# Graph-based procedure




| Arc | Weight |
|---|---|
| 1-2 | 9 |
| 1-5 | 0 |
| 2-3 | 12 |
| 2-4 | 13 |
| 2-5 | 7 |
| 3-4 | 20 |
| 4-5 | 2 |
| | 63 (total) |

(*a*)

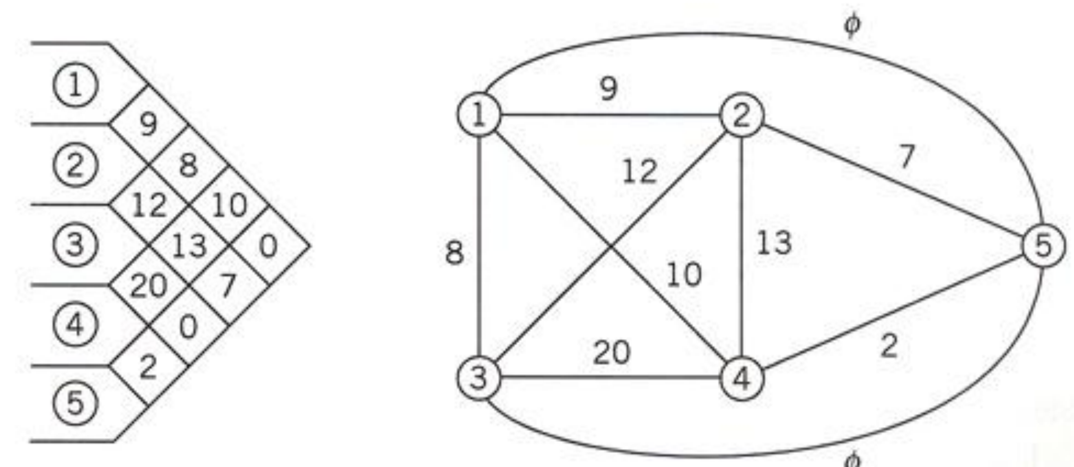



| Arc | Weight |
|---|---|
| 1-5 | 0 |
| 2-5 | 7 |
| 1-2 | 9 |
| 1-4 | 10 |
| 2-4 | 13 |
| 2-3 | 12 |
| 3-4 | 20 |
| | 71 (total) |

(*b*)

**Figure 6.11** Adjacency graphs for alternative block layouts.

# Graph-based procedure




(*a*) Relationship Chart (*b*) Relationship Diagram

**Figure 6.12** Relationship chart and relationship diagram for graph-based example.

# Graph-based procedure

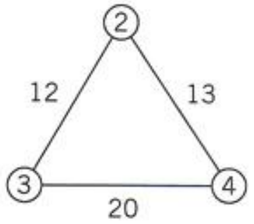
- Procedure
  - Step 1: From the relationship chart, select the department pair with the largest weight. Ties are broken arbitrarily.
  - Step 2: Select the third department to enter. The third department is selected based on the sum of the weights with respect to departments selected in step 1.
  - Step 3: Pick the fourth department to enter by evaluating the sum of adding one of the unassigned departments on a face of the graph. A face of a graph is a bounded region of a graph. The step will form a tetrahedron.
  - Step 4: Pick the fifth department considering all the faces of the graph and a external face. The external face is the outside region of the graph. Repeat step 4 until all departments are assigned.
  - Step 5: Construct a corresponding block layout.

# Graph-based procedure

a. Step 2

| | 3 | 4 | Total |
|---|---|---|---|
| 1 | 8 | 10 | 18 |
| 2 | 12 | 13 | 25 (best) |
| 5 | 0 | 2 | 2 |

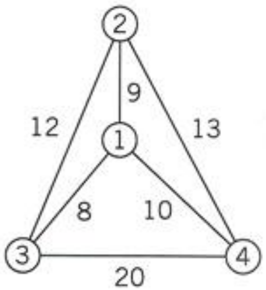
→




b. Step 3

| | 2 | 3 | 4 | Total |
|---|---|---|---|---|
| 1 | 9 | 8 | 10 | 27 (best) |
| 5 | 7 | 0 | 9 | 9 |

→




c. Step 4

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 5 | 0 | 7 | 0 | 2 |

| Faces | Total |
|---|---|
| 1-2-3 | 7 |
| 1-2-4 | 9 (best) |
| 1-3-4 | 2 |
| 2-3-4 | 9 (best) |

→

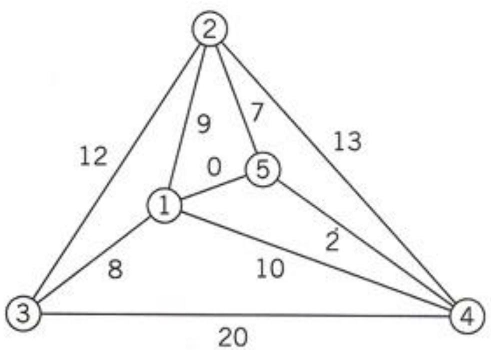
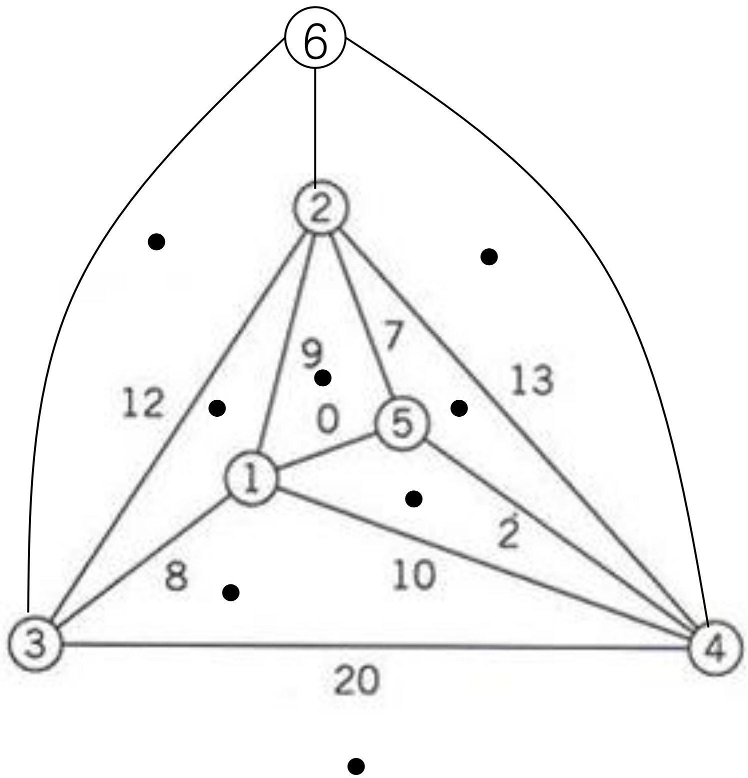



**Figure 6.13** Steps in graph-based procedure.

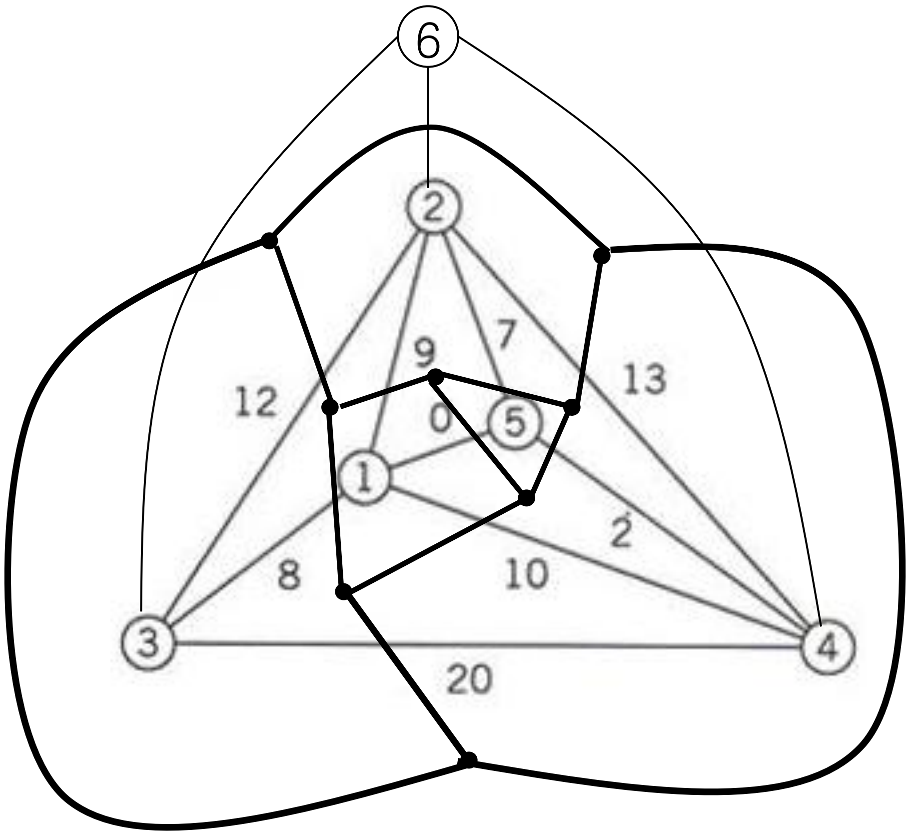
# Graph-based procedure

- Construction of a block plan
  - Step1:Add a node corresponding to the external boundary (i.e. external node) of the final graph and connect it to boundary nodes of graph.
  - Step2:Place a dot in the middle of each face in the graph and connect the dots to enclose all the nodes except the external node.

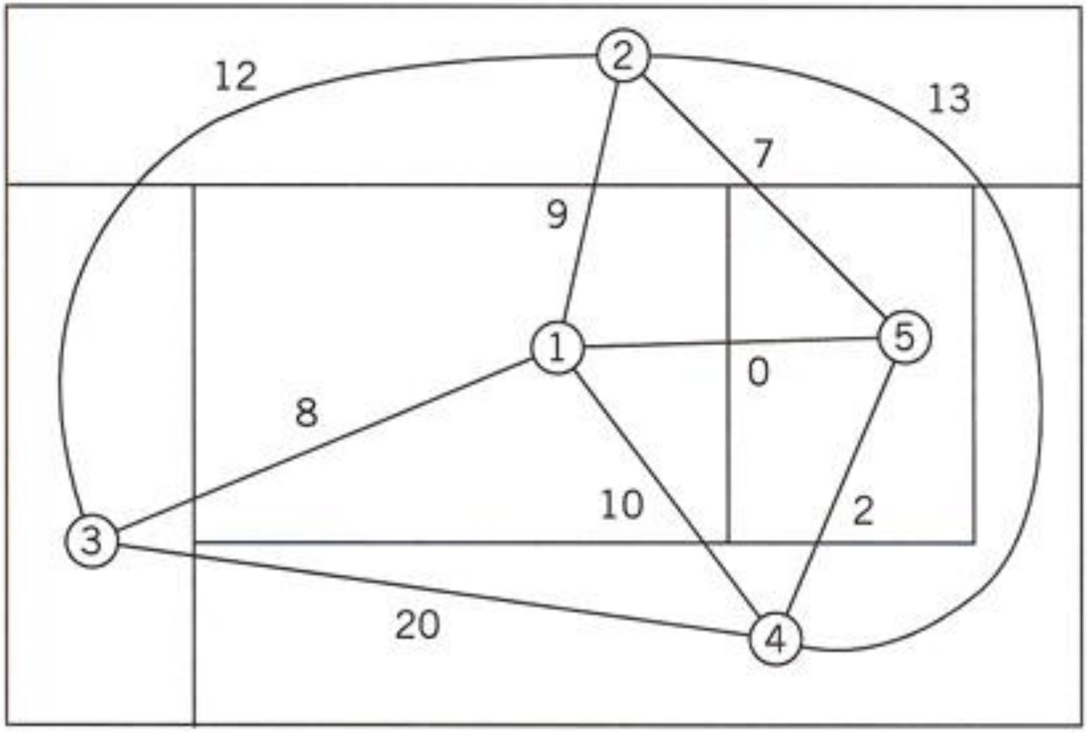
# Graph-based procedure



# Graph-based procedure



# Graph-based procedure




| Arc | Weight |
|---|---|
| 1-2 | 9 |
| 1-3 | 8 |
| 1-4 | 10 |
| 1-5 | 0 |
| 2-3 | 12 |
| 2-4 | 13 |
| 2-5 | 7 |
| 3-4 | 20 |
| 4-5 | 2 |
| | 81 (total) |

**Figure 6.14** Block layout from the final adjacency graph.