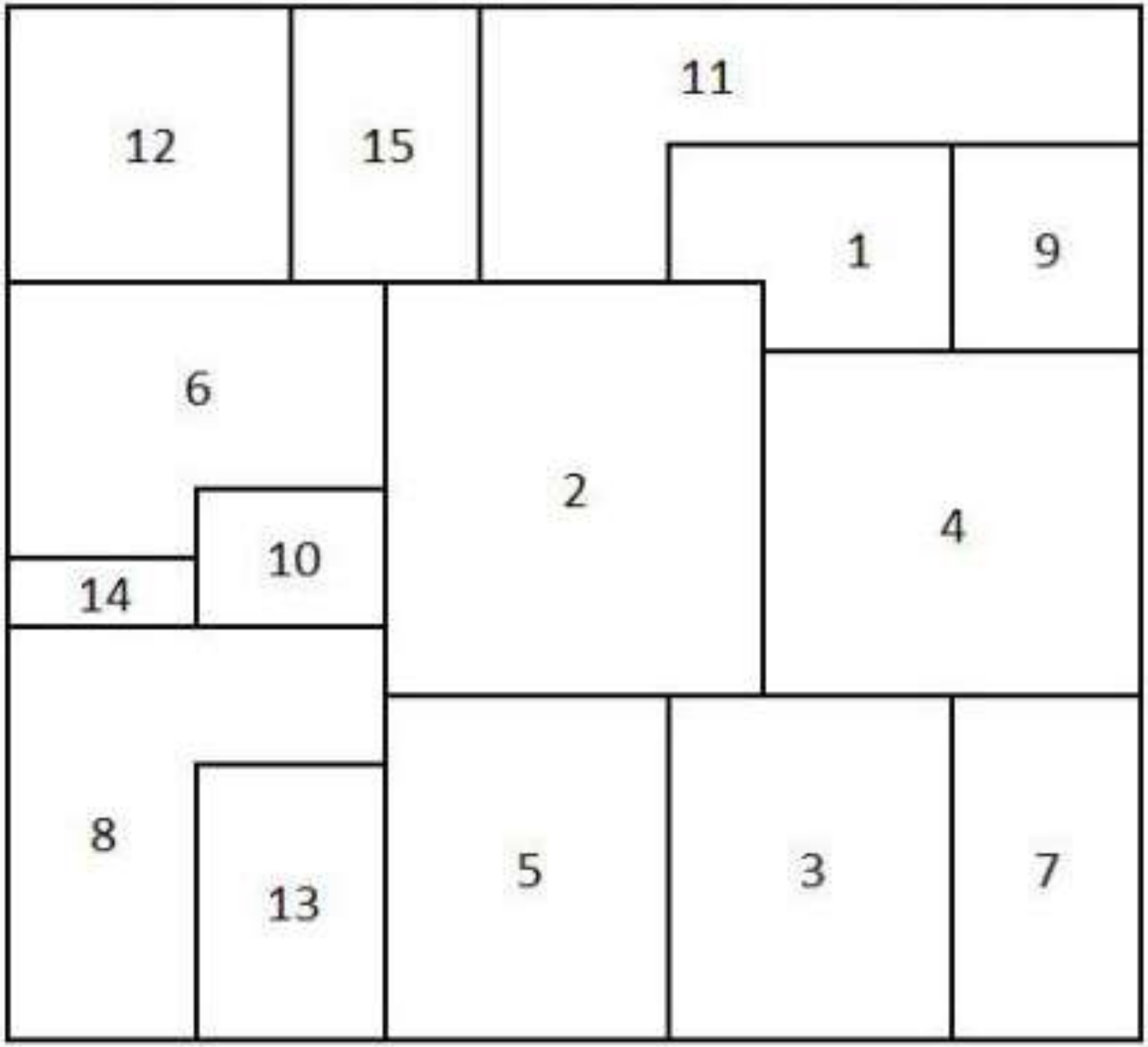
Chapter 6

Layout Planning Models and Design Algorithms

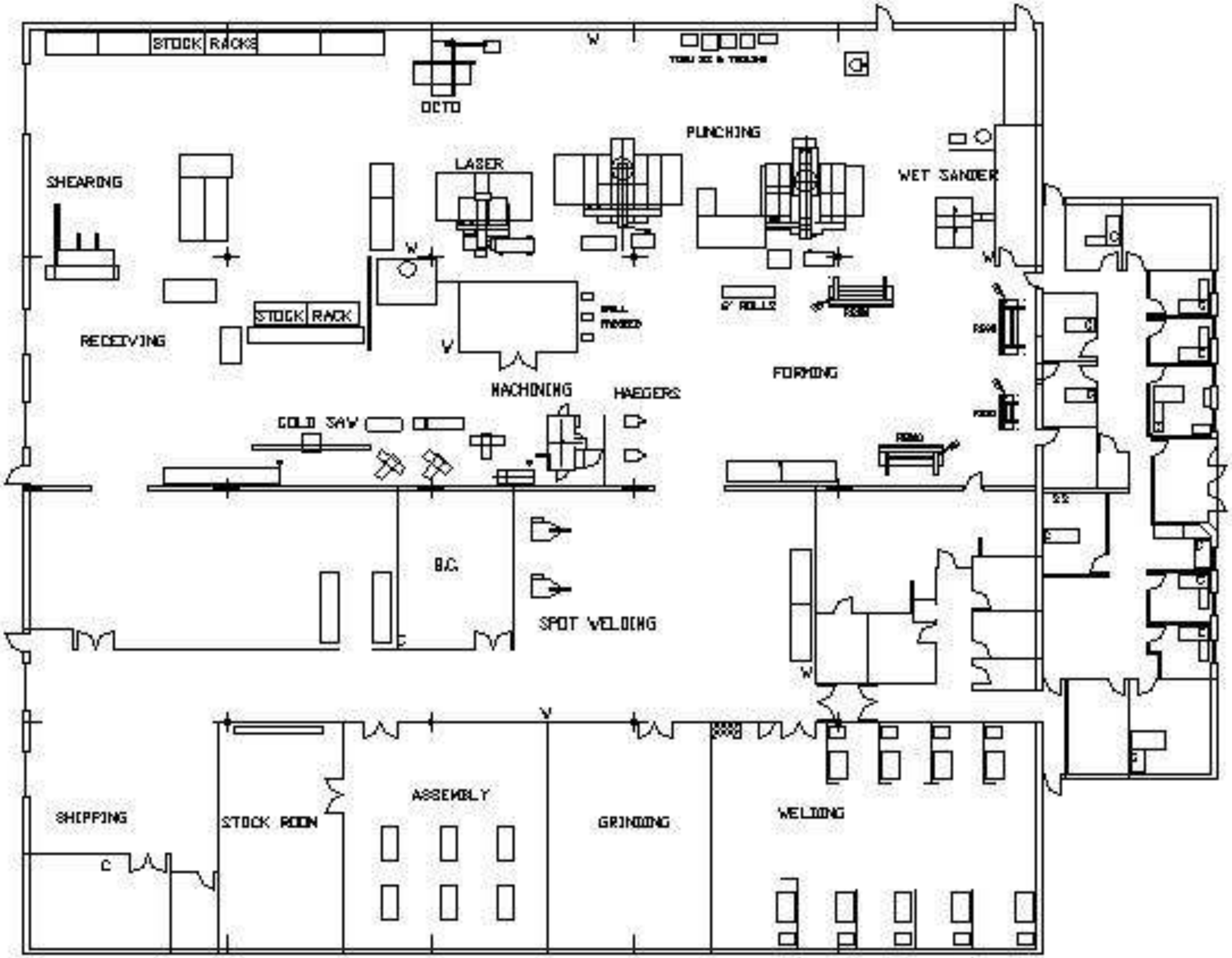
Basic layout types

- Layout: will serve to establish the physical relationship between activities.
- Types of layout designs:
  - **Block layout**
    - Shows relative locations and sizes of the departments
  - **Detailed layout**
    - Show the exact locations of all the equipment, workstations, storage within the departments

The final layout plan is the end result of Facilities Design.



Block Layout

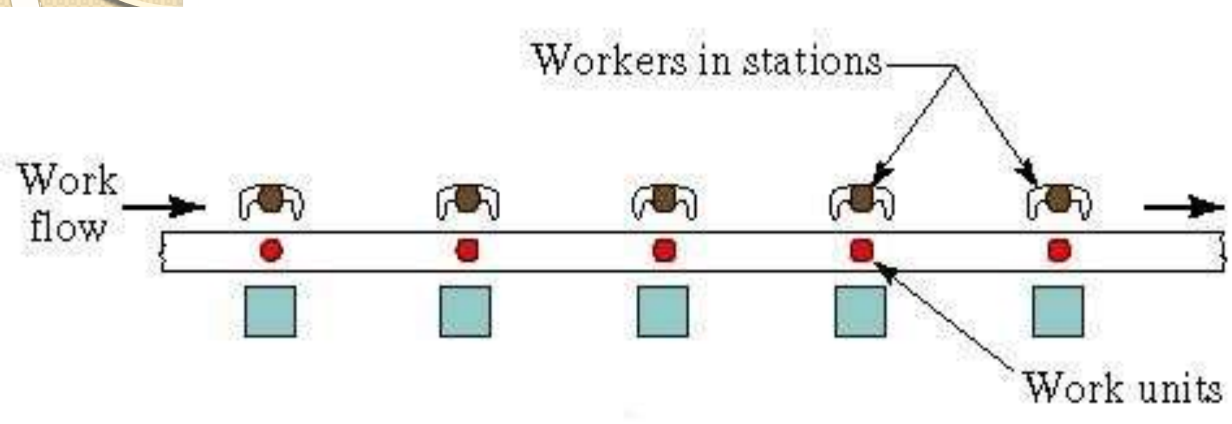


Detailed Layout

Types of Layout

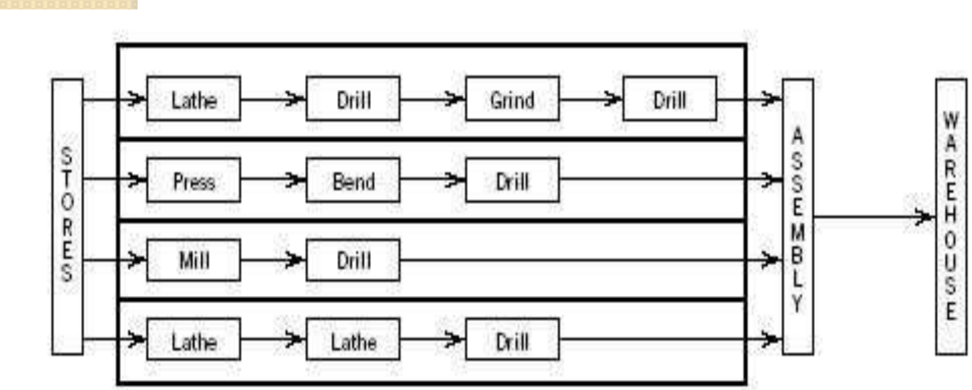
1. Product layout
2. GT based (or Product Family) layout
3. Process layout
4. Fixed product layout
5. Hybrid layout

Product Layout



Product:

- Standardized
- Large stable demand



Layout:

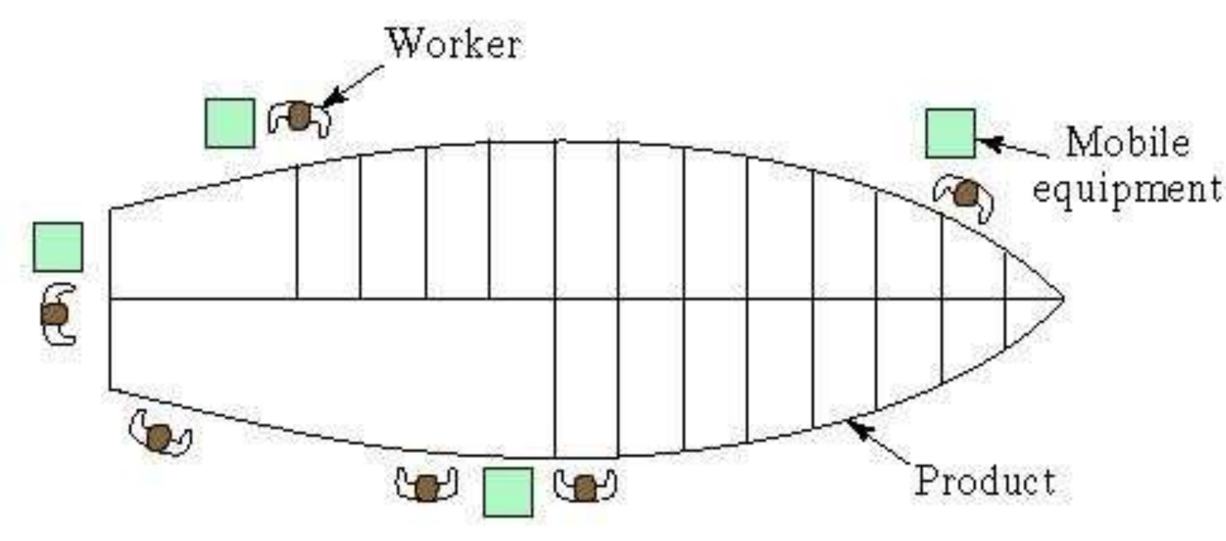
- Combines all workstations required to produce the product

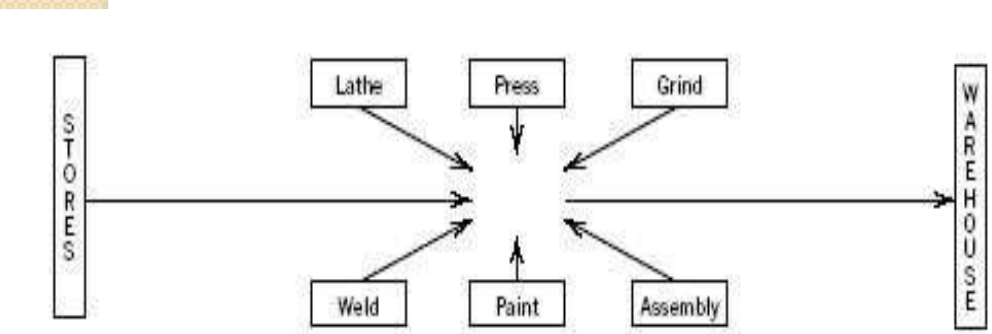
Product Layout

The product flows through an assembly line while the personnel and equipment movements are limited

- Advantages
  - Smooth, simple, logical and direct flow
  - High Production Rate
  - Low cost per unit cost
  - High machine/worfkforce utilization
  - Lower material handling costs
  - Less personnel skill is required
  - Lower Work-In-Process Inventory (WIP)
- Disadvantages
  - High machine utilization is risky
  - Process performance depends on the bottleneck operation
  - May not be flexible enough for product design, volume changes
  - Decreased employee motivation
  - Huge investment is required

Fixed Product Layout





Product:

- Physically large
- Awkward to move
- Low sporadic demand

Layout:

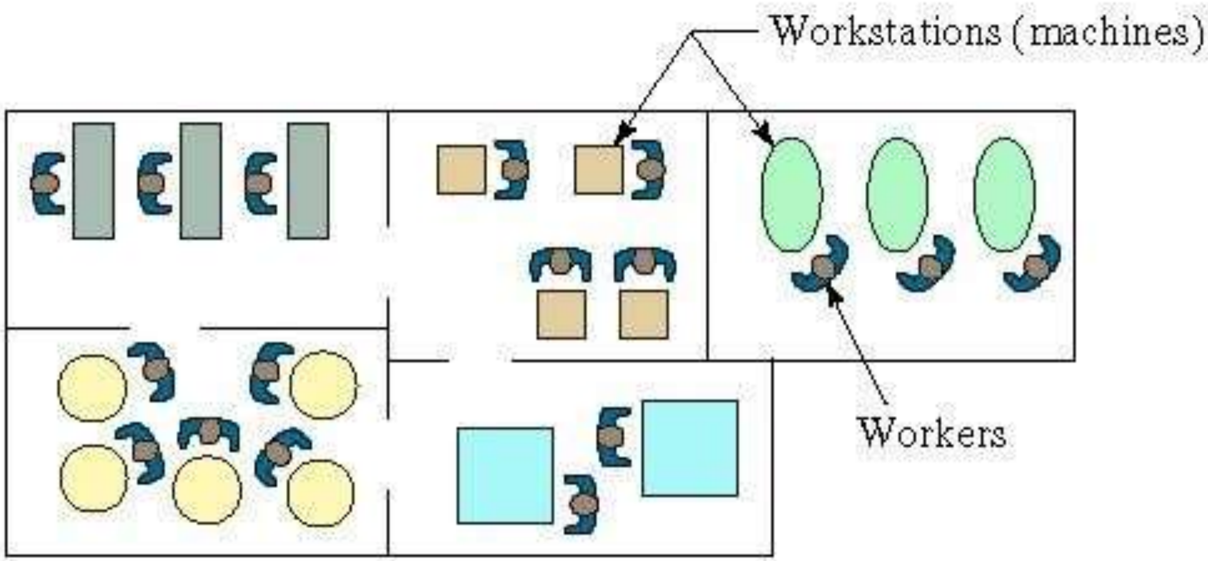
- Combines all workstations required to produce the product with the area required for staging the product

Fixed Product Layout

Production is executed at a fixed location; materials, equipment, and personnel flow into this location.

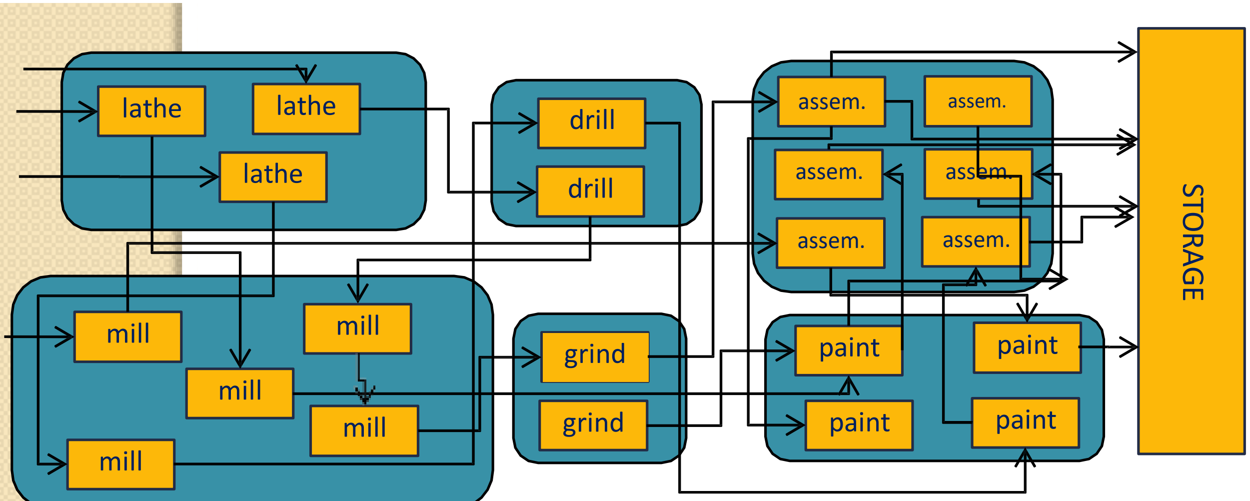
- Advantages
  - Material movement is reduced
  - An individual can complete the whole process
  - Job enrichment opportunities
  - Highly flexible; can accommodate any changes in design
- Disadvantages
  - Personal and equipment movement is increased
  - Risk of duplication of equipment
  - Requires greater worker skills
  - Not suitable for high production volumes
  - Close control and coordination in scheduling

Process Layout



Product:

- Great variety



Layout:

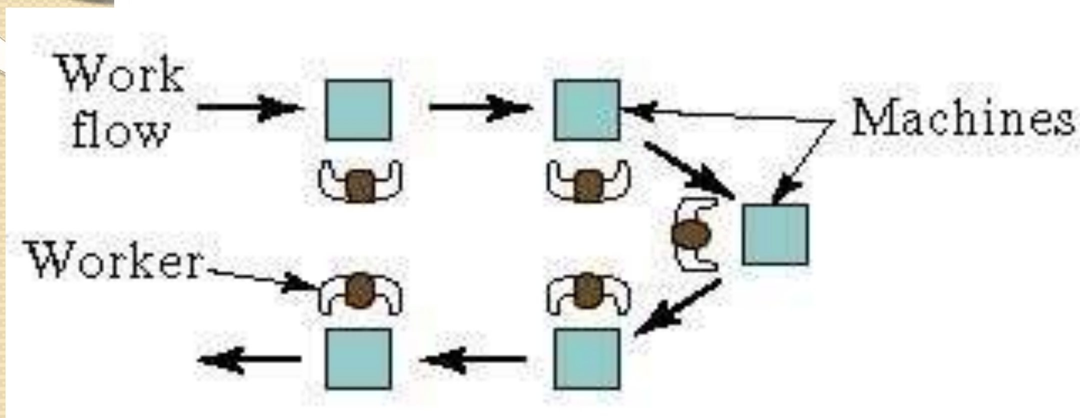
- Combines identical workstations into departments
- Combines similar departments

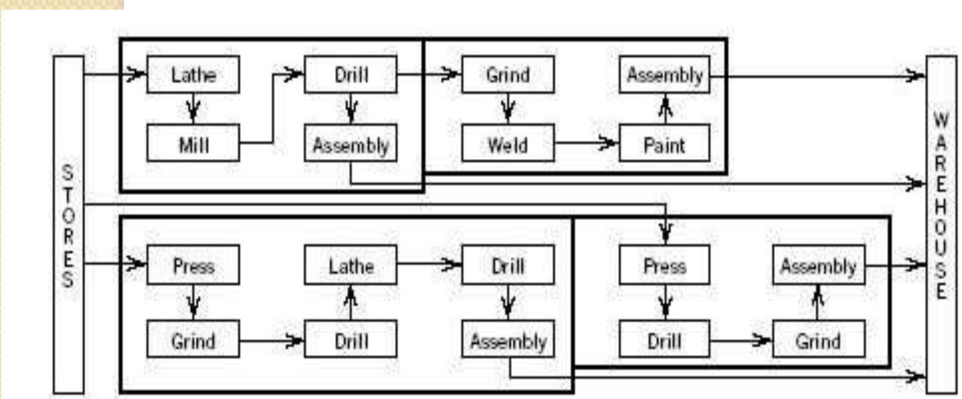
Process Layout

Similar/Same processes are grouped together.

- Advantages
  - Increased machine utilization
  - Flexible in allocating personnel and equipment
  - Robust against machine breakdowns
  - Robust against design, volume changes
  - Specialized supervision is possible
- Disadvantages
  - Material handling requirements are increased
  - Increased WIP
  - Longer production lines
  - Difficult to schedule the jobs
  - Higher skills are required
  - Difficult to analyze the process performance

Product Family - Group Layout





Product:

- Capable of being grouped into families of similar parts

Layout:

- Combine all workstations required to produce the family of products

Product Family - Group Layout

Product Family Layouts are like a combination of Product Layouts and Process Layouts

- Advantages
  - Combines benefits of product and process layouts
  - Higher machine utilization
  - Smoother flow lines and shorter distance
  - Team atmosphere
- Disadvantages
  - General supervision required
  - Greater labor skills requirement
  - Balancing manufacturing cells are difficult and unbalanced cells may increase WIP

Product Family - Group Layout

Product Family Layouts are like a combination of Product Layouts and Process Layouts

- Advantages
  - Combines benefits of product and process layouts
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  - Team atmosphere
- Disadvantages
  - General supervision required
  - Greater labor skills requirement
  - Balancing manufacturing cells are difficult and unbalanced cells may increase WIP

Layout Procedures

Two different categories:

1. Construction type: involves developing a new layout "from scratch". General questions:
   a) How to construct the layout? In what sequence will we consider the departments, i.e. which department do we place in first, which second, etc.?
   b) How do we place the departments into the layout? Where do we put them?
   c) How do we "score" the layout?

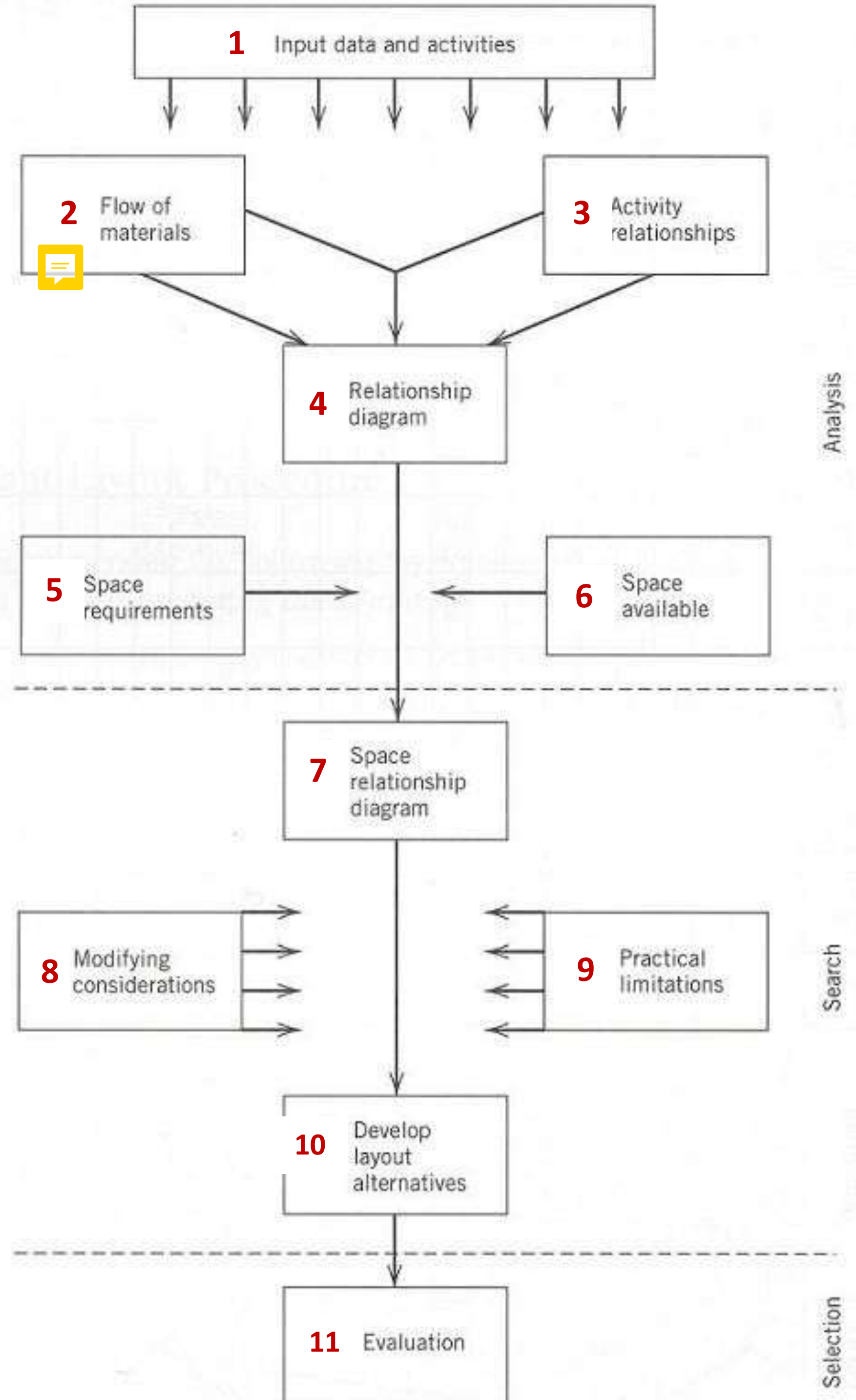
2. Improvement type: generate layout alternatives based on an existing layout. General questions:
   a) How to rearrange the departments? How to measure improvement? How do we "score" the layout?

Layout Techniques

1. Manual: Examples:
    1. Apple's method (read the description in the text book)
    2. Reed's method (read the description in the text book)
    3. Systematic Layout Planning (SLP)
    4. Graph based method

2. Computerized: Examples:
    1. CRAFT
    2. BLOCPLAN
    3. MIP
    4. LOGIC
    5. MULTIPLE

Systematic layout planning procedure (SLP)



1. Input data and activities

- Bill of materials
- Operation process chart

BILL OF MATERIALS

Company T. W., Inc. Prepared by J. A.
Product Air Flow Regulator Date

Level	Part No.	Part Name	Drwg. No.	Quant./ Unit	Make or Buy	Comm
0	0021	Air flow regulator	0999	1	Make	
1	1050	Pipe plug	4006	1	Buy	
1	6023	Main assembly	—	1	Make	
2	4250	Lock nut	4007	1	Buy	
2	6022	Body assembly	—	1	Make	
3	2200	Body	1003	1	Make	
3	6021	Plunger assembly	—	1	Make	
4	3250	Seat ring	1005	1	Make	
4	3251	O-ring	—	1	Buy	
4	3252	Plunger	1007	1	Make	
4	3253	Spring	—	1	Buy	
4	3254	Plunger housing	1009	1	Make	
4	3255	O-ring	—	1	Buy	
4	4150	Plunger retainer	1011	1	Make	

Figure 2.8 Bill of materials for an air flow regulator.

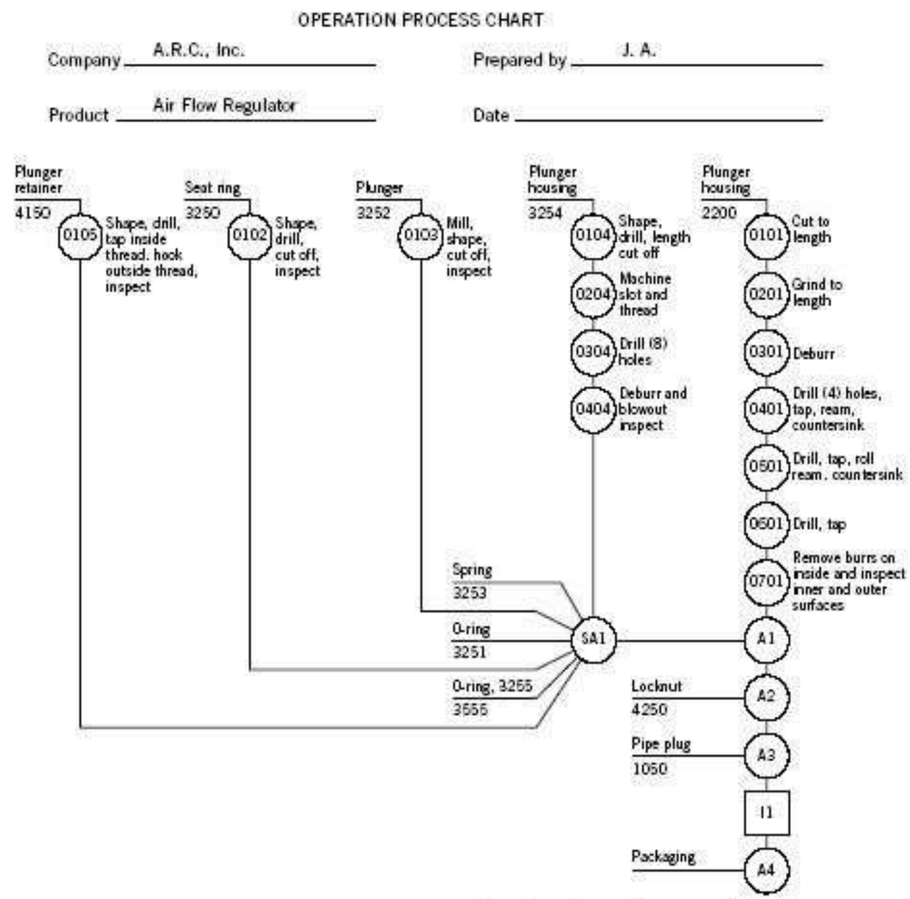
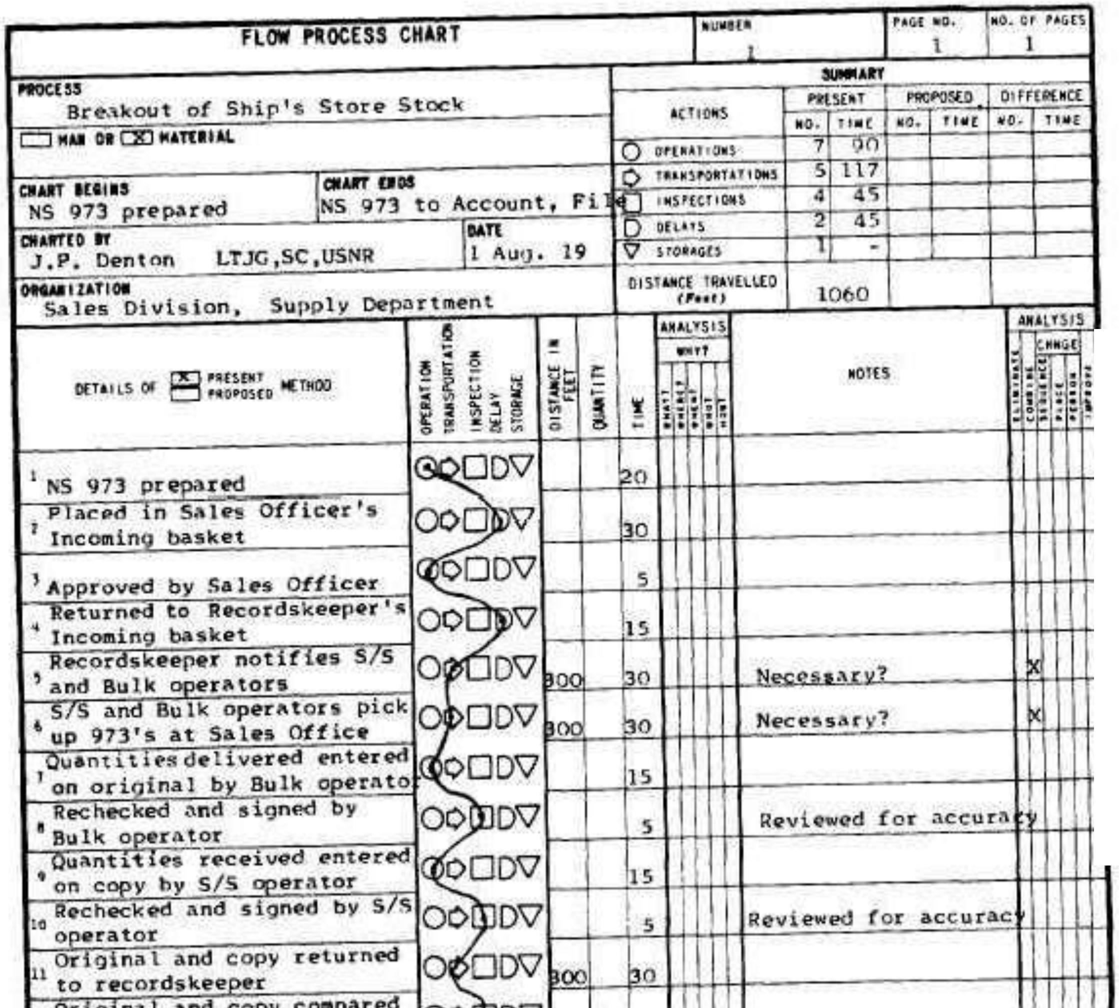


Figure 2.13 Operation process chart for the air flow regulator.

2. Flow of materials

Flow process chart



FLOW PROCESS CHART | NUMBER 1 | PAGE NO. 1 | NO. OF PAGES 1

PROCESS: Breakout of Ship's Store Stock
MAN OR [X] MATERIAL

CHART BEGINS: NS 973 prepared
CHART ENDS: NS 973 to Account, File
CHARTED BY: J.P. Denton LTJG,SC,USNR
DATE: 1 Aug. 19
ORGANIZATION: Sales Division, Supply Department

SUMMARY – ACTIONS	PRESENT NO.	PRESENT TIME	PROPOSED NO.	PROPOSED TIME	DIFFERENCE NO.	DIFFERENCE TIME
OPERATIONS	7	90				
TRANSPORTATIONS	5	117				
INSPECTIONS	4	45				
DELAYS	2	45				
STORAGES	1	-				
DISTANCE TRAVELLED (Feet)	1060					

	DETAILS OF [X] PRESENT / PROPOSED METHOD	DISTANCE IN FEET	TIME	NOTES
1	NS 973 prepared		20	
2	Placed in Sales Officer's Incoming basket		30	
3	Approved by Sales Officer		5	
4	Returned to Recordskeeper's Incoming basket		15	
5	Recordskeeper notifies S/S and Bulk operators	300	30	Necessary?
6	S/S and Bulk operators pick up 973's at Sales Office	300	30	Necessary?
7	Quantities delivered entered on original by Bulk operato		15	
8	Rechecked and signed by Bulk operator		5	Reviewed for accuracy
9	Quantities received entered on copy by S/S operator		15	
10	Rechecked and signed by S/S operator		5	Reviewed for accuracy
11	Original and copy returned to recordskeeper	300	30	
	Original and copy compared			

From-to chart

	Stores	Milling	Turning	Press	Plate	Assembly	Warehouse
Stores	–	24	12	16	1	8	–
Milling	–	–	–	–	14	3	1
Turning	–	3	–	–	8	–	1
Press	–	–	–	–	3	1	1
Plate	–	3	2	–	–	4	3
Assembly	2	–	–	–	–	–	7
Warehouse	–	–	–	–	–	–	–

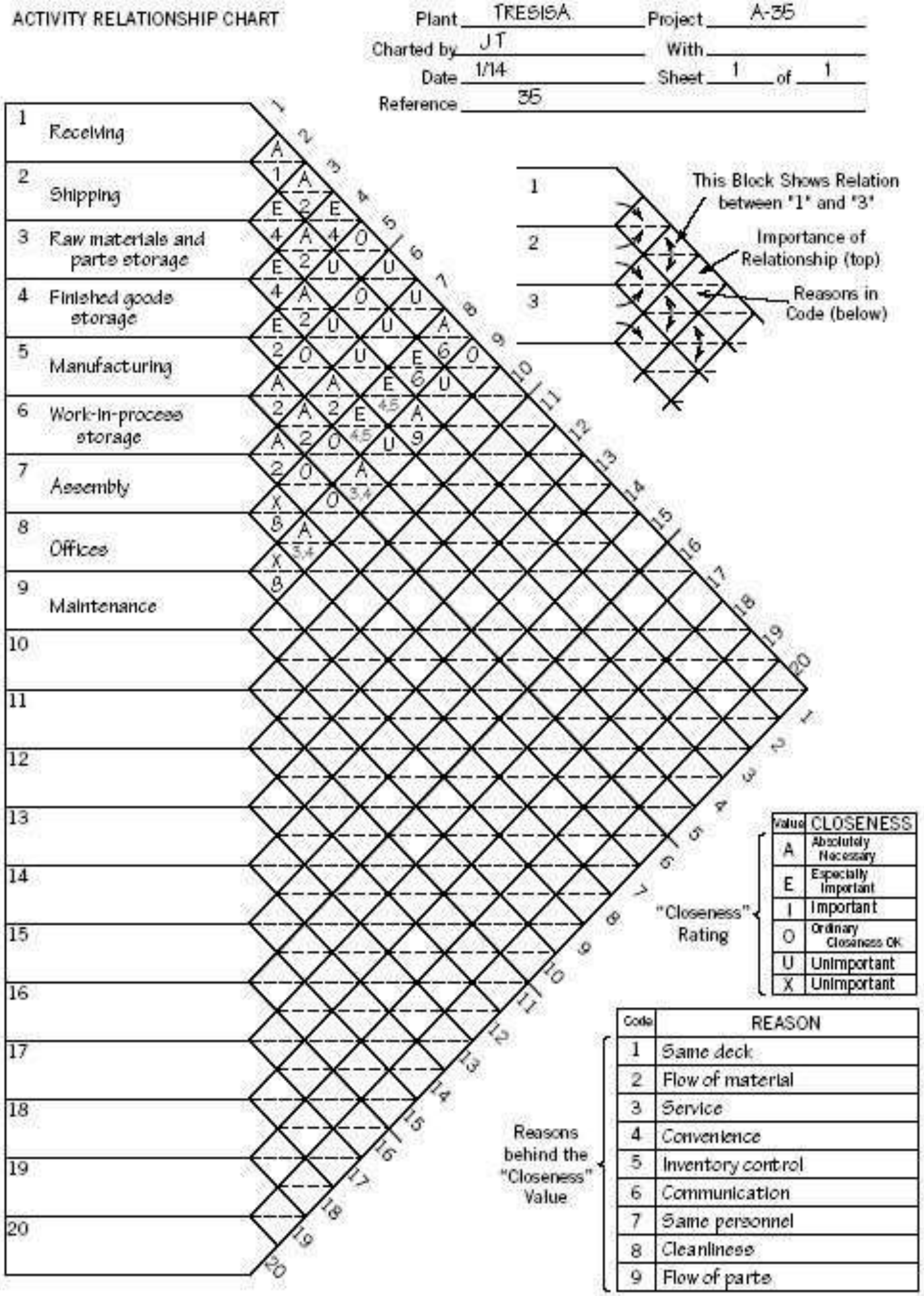


Figure 6.4 Activity relationship chart.

3. Activity relationships

- Relationship Chart measures the flows qualitatively using the **closeness relationships values**

Rating	CLOSENESS VALUES
A	Absolutely Necessary
E	Especially Important
I	Important
O	Ordinary Closeness
U	Unimportant
X	Undesirable

4. Relationship diagram

- The relationship diagram positions activities spatially
  - Proximities reflect the relationship between pairs of activities
  - Usually two dimensional

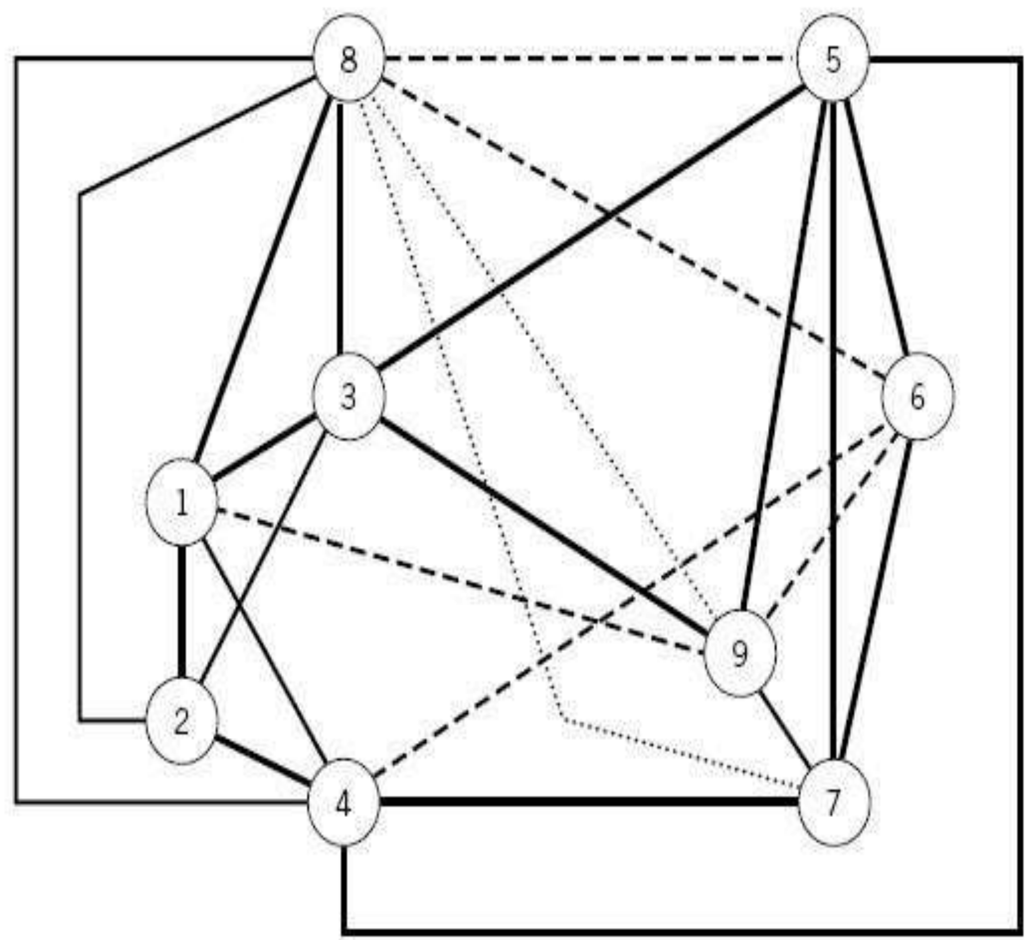


Figure 6.5 Relationship diagram.

5. Space requirements

- Required departmental area

Depart.	Function	Area (ft^2)
D1	Receiving	12,000
D2	Milling	8,000
D3	Press	6,000
D4	Screw machine	12,000
D5	Assembly	8,000
D6	Plating	12,000
D7	Shipping	12,000

7. Space relationship diagram

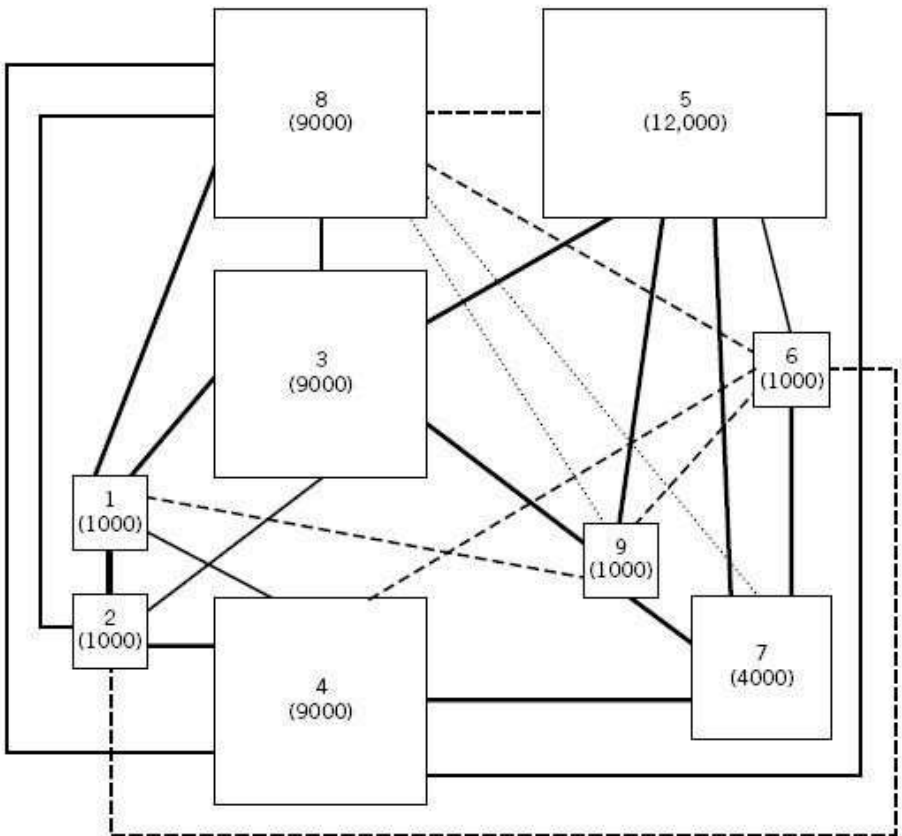
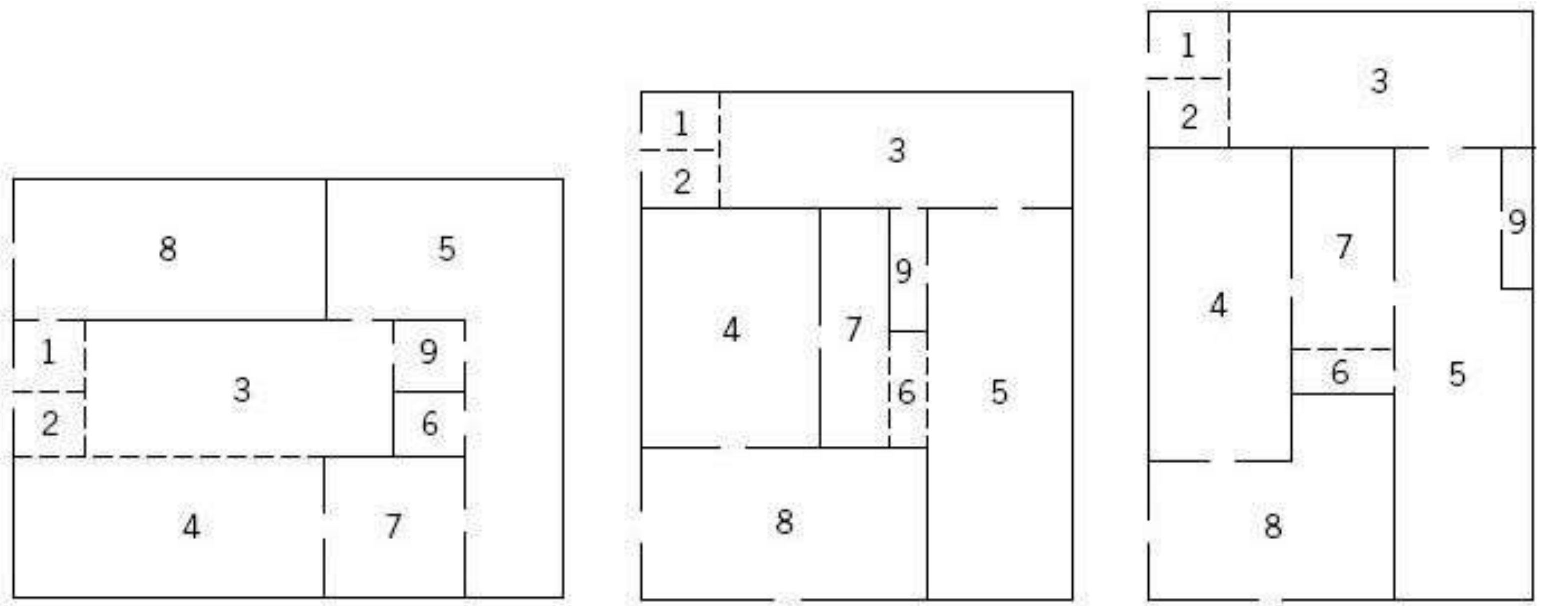


Figure 6.6 Space relationship diagram.

- Space relationship diagram combines space requirements with relationship diagram

10. Layout alternatives



- Conversion of a space relationship diagram into several feasible alternative **block layouts**
  - not a mechanical process
  - importance of intuition, judgment and experience

Pairwise Exchange Method

- Improvement-type layout algorithm.
- Although it can be used with both an adjacency-based and distance-based objective, it is often used with the later.
- Example:

From / To

	1	2	3	4
1	-	10	15	20
2		-	10	5
3			-	5
4				-

Material Flow Matrix

To

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

Distance matrix based on existing layout

Pairwise Exchange Method

- Example (contd.):
- Phase I: Construct Phase. Initial Solution (1,2,3,4)
- Phase II: Improvement – Pair Wise Exchange
  - (a) Exchange two departments
  - (b) If results in better solution, accept; go to (a)
  - otherwise stop

Pairwise Exchange Method

- Example (contd.):

(*a*) Iteration 0

1	2	3	4

(*b*) Iteration 1

3	2	1	4

(*c*) Iteration 2

2	3	1	4

Figure 6.10 Layouts on iteration.

To Department / From Department

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

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

Pairwise Exchange Method

- Example (contd.): Iteration 0

$$TC_{2134}(1\text{-}2) = 10(1) + 15(1) + 20(2) + 10(2) + 5(3) + 5(1) = 105$$

$$TC_{3214}(1\text{-}3) = 10(1) + 15(2) + 20(1) + 10(1) + 5(2) + 5(3) = 95$$

$$TC_{4231}(1\text{-}4) = 10(2) + 15(1) + 20(3) + 10(1) + 5(1) + 5(2) = 120$$

$$TC_{1324}(2\text{-}3) = 10(2) + 15(1) + 20(3) + 10(1) + 5(1) + 5(2) = 120$$

$$TC_{1432}(2\text{-}4) = 10(3) + 15(2) + 20(1) + 10(1) + 5(2) + 5(1) = 105$$

$$TC_{1243}(3\text{-}4) = 10(1) + 15(3) + 20(2) + 10(2) + 5(1) + 5(1) = 125$$

Pairwise Exchange Method

- Example (contd.): Iteration 1

$$TC_{3124}(1\text{-}2) = 10(1) + 15(1) + 20(2) + 10(1) + 5(1) + 5(3) = 95$$

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

$$TC_{3241}(1\text{-}4) = 10(2) + 15(3) + 20(1) + 10(1) + 5(1) + 5(2) = 110$$

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

$$TC_{3412}(2\text{-}4) = 10(1) + 15(2) + 20(1) + 10(3) + 5(2) + 5(2) = 105$$

$$TC_{4213}(3\text{-}4) = 10(1) + 15(1) + 20(2) + 10(2) + 5(1) + 5(3) = 105$$

Pairwise Exchange Method

- Example (contd.): Iteration 2

$$TC_{3214}(1\text{-}2) = 10(1) + 15(2) + 20(1) + 10(1) + 5(2) + 5(3) = 95$$

$$TC_{1324}(1\text{-}3) = 10(2) + 15(1) + 20(3) + 10(1) + 5(1) + 5(2) = 120$$

$$TC_{3421}(1\text{-}4) = 10(1) + 15(3) + 20(2) + 10(2) + 5(1) + 5(1) = 125$$

$$TC_{2134}(2\text{-}3) = 10(1) + 15(1) + 20(2) + 10(2) + 5(3) + 5(1) = 105$$

$$TC_{3142}(2\text{-}4) = 10(2) + 15(1) + 20(1) + 10(3) + 5(1) + 5(2) = 100$$

$$TC_{4123}(3\text{-}4) = 10(1) + 15(2) + 20(1) + 10(1) + 5(2) + 5(3) = 95$$

Pairwise Exchange Method

- **Limitations:**
  - No guarantee of optimality,
    - The final solution depends on the initial layout
    - Leads to suboptimal solution
  - Does not consider size and shape of departments
    - Additional work has to be done (re-arrange the departments) if shapes are not equal.

Graph Based Method

- Graph based method dates back to the later 1960s and early 1970s.
- It is a construction-type layout algorithm.
- The method starts with an adjacency relationship chart.
- Then, we assign weight to the adjacency relationships between departments.
- A graph, called adjacency graph is constructed:
  - Node: to represent department.
  - Arc : to represent adjacency.
  - Weight on arc: represents the adjacency score.

Graph Based Method

- Adjacency graph should be **planar**. (The graph obtained from the relationship diagram is usually a nonplanar graph).
  - A planar graph is a graph where there is no intersection of arcs (flow of material).

- Goal: To find a graph with maximum sum of arc weights (adjacency-based objective).

Graph-based Method

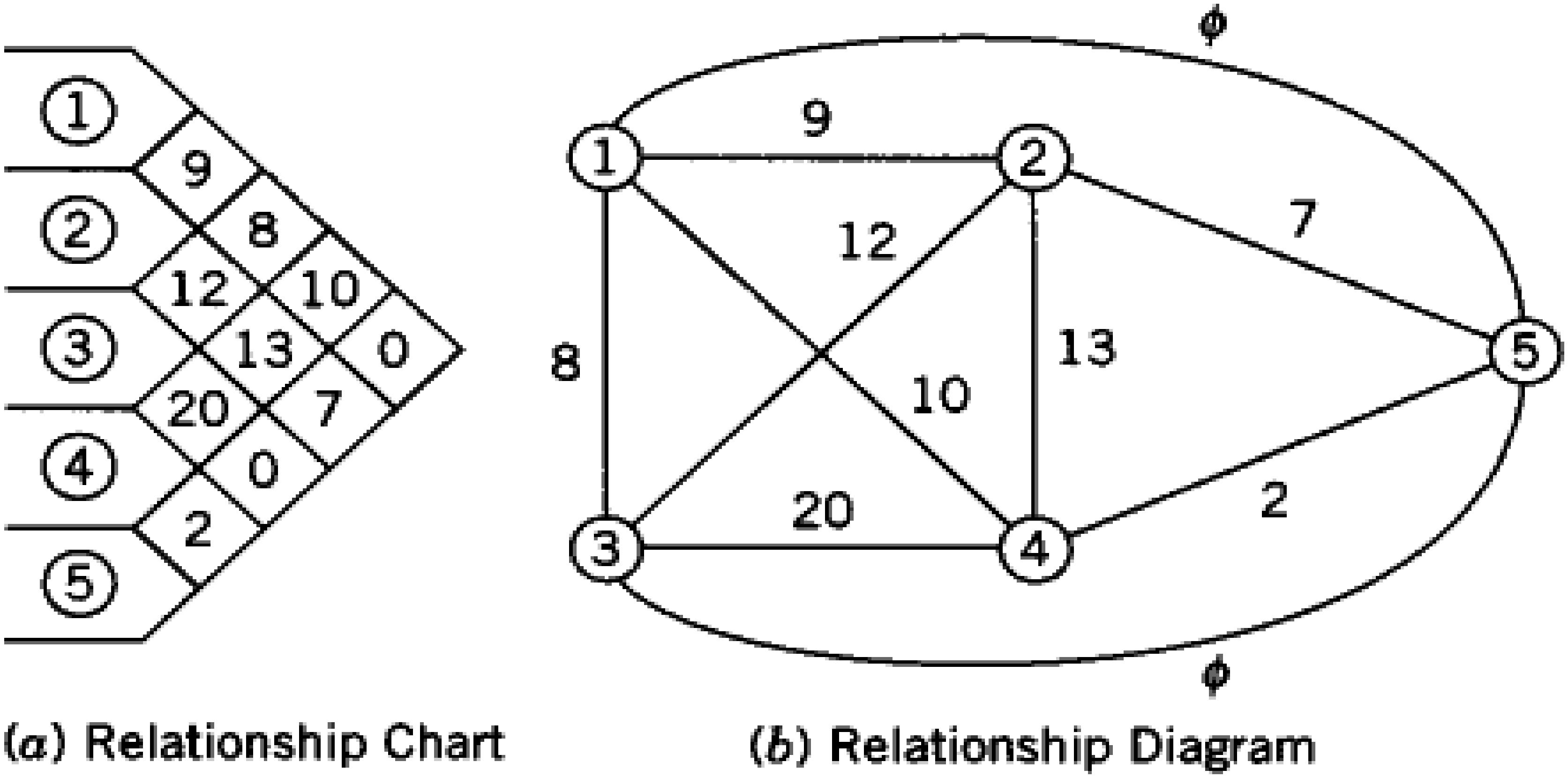
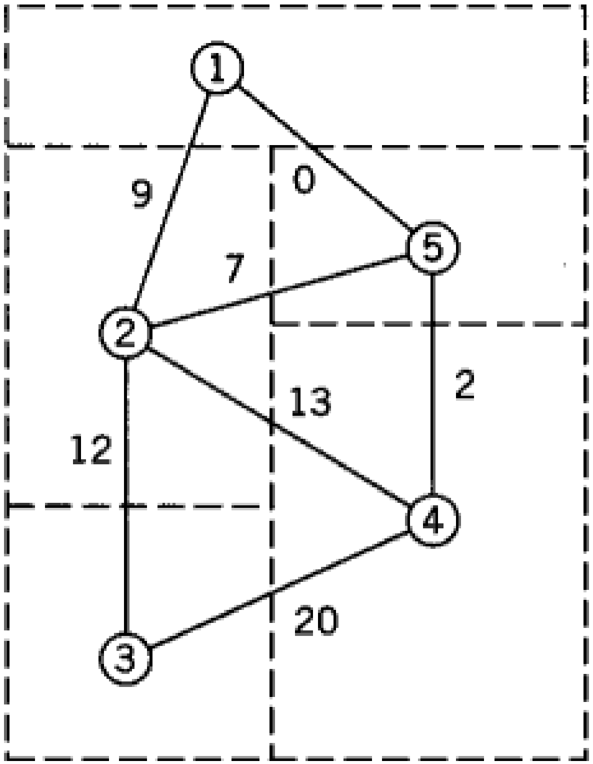


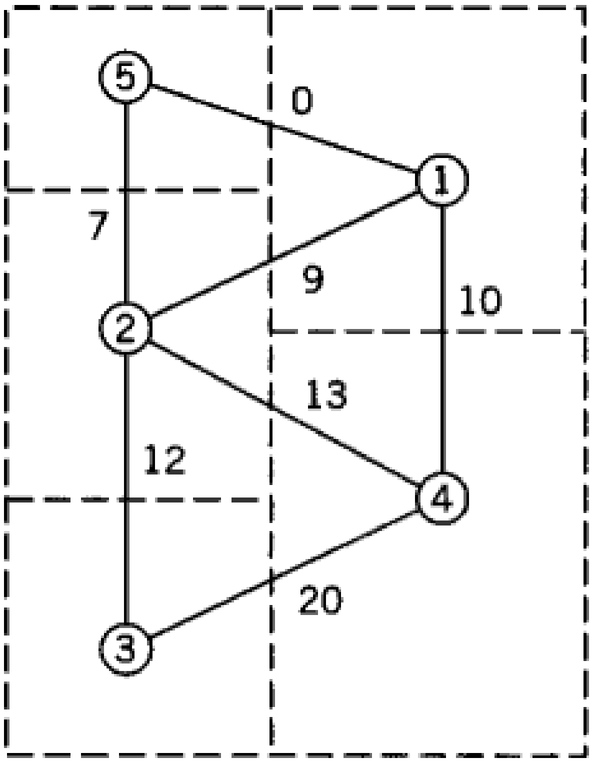
Figure 6.12 Relationship chart and relationship diagram for graph-based example.

Graph-based Method



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

(*a*)



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

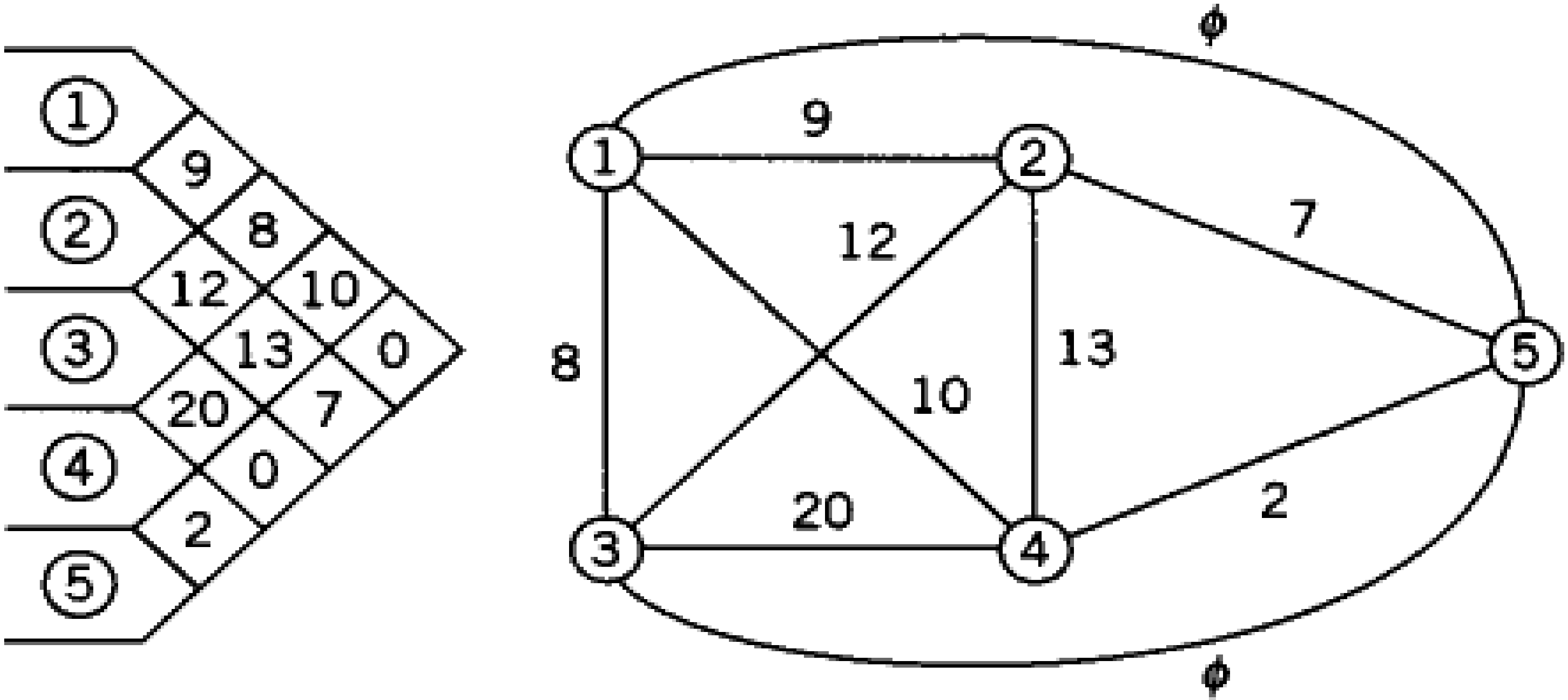
(*b*)

Figure 6.11 Adjacency graphs for alternative block layouts.

Procedure to Find Maximum Weight Adjacent Planar Graph

- Step 1: Select a department pair with largest weight
- Step 2: Select a third department based on the sum of the weights with the two departments selected.
- Step 3: Select next unselected department to enter by evaluating the sum of weights and place the department on the face of the graph.
  - Here, a face of a graph is a bounded region of a graph
- Step 4: Continuing the Step 3 until all departments are selected
- Step 5: Construct a block layout from the planar graph

Graph-based Method



(a) Relationship Chart (b) Relationship Diagram

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

Graph-based Method

a. Step 2

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

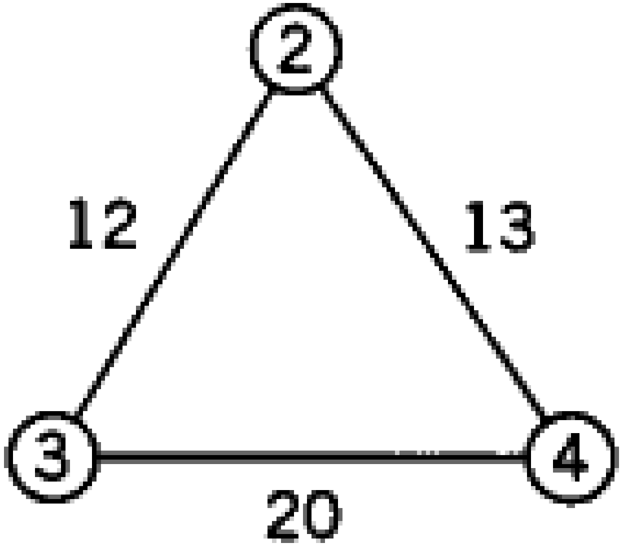


Figure 6.13 graph-based procedure.

Graph-based Method

b. Step 3

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

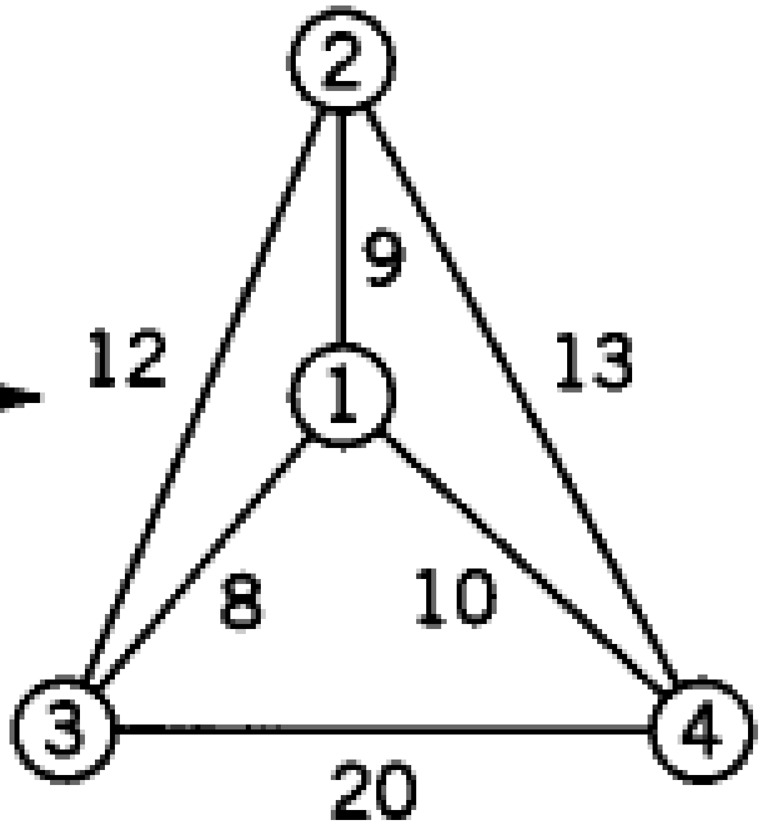


Figure 6.13 graph-based procedure.

Graph-based Method

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)

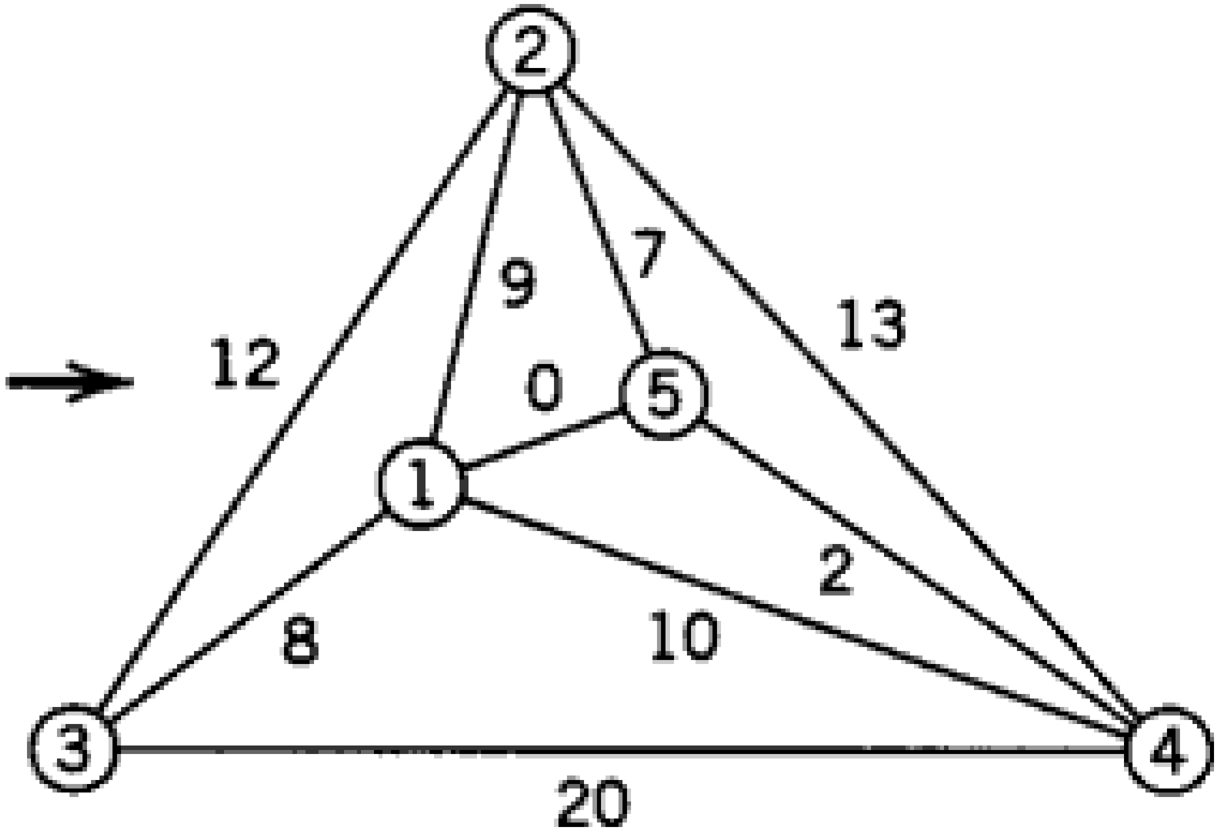
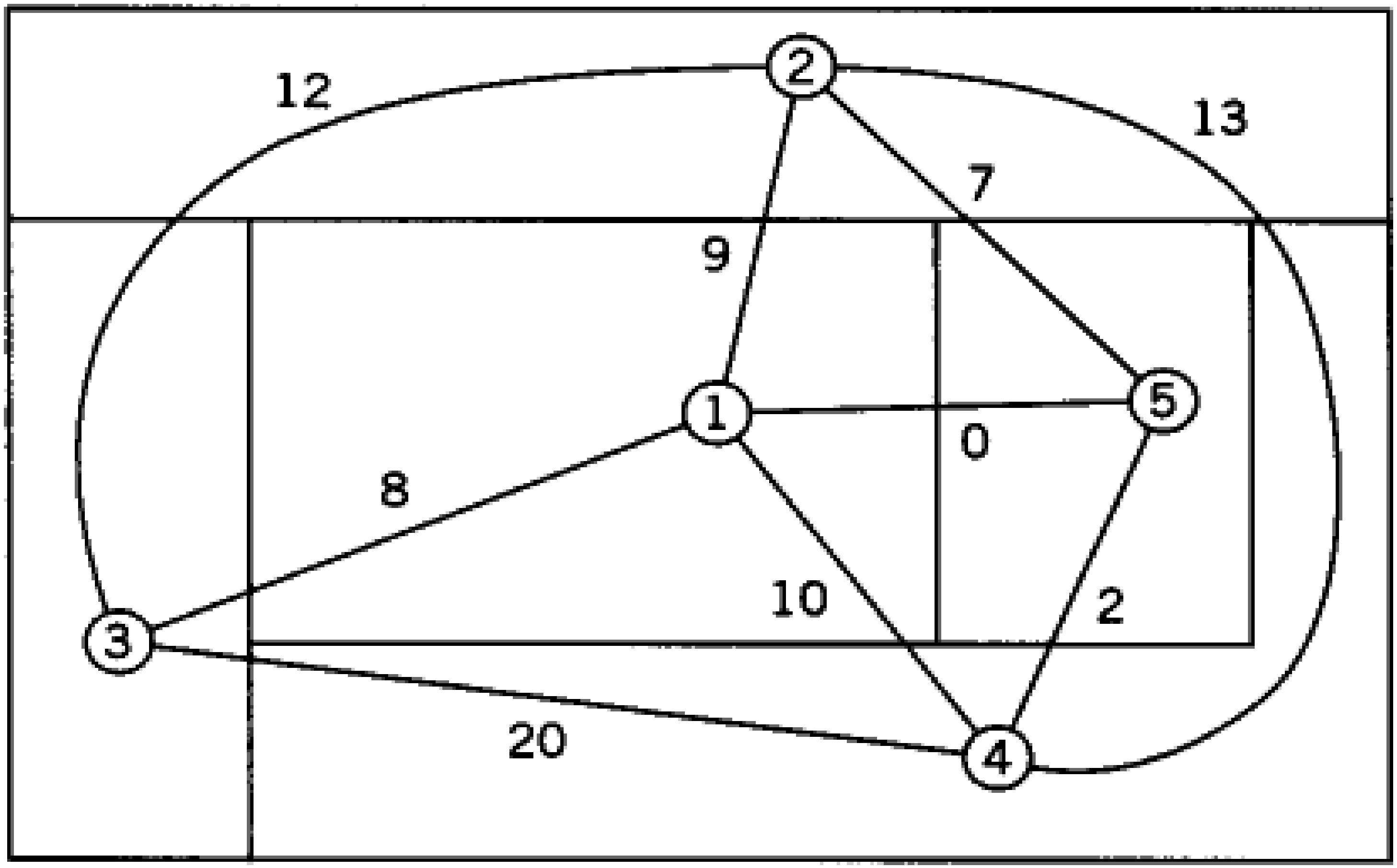


Figure 6.13 graph-based procedure.

Graph-based Method



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
(total)	81

Figure 6.14 Block layout from the final adjacency graph.

Limitation of Graph Based Method

- **Limitations**
  - The adjacency score does not account for distance, nor does it account for relationships other than those between adjacent department.
  - Although size is considered in this method, the specific dimension is not, the length between adjacent departments are also not considered.
  - We are attempting to construct graphs, called planar graphs, whose arcs do not intersect.
  - The final layout is very sensitive to the assignment of weights in the relationship chart.

Algorithm Classification

- The basis of the layout planning is the closeness ratings or material flow intensities.

- Layout algorithms can be classified according to the type of input data they require:
  - Some algorithms accept only **qualitative flow data** (relationship chart).
  - Some algorithms work with **quantitative flow data** (from-to chart)
  - Some algorithms **accept both**.

Algorithm Classification

- Layout algorithms can be also classified according to their objective function:

1. Minimize the sum of flows times distance:

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

Where m: number of departments

f_{ij}: the flow from department i to j.

c_{ij}: the cost of moving one unit load one distance unit from i to j.

d_{ij}: the distance from department i to j.

More suitable when the input data is expressed as from-to chart.

Algorithm Classification

2. Maximize the closeness (adjacency):

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

Where

f_{ij}: the flow from department i to j.

x_{ij}=1 if department i and j are adjacent (share a border)

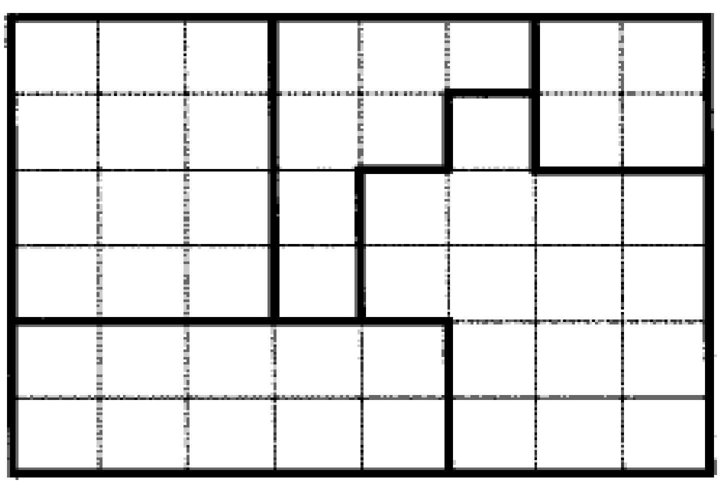
0 otherwise

- Helpful in comparing two or more alternate layouts.
- But, it disregards the distance or separation between non-adjacent departments.

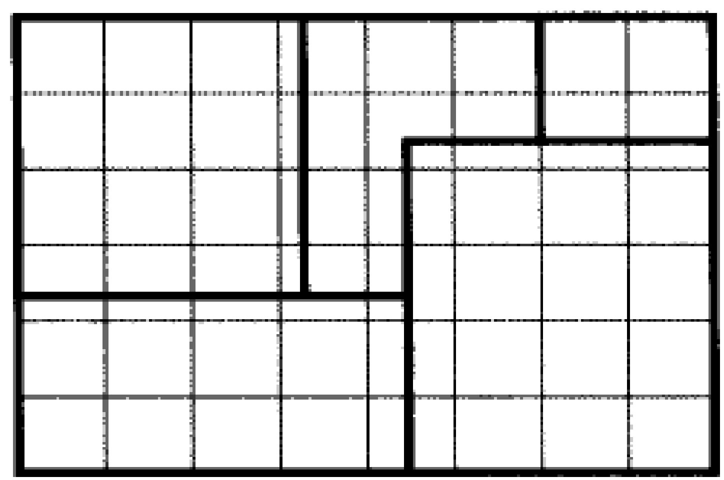
Algorithm Classification

- Layout algorithms can be also classified according to the format for layout representation :

1. Discrete representation:
   - The area for each department is rounded off to the nearest integer number of grids.
   - Selecting the appropriate grid size is an important decision.
2. Continuous representation: no grids, restricted to rectangular buildings and departments.



Discrete



continuous

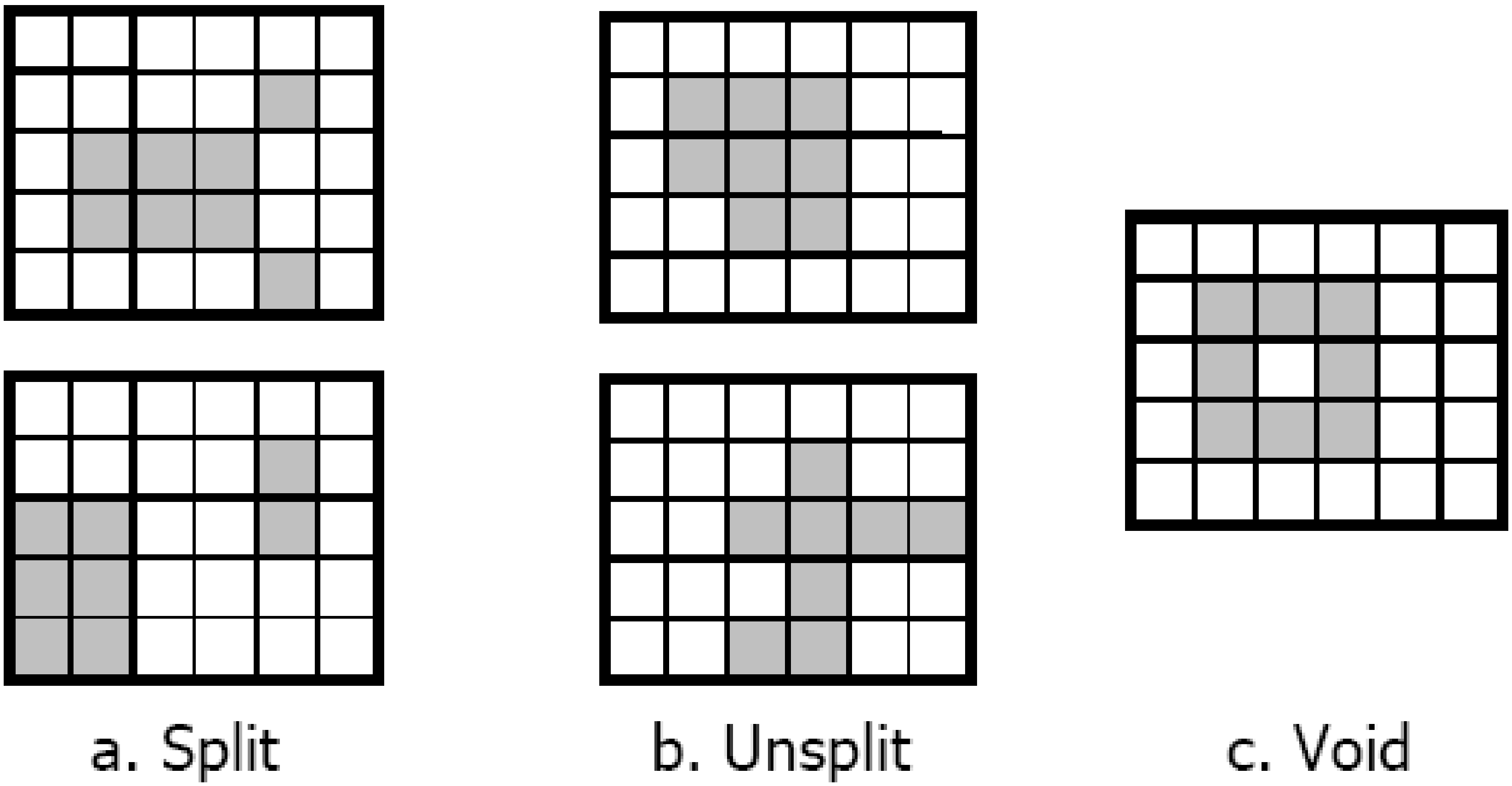
Algorithm Classification

- Layout algorithms can be also classified according to their primary function: improvement versus construction.

1. Improvement-type algorithms:
   - start with an initial layout and seek to improve the objective function through incremental changes in the layout
2. Construction-type layout algorithms:
   1. Assume the building dimensions are given.
   2. Assume the building dimensions are Not given.

Algorithm Classification

- A layout algorithm should not "split" a department into two or more pieces.



Layout Evaluation

An algorithm needs to distinguish between "good" layouts and "bad" ones

- Minimize the total cost/traveling/load etc:

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

- Maximize the total relationship:

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

- Maximize the total satisfaction (Prioritization Matrix)

Layout Evaluation

Distance Based Scoring

- Suitable for input data from From-to chart
- Approximates the cost of flow between activities
- Requires explicit evaluation of the flow volumes and costs

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

m: number of departments
f_{ij}: flow from department ***i*** to department ***j***
c_{ij}: cost of moving from ***i*** to ***j***
d_{ij}: the distance between departments ***i*** and ***j***

- Distance often depends on the aisle layout and material handling equipment
- Distance is often calculated as the rectilinear distance between department centroids

Layout Evaluation

Adjacency Based Scoring

- Adjacency-based scoring is based on the relationship chart and relationship diagram

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

***m**:* number of departments

x_{ij}: *1* if ***i*** and ***j*** are adjacent, *0* otherwise

f_{ij}= Relationship value between department ***i*** to department ***j***

The weights f_i can also be represented by the flow amounts between the adjacent departments instead of scores assigned to A, E, I, O, U, X.

Layout Evaluation

Adjacency Based Scoring

- **Efficiency rating:** When we compare the alternatives, we normalize each objective function

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

Layout Evaluation

Adjacency Based Scoring

- **Efficiency rating:** In some cases, the layout planner may represent an X relationship between departments i and j by assigning a negative value to f_{ij}.

$$z = \frac{\sum_{(i,j)\in F} f_{ij} x_{ij} + \sum_{(i,j)\in \bar{F}} f_{ij}(1 - x_{ij})}{\sum_{(i,j)\in F} f_{ij} - \sum_{(i,j)\in \bar{F}} f_{ij}}$$

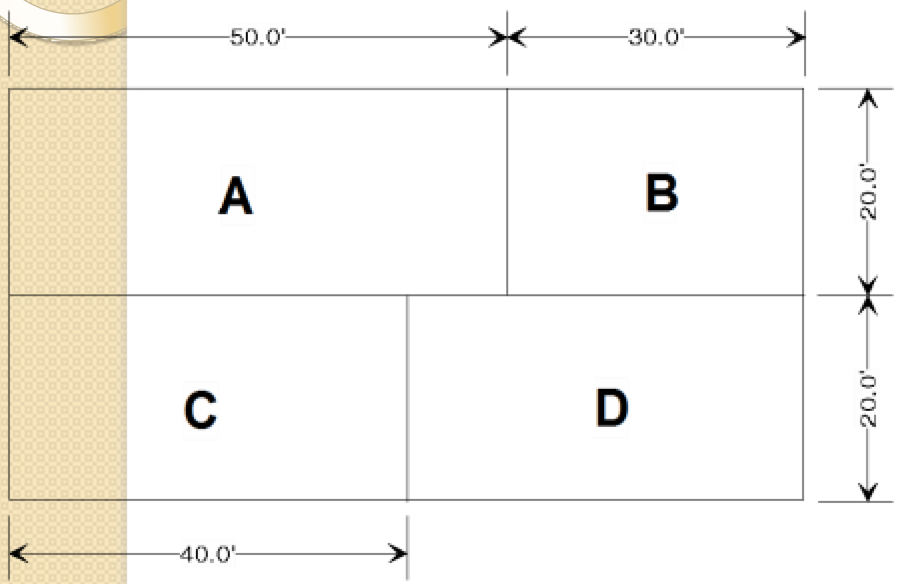
Layout Evaluation

Distance Based Scoring

$$z = f_{ij} c_{ij} d_{ij}$$

Example

Initial Layout



Flow Data f_{ij}

From/To	A	B	C	D
A	-	2	4	4
B	1	-	1	3
C	2	1	-	2
D	4	1	0	-

Distance Data d_{ij}

From/To	A	B	C	D
A	-	40	25	55
B	40	-	65	25
C	25	65	-	40
D	55	25	40	-

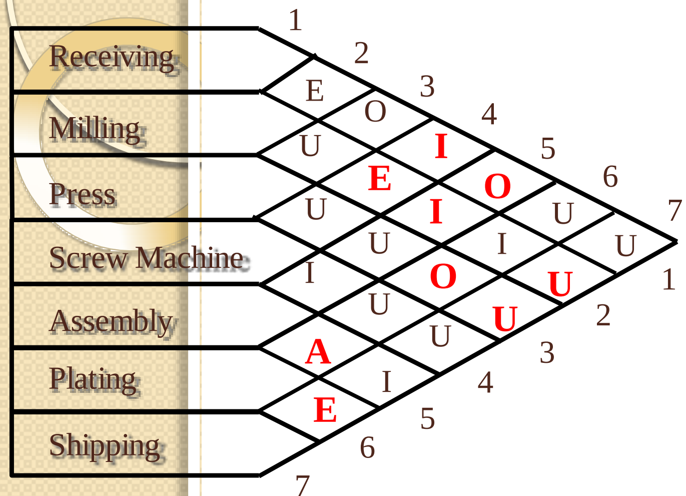
Total Score (Cost) Z

From/To	A	B	C	D	Total
A	-	80	100	220	400
B	40	-	65	75	180
C	50	65	-	80	195
D	220	25	0	-	245
Total	310	170	165	375	1020

Adjacency Based Scoring

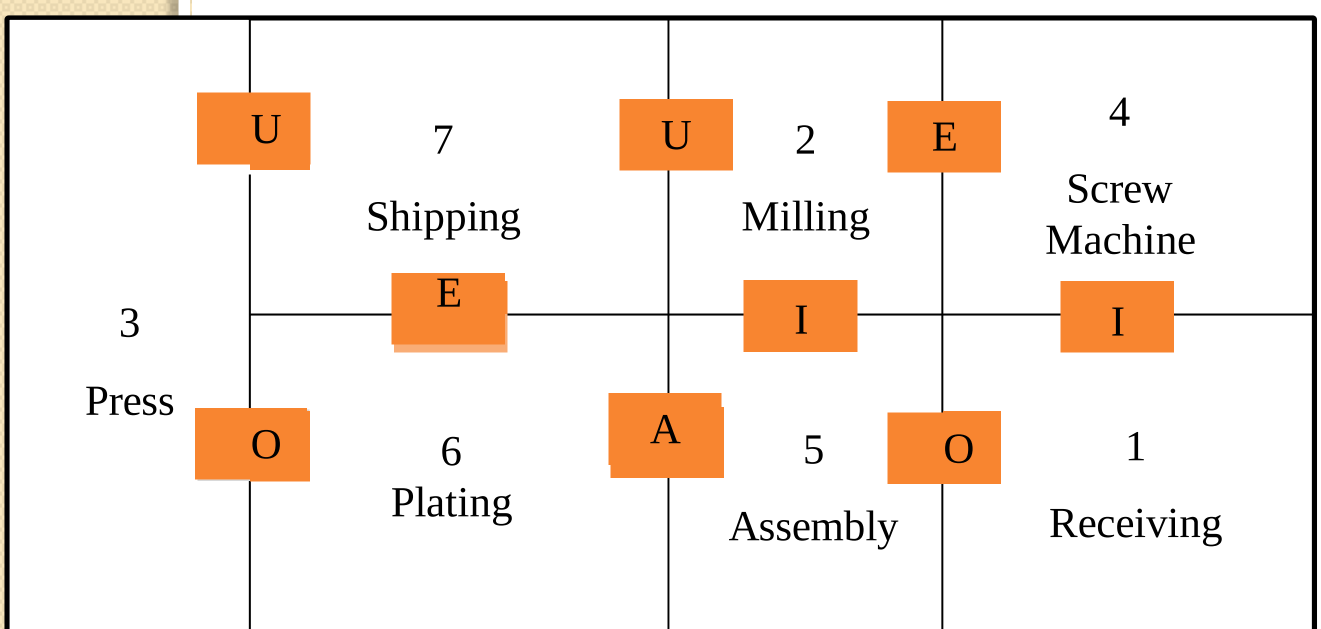
Example

$$z = f_{ij} x_{ij}$$



	1	2	3	4	5	6	7		
1				I	O			4+1	=5
2				E	I		U	16+4+0	=20
3						O	U	1+0	=1
4								----	
5						A		64	=64
6							E	16	=16
7									

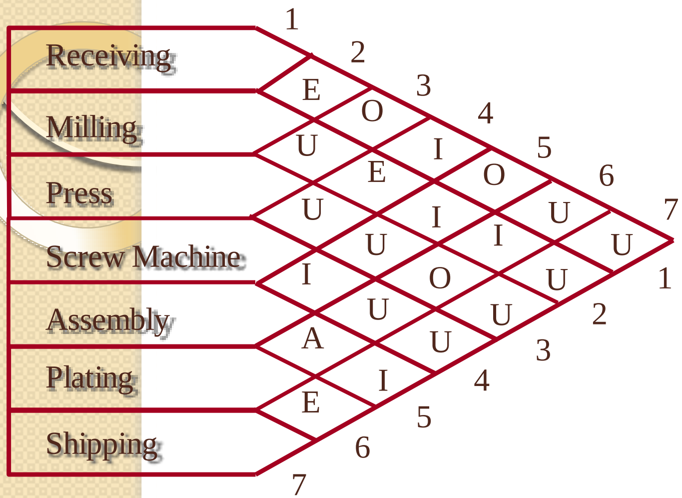
Total Score 106



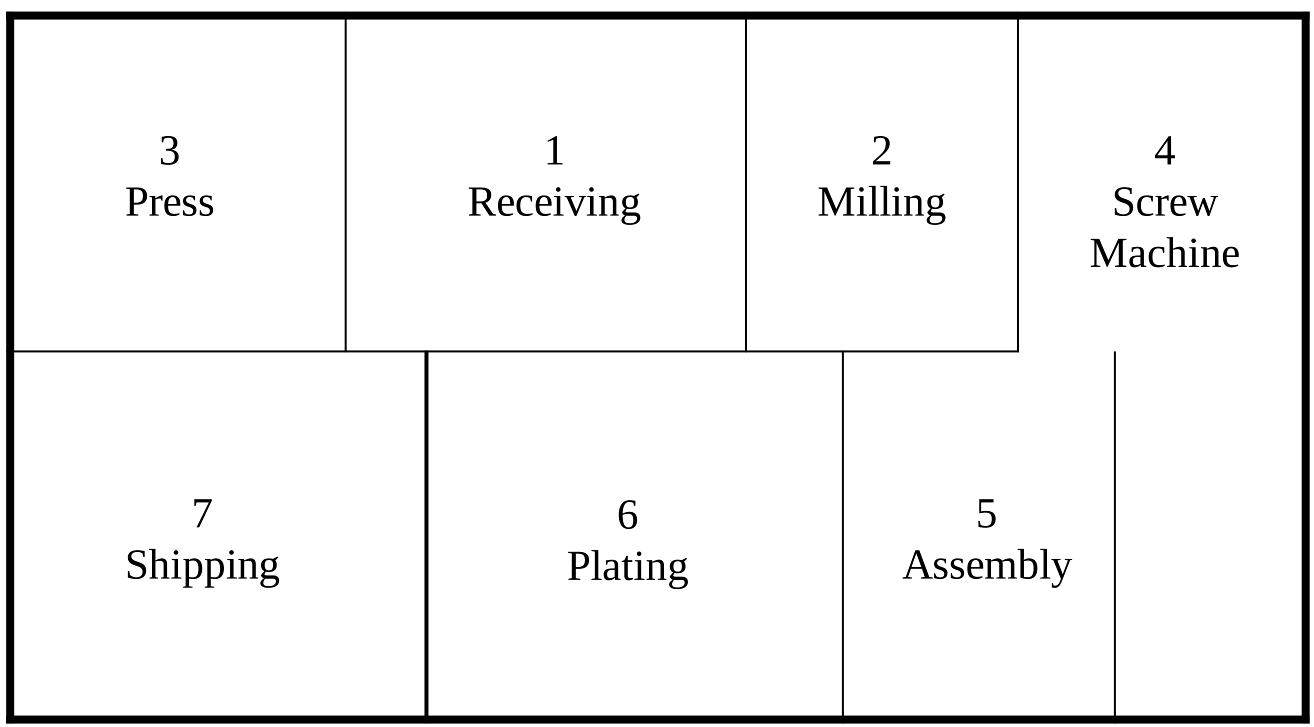
Weights:
- A=64
- E=16
- I=4
- O=1
- U=0
- X=-1024

Adjacency Based Scoring

Example

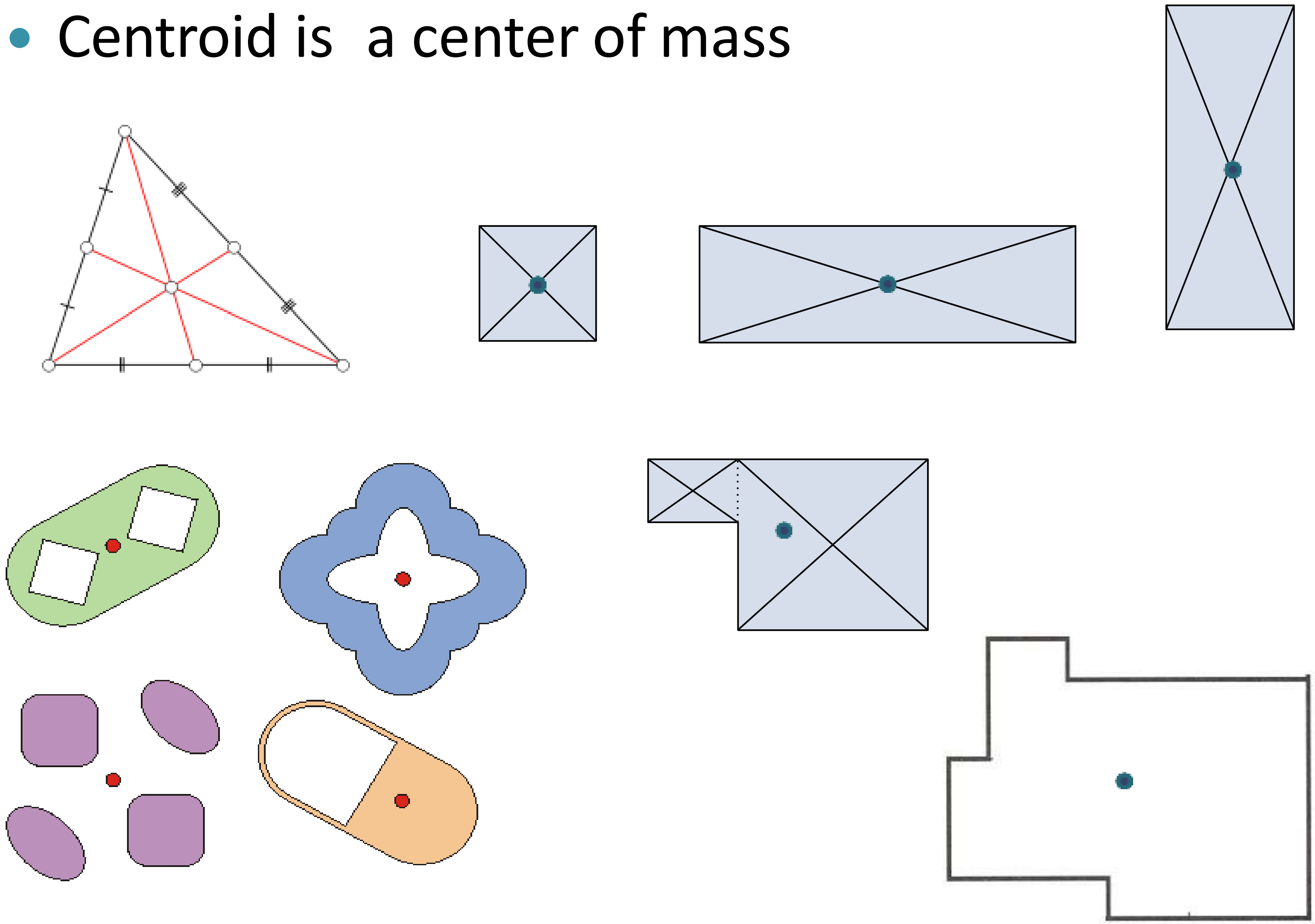


Exercise: **Find the score of the layout shown below. Use A=8, E=4, I=2, O=1, U=0 and X=-8.**



Distance Calculations

- Centroid is a center of mass



Distance Calculations

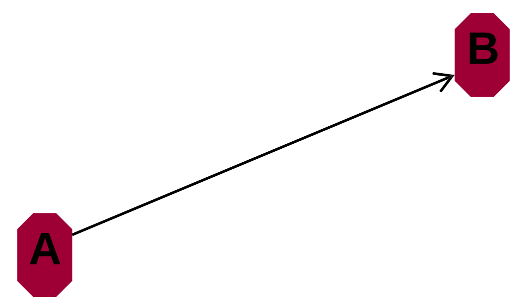
- If (x_i,y_i) and (x_j,y_j) represent the coordinates of two locations *i* and *j* then the distance model measures can be:

  - **Rectilinear:**
    - distance between *i* and *j* is

$$D = |x_i - x_j| + |y_i - y_j|$$

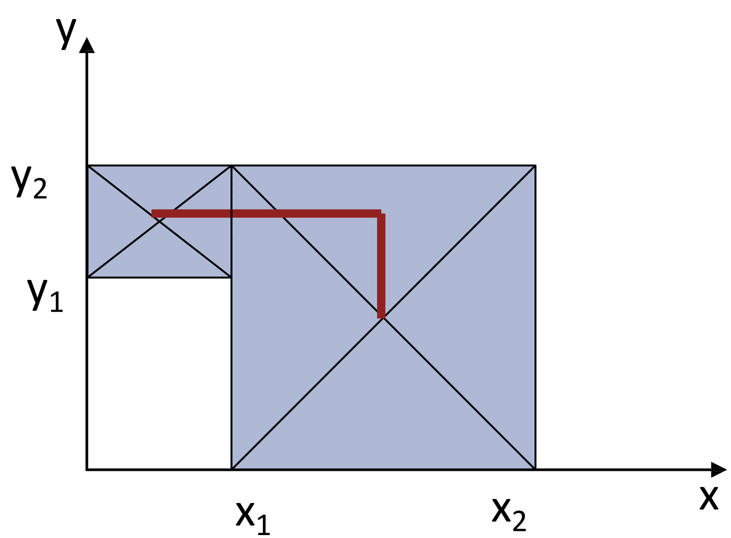
  - **Euclidean:**
    - distance between *i* and *j* is

$$D = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

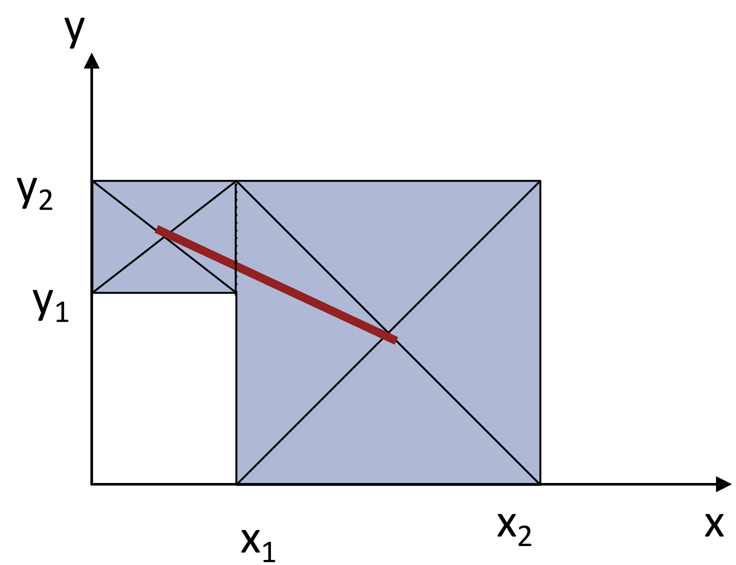


Distance Calculations

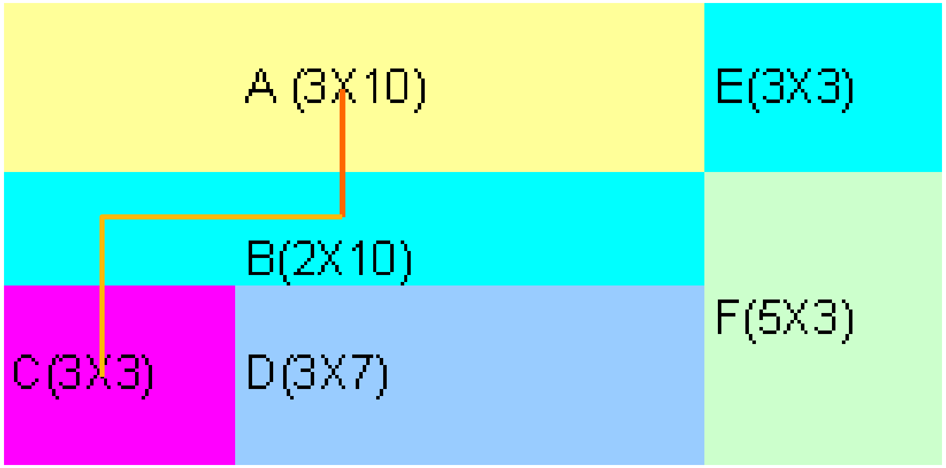
- Rectilinear distance from centroid to centroid



- Euclidean distance from centroid to centroid



Distance Calculations



Rectilinear distance from A to B:

D (AB) = 1.5 + 1 = 2.5

Rectilinear distance from B to C:

D (BC) = 1+1.5+2+1.5= 6

CRAFT

Computerized **R**elative **A**llocation of **F**acilities **T**echnique

- For improvement of an existing facility
- Attempts to minimize transportation cost, where

  Transportation cost = flow * unit cost * distance

$$Min \quad z = \sum_{i=1}^{m}\sum_{j=1}^{m} f_{ij}\, c_{ij}\, d_{ij}$$

- Assumptions
  - Moving costs are linearly related to the length of the move.

- Distance metric used is the rectilinear distance between department centroids.
- Input is FT Chart (From-To chart)
- Department shapes are not restricted to the rectangular ones

CRAFT

Procedure

1. Determine department centroids.
2. Calculate rectilinear distance between centroids.
3. Calculate transportation cost for the layout.
4. Consider department exchanges of either **equal area departments** or **departments sharing a common border**.
5. Determine the estimated change in transportation cost of each possible exchange.
6. Select and implement the departmental exchange that offers the greatest reduction in transportation cost.
7. Repeat the procedure for the new layout until no interchange is able to reduce the transportation cost.

CRAFT
Example

- A facility with 7 departments
- Cost of carrying any material $c_{ij} = 1$ for all *i* and *j* pairs.
- Each grid size is *20 X 20*, total *72,000 m^2* is available
- Total requirement is *70,000* m^2
- Location of receiving (A) and shipping (G) departments are fixed

Dept. Name	Area	No of Grids	Flow A	Flow B	Flow C	Flow D	Flow E	Flow F	Flow G	Flow H
A: Receiving	12,000	30	0	45	15	25	10	5	0	0
B: Milling	8,000	20	0	0	0	30	25	15	0	0
C: Press	6,000	15	0	0	0	0	5	10	0	0
D: Screw	12,000	30	0	20	0	0	35	0	0	0
E: Assembly	8,000	20	0	0	0	0	0	65	35	0
F: Plating	12,000	30	0	5	0	0	25	0	65	0
G: Shipping	12,000	30	0	0	0	0	0	0	0	0
H: Dummy	2,000	5	0	0	0	0	0	0	0	0

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G
2	A				Receiving D.					A	G							G
3	A	A	A	A	A	A	A	A	A	A	G	G	G		Shipping D.			G
4	B	B	B	B	B	C	C	C	C	C	E	E	G	G	G	G	G	G
5	B				B	C				C	E	E	E	E	E	E	E	E
6	B				B	C	C	C	C	C	E	E	E	E	E	E	E	E
7	B	B	B	B	B	D	D	D	D	F	F	F	F	F	F	F	E	E
8	D	D	D	D	D	D			D	F							F	F
9	D								D	F	F	F	F	F				F
10	D	D	D	D	D	D	D	D	H	H	H	H	H	F	F	F	F	F

Dummy Department

➢ Improve the layout

- Total available space > total required space:

  therefore we use a dummy department (H) with the size of 2,000 m^2

CRAFT Example

1. Determine department centroids.
2. Calculate rectilinear distance between centroids.
3. Calculate transportation cost for the layout.

Figure 6.15 Initial CRAFT layout and department centroids for Example 6.1 ($z = 2974 \times 20 = 59{,}480$ units).

Distance between A and B is 6 units (illustrated by the red line above)

$$z = \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} c_{ij} d_{ij}$$

Dept. Name	Area	No of Grids	Flow							
			A	B	C	D	E	F	G	H
A: Receiving	12,000	30	0	45	15	25	10	5	0	0
B: Milling	8,000	20	0	0	0	30	25	15	0	0
C: Press	6,000	15	0	0	0	0	5	10	0	0
D: Screw	12,000	30	0	20	0	0	35	0	0	0
E: Assembly	8,000	20	0	0	0	0	0	65	35	0
F: Plating	12,000	30	0	5	0	0	25	0	65	0
G: Shipping	12,000	30	0	0	0	0	0	0	0	0
H: Dummy	2,000	5	0	0	0	0	0	0	0	0

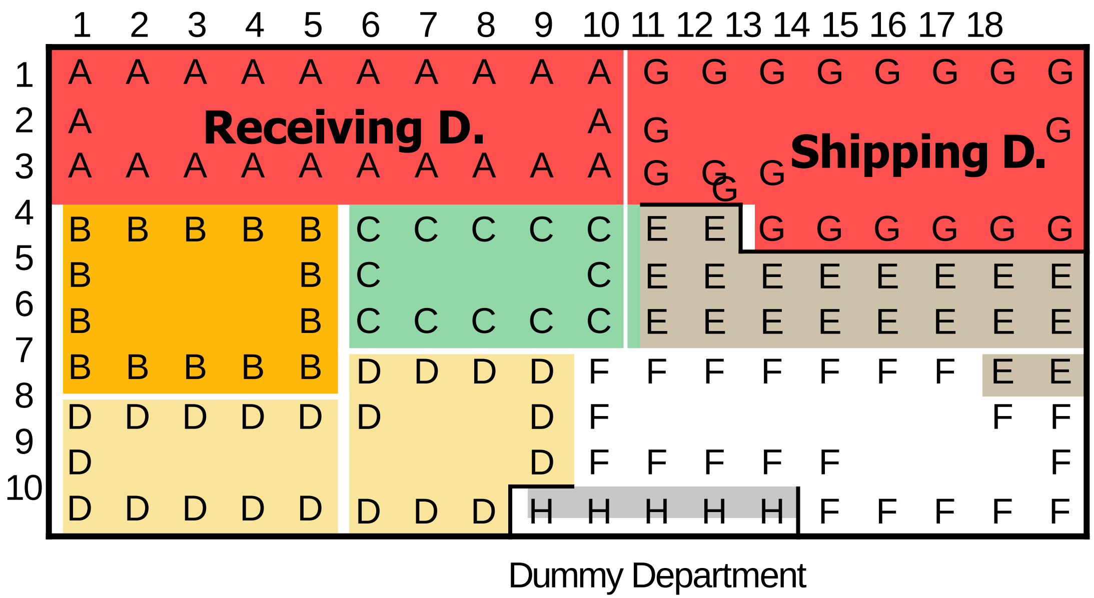
- **Distance Matrix**

	A	B	C	D	E	F	G	H
A		6	5	6	13	16		
B				6	11	14		
C					7	10		
D		6			12			
E						3	4	
F		14			3		7	
G								
H								

- **Cost Matrix**

	A	B	C	D	E	F	G	H	Total
A		270	75	150	130	80			705
B				180	275	210			665
C					35	100			135
D		120			420				540
E						195	140		335
F		70			75		455		600
G									0
H									0
									2980

CRAFT Example



Which departments to exchange?

- Cost Matrix

	A	B	C	D	E	F	G	H	Total
A		270	75	150	130	80			705
B				180	275	210			665
C					35	100			135
D		120			420				540
E						195	140		335
F		70			75		455		600
G									0
H									0
									2980

1. Bringing the departments **E and D** closer might help to reduce total material flow
2. Bringing the departments **F and G** closer might help to reduce total material flow

Exchange E and F

Departments E and F can be reorganized only if they have **the same areas** **OR** they have **common border**

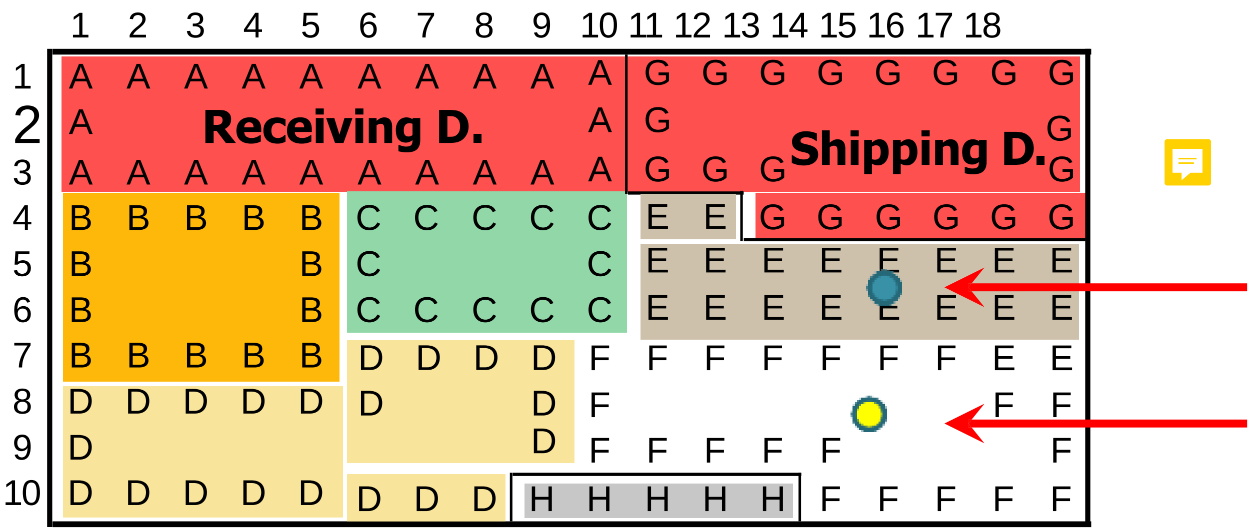
CRAFT

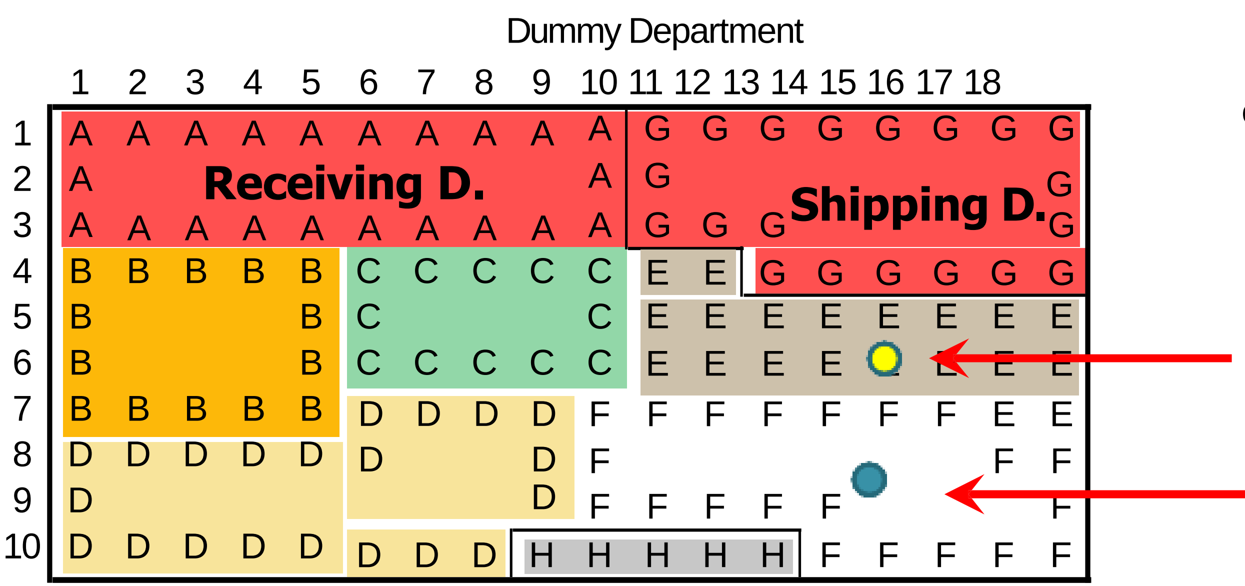
Selection Criterion for Exchange

- Estimated change in the transportation cost:
  - Consider two departments ***i*** and ***j***:
    - Let the centroids of each location be L_i and L_j
    - Assume that after the exchange, the new centroid of *i* becomes L_j and the centroid of *j* becomes L_i.
    - Compute the change in the total transportation cost by using the new **estimated centroids**
      - Centroids of the two departments are temporarily swapped
      - The actual size of cost reduction can be overestimated or underestimated

CRAFT

Swapping the centroids





To calculate the estimated change in cost after the exchange:

CRAFT **Example**

- **Estimation** of the change in transportation cost

Trial distance matrix

	A	B	C	D	E	F	G	H
A		6	5	6	16	13		
B				6	14	11		
C					10	7		
D		6			9			
E						3	7	
F		11			3		4	
G								
H								

Initial cost matrix

	A	B	C	D	E	F	G	H	Total
A		270	75	150	130	80			705
B				180	275	210			665
C					35	100			135
D		120			420				540
E						195	140		335
F		70			75		455		600
G									0
H									0
									2980

Trial cost matrix

	A	B	C	D	E	F	G	H	Total
A		270	75	150	160	65			720
B				180	350	165			695
C					50	70			120
D		120			315				435
E						195	245		440
F		55			75		260		390
G									0
H									0
									2800

CRAFT
Exchanging two departments

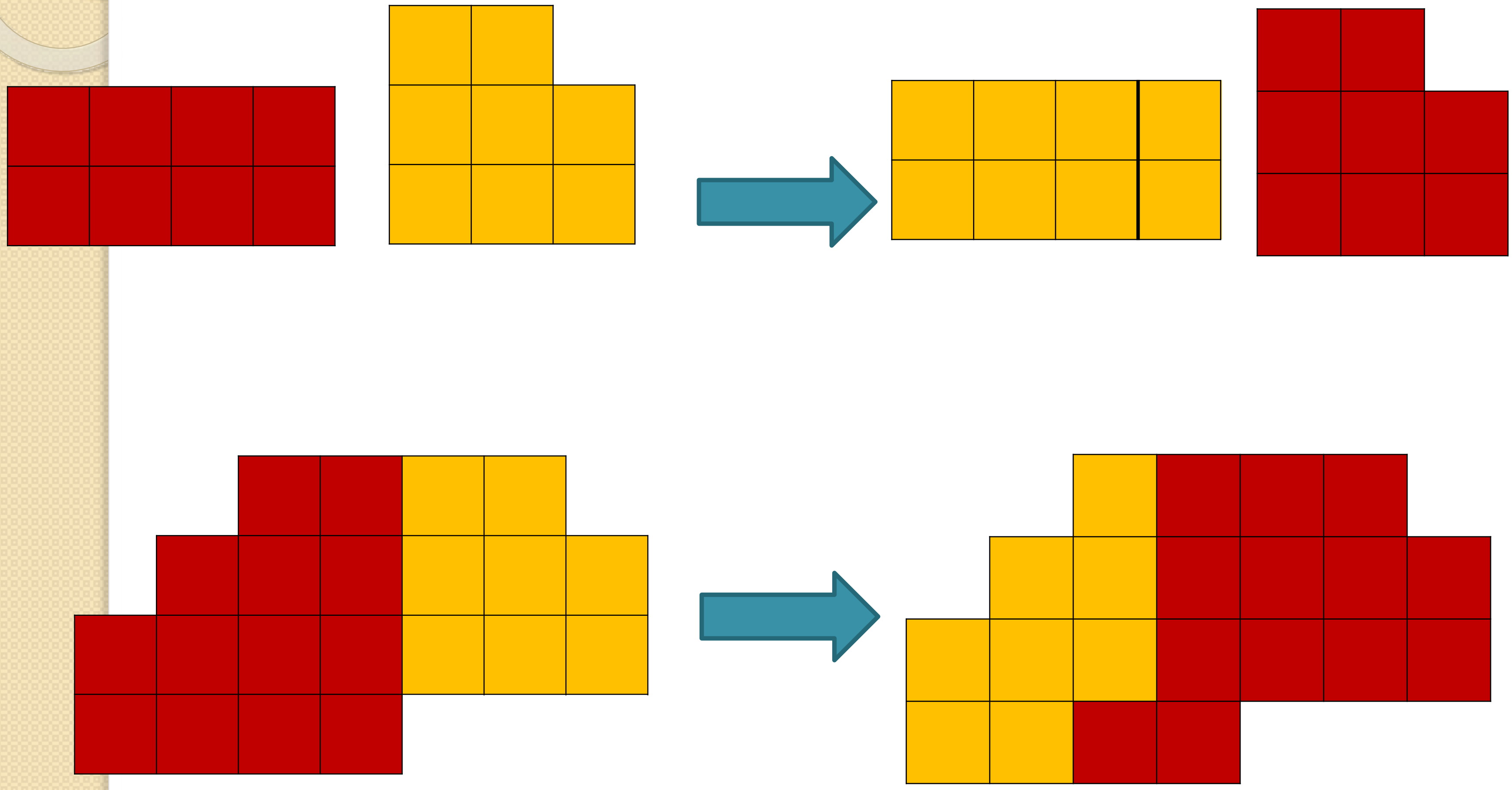
- If the areas of the two departments are of **equal sizes** one department takes the shape of the other.

- If the areas **are not identical**:
  - Draw a box enclosing the two departments (this enclosed shaped includes the grids of the two departments only)

  - Count the number of grids of the smaller department. Let this count be *k*

  - Count *k* grids from the non-adjacent side of the larger department. These grids now become the new location of the smaller department. The space emptied by the smaller department now becomes part of the larger department's new territory

CRAFT
Exchanging two departments

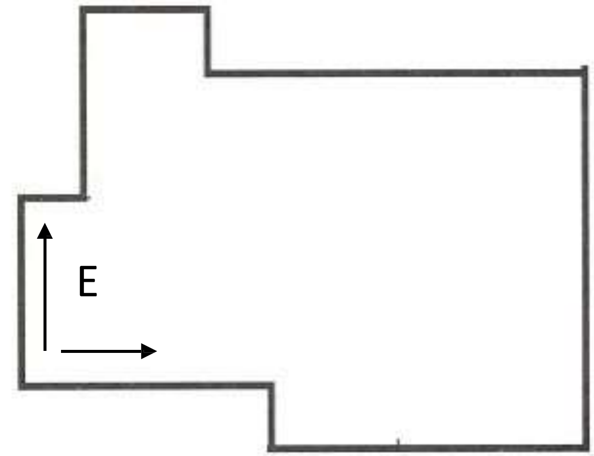


CRAFT Example – exchanging E and F

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G
2	A									A	G							G
3	A	A	A	A	A	A	A	A	A	A	G	G	G					G
4	B	B	B	B	B	C	C	C	C	C	E	E	G	G	G	G	G	G
5	B				B	C				C	E	E	E	E	E	E	E	E
6	B				B	C	C	C	C	C	E	E	E	E	E	E	E	E
7	B	B	B	B	B	D	D	D	D	F	F	F	F	F	F	F	E	E
8	D	D	D	D	D	D			D	F							F	F
9	D								D	F	F	F	F	F				F
10	D	D	D	D	D	D	D	D	H	H	H	H	H	F	F	F	F	F

Receiving D. **Shipping D.**

Dummy Department



Department E needs less space than department F. Then:

Starting from the non-adjacent side of department F, locate all the cells for department E

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G
2	A									A	G							G
3	A	A	A	A	A	A	A	A	A	A	G	G	G					G
4	B	B	B	B	B	C	C	C	C	C	F	F	G	G	G	G	G	G
5	B				B	C				C	F	F	F	F	F	F	F	F
6	B				B	C	C	C	C	C	F	F	F	F	F	F		F
7	B	B	B	B	B	D	D	D	D	E	E	E	E	E	E	F		F
8	D	D	D	D	D	D			D	E					E	F		F
9	D								D	E	E	E	E	E	E	F		F
10	D	D	D	D	D	D	D	D	H	H	H	H	H	E	E	F	F	F

Receiving D. **Shipping D.**

New Layout – after exchanging E and F

CRAFT **Example**

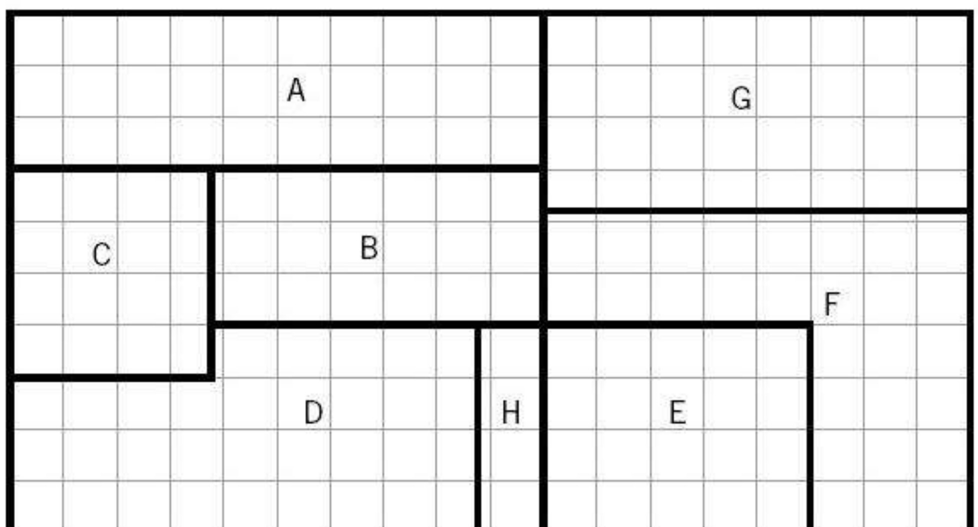
Final Layout – after exchanging B and C

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G
2	A			**Receiving D.**						A	G							G
3	A	A	A	A	A	A	A	A	A	A	G	G	G	**Shipping D.**				G
4	C	C	C	B	B	B	B	B	B	B	F	F	G	G	G	G	G	G
5	C		C	C	B					B	F	F	F	F	F	F	F	F
6	C			C	B	B	B	B	B	B	F	F	F	F	F	F		F
7	C	C	C	C	B	D	D	D	D	E	E	E	E	E	E	F		F
8	D	D	D	D	D	D			D	E					E	F		F
9	D								D	E	E	E	E	E	E	F		F
10	D	D	D	D	D	D	D	D	H	H	H	H	H	E	E	F	F	F

CRAFT **Example**

Manual Adjustment on CRAFT output

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	A	A	A	A	A	A	A	A	A	A	G	G	G	G	G	G	G	G
2	A									A	G							G
3	A	A	A	A	A	A	A	A	A	A	G	G	G					G
4	C	C	C	B	B	B	B	B	B	B	F	F	G	G	G	G	G	G
5	C		C	C	B					B	F	F	F	F	F	F	F	F
6	C			C	B	B	B	B	B	B	F	F	F	F	F	F		F
7	C	C	C	C	B	D	D	D	D	E	E	E	E	E	E	F		F
8	D	D	D	D	D	D			D	E					E	F		F
9	D							D	D	E	E	E	E	E	E	F		F
10	D	D	D	D	D	D	D	D	H	H	H	H	H	E	E	F	F	F



CRAFT Insufficiency of Adjacency for Exchange

- If 2 departments are not equal in area, then adjacency is a necessary but not sufficient condition for an exchange

6	6	6	5	5
6	6	6	5	5
6	6	6	5	4
6	6	6	4	4
2	2	2	2	2
1	1	2	3	3
1	1	2	3	3

CRAFT is unable to exchange departments 2 and 4 without splitting the department 2 or shifting other departments

CRAFT - Pros

- CRAFT is flexible with respect to department shapes.
  - In theory, CRAFT is applicable only to rectangular facilities, yet using dummy extensions, we can still apply CRAFT algorithm to non-rectangular shapes.
- **Dummy departments**
  - Have no flows or interaction with other departments
  - Require certain area
  - Can be fixed
  - Used for:
    - Non-rectangular facilities
    - Fixed areas in the layout (obstacles, unusable areas, etc.)
    - Aisle locations
    - Extra space
    - Building irregularities
- CRAFT captures the initial layout with reasonable accuracy

CRAFT - **Cons**

- **Locally optimal solution** only
  - CRAFT is a path-oriented method so the final layout is dependent on the initial layout. Therefore, a number of different initial layouts should be used as input to the CRAFT procedure.
- CRAFT may lead to **irregular shapes** both for individual departments and the facility itself.
  - Most of the time, a manual “finishing” must be done before presenting the CRAFT output.
- It is not always possible to exchange two unequal size, adjacent departments without splitting the larger one.