Capacity and Facilities Design

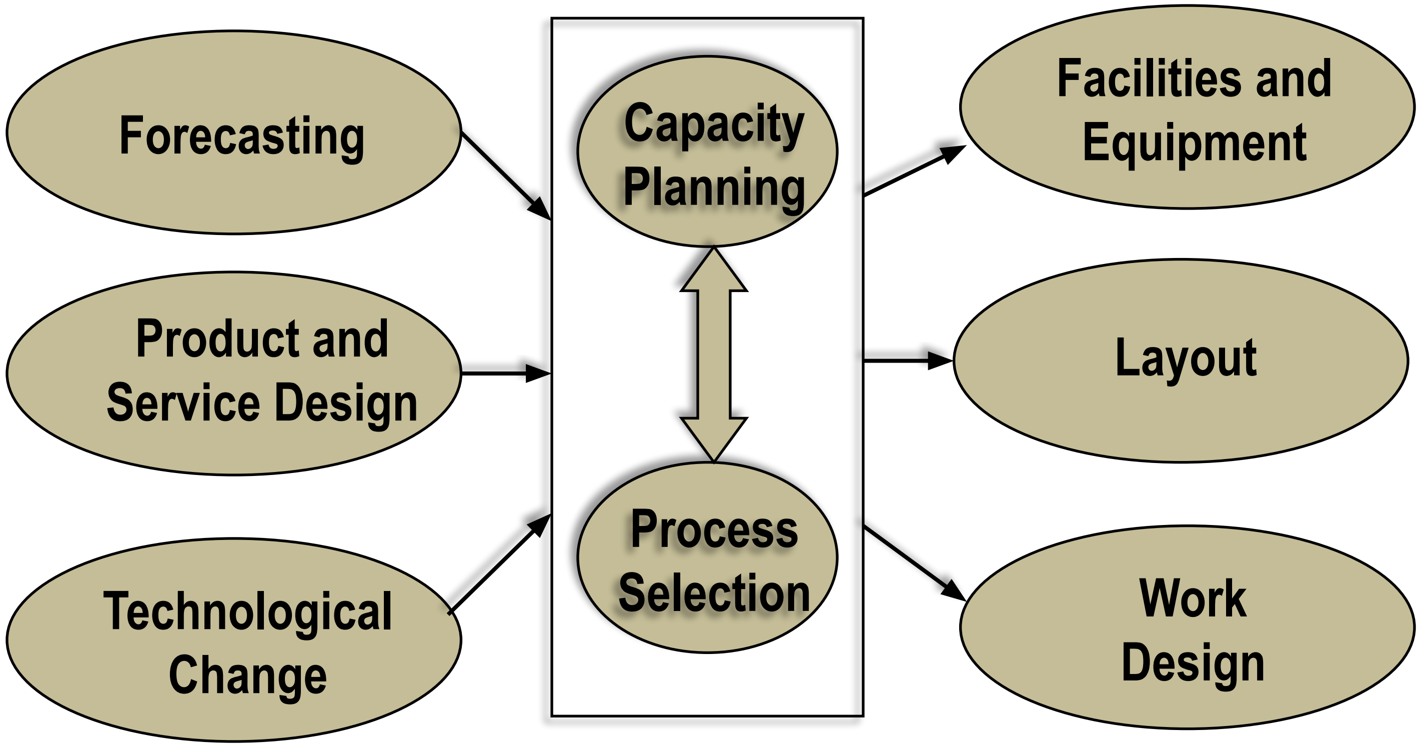
Lecture Outline

- Capacity Planning
- Basic Layouts
- Designing Process Layouts
- Designing Service Layouts
- Designing Product Layouts
- Hybrid Layouts

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

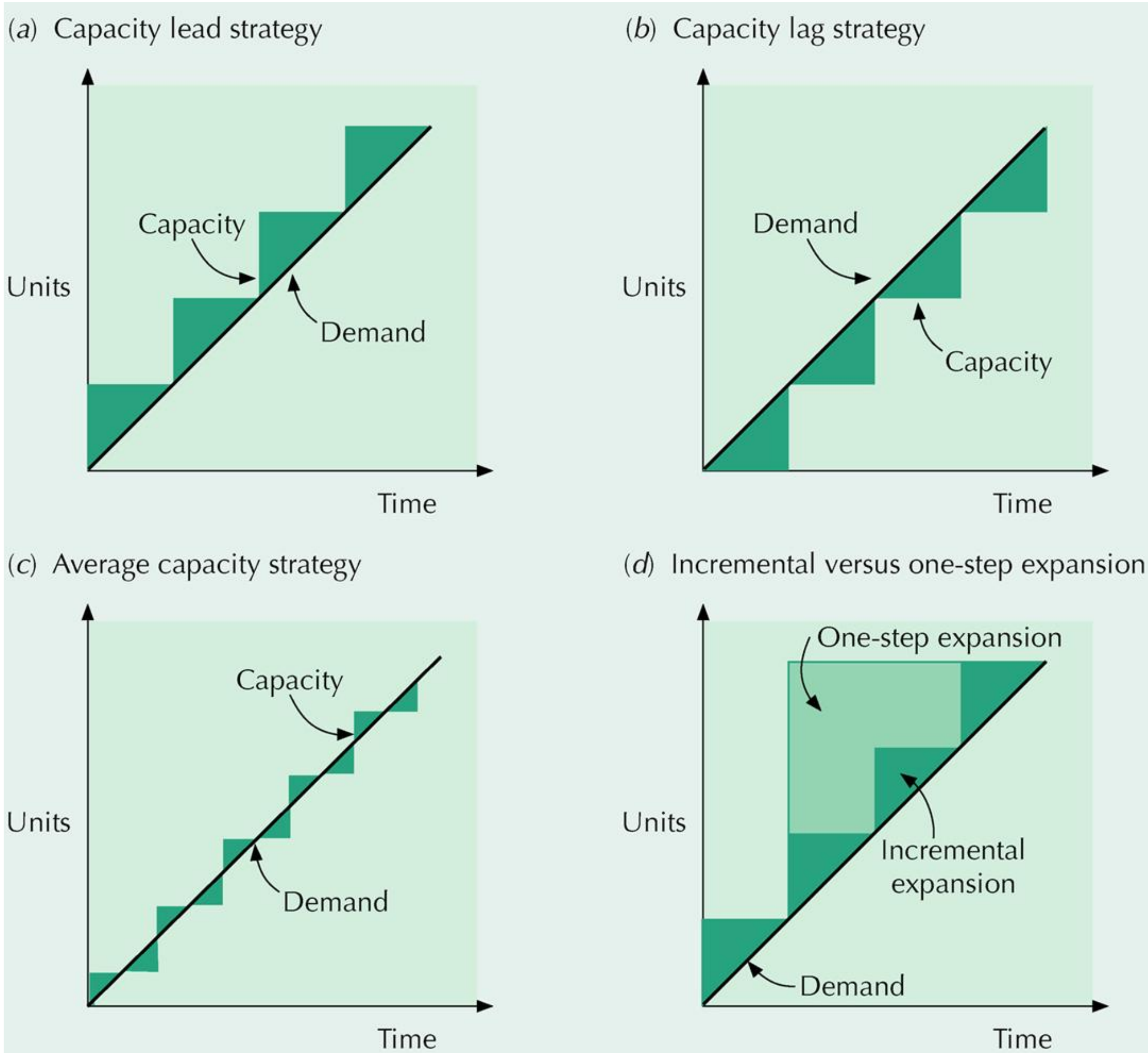
Process Selection and System Design



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



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

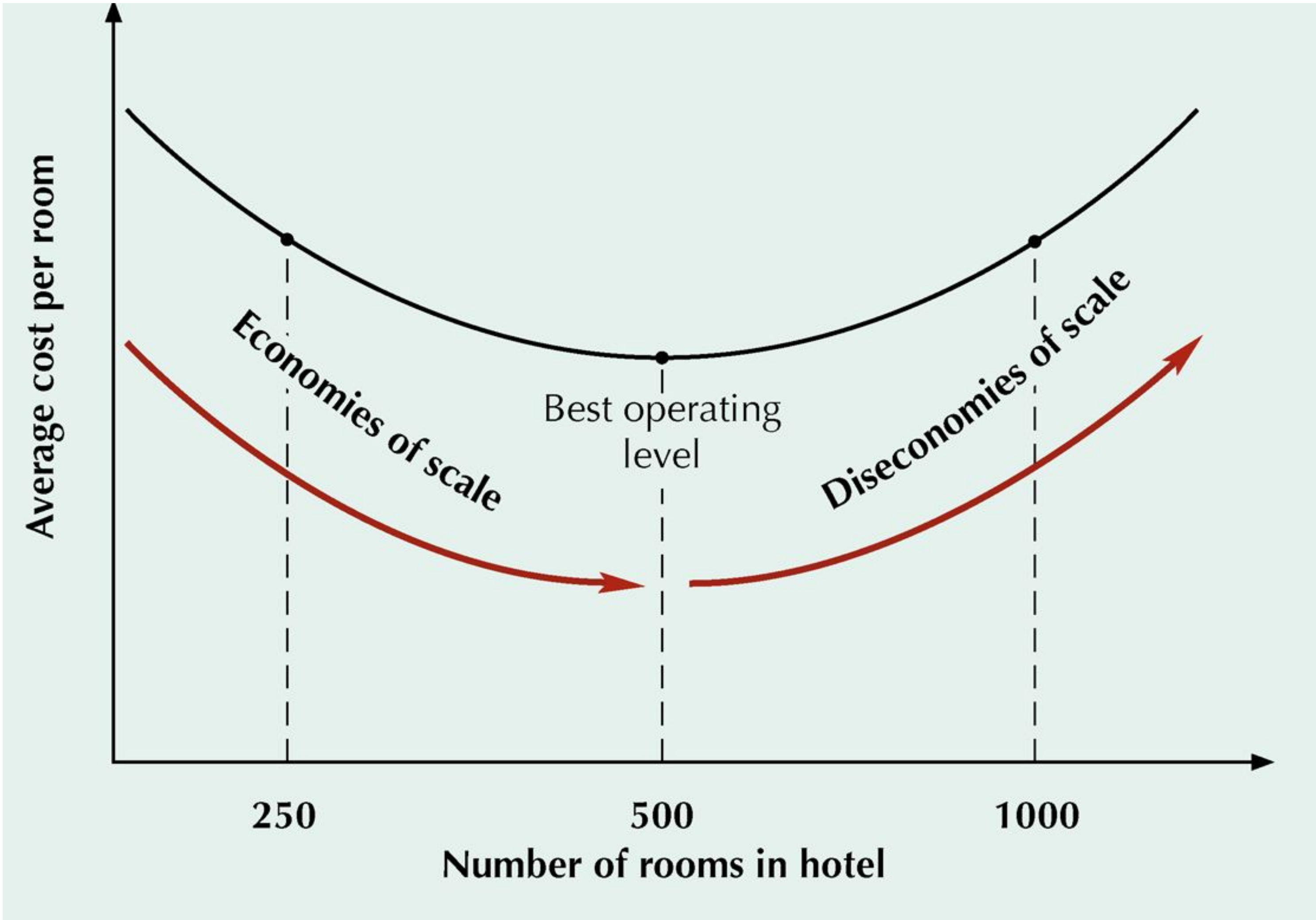
Economies of Scale

- 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



Facilities Layout

- **Layout**
  - the configuration of departments, work centers, and equipment, with particular emphasis on movement of work (customers or materials) through the system
  - Facilities layout decisions arise when:
    - Designing new facilities
    - Re-designing existing facilities

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

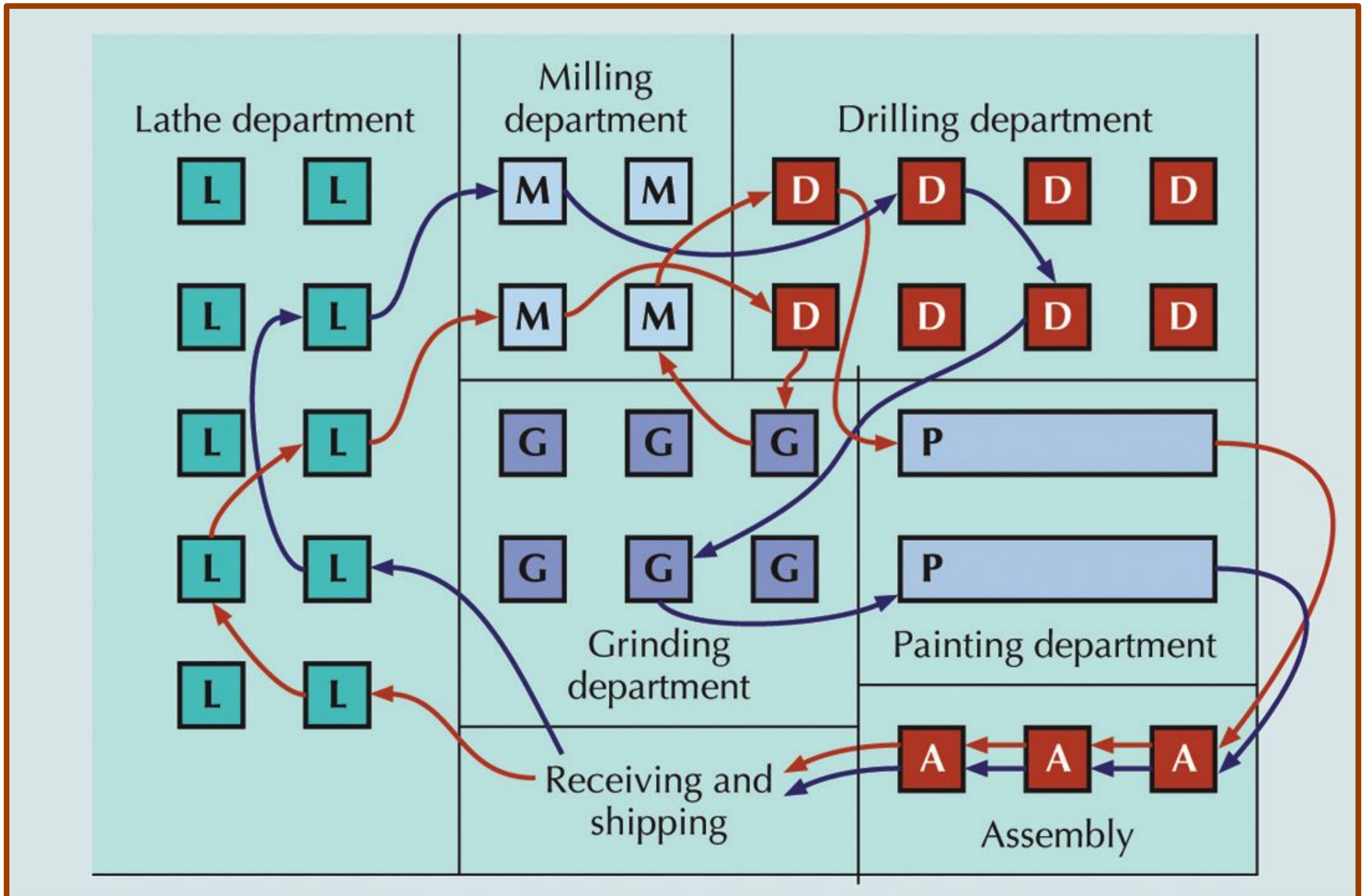
Objectives of Facility Layout

- 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

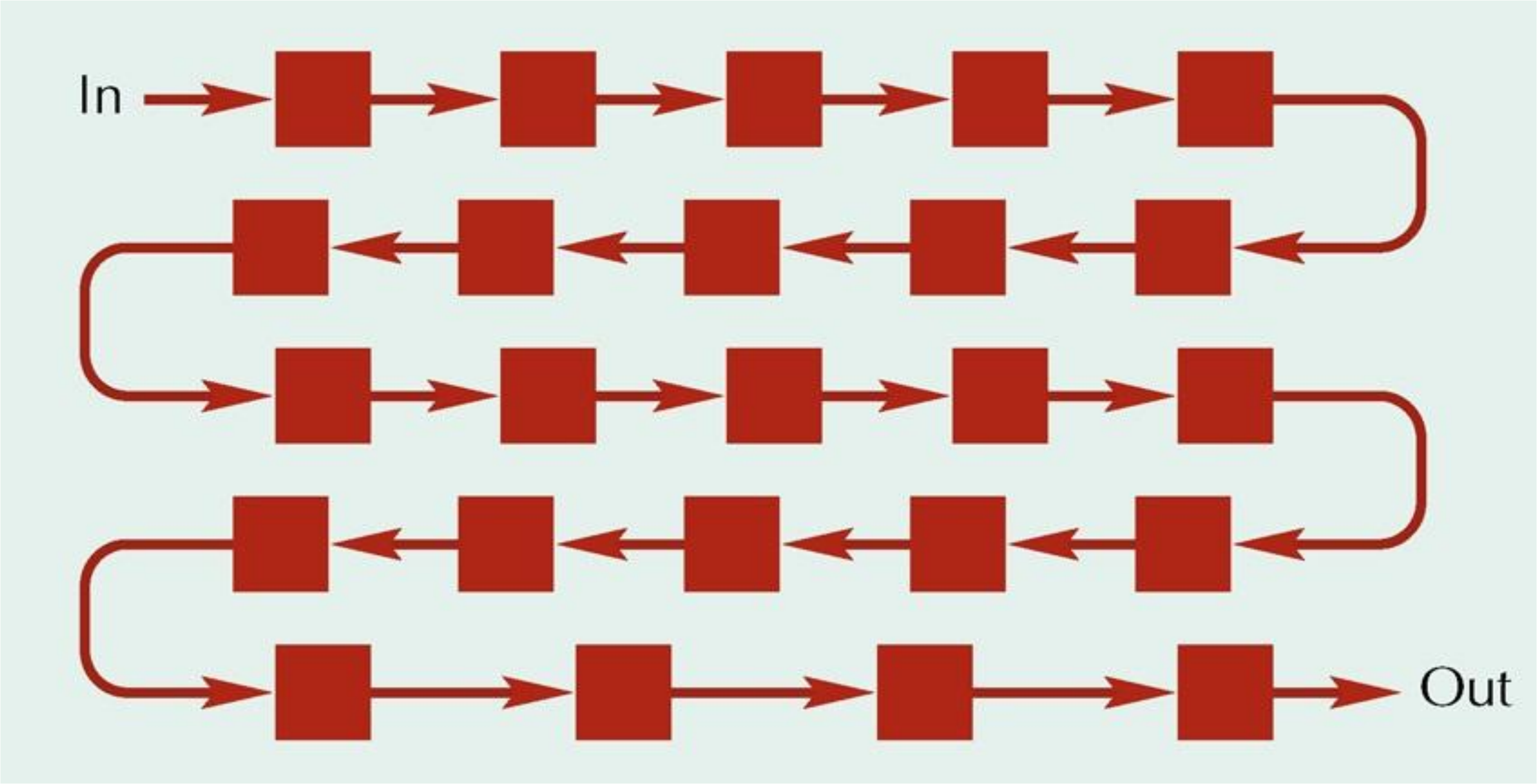
Basic Layouts

- 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

Manufacturing Process Layout



A Product Layout



Comparison of Product and Process Layouts

	Product	Process
Description	Sequential arrangement of activities	Functional grouping of activities
Type of process	Continuous, mass production, mainly assembly	Intermittent, job shop, batch production, mainly fabrication
Product	Standardized, made to stock	Varied, made to order
Demand	Stable	Fluctuating
Volume	High	Low
Equipment	Special purpose	General purpose

Comparison of Product and Process Layouts

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

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

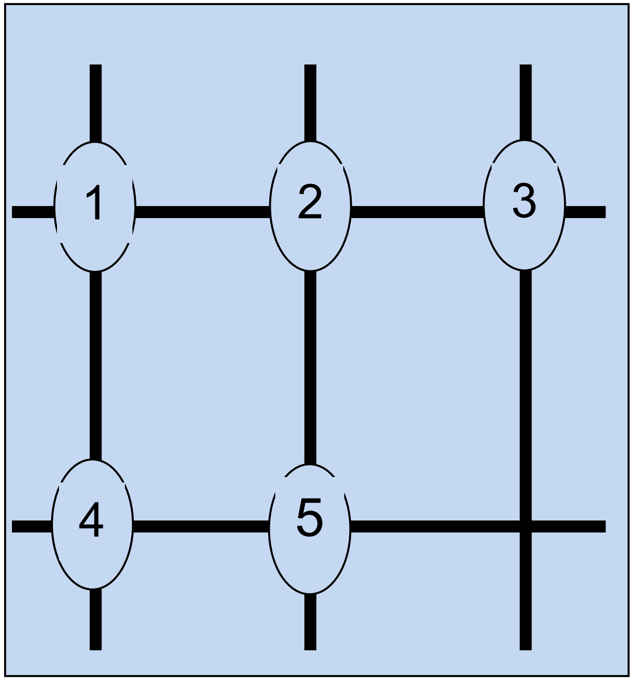
Designing Process Layouts

- 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

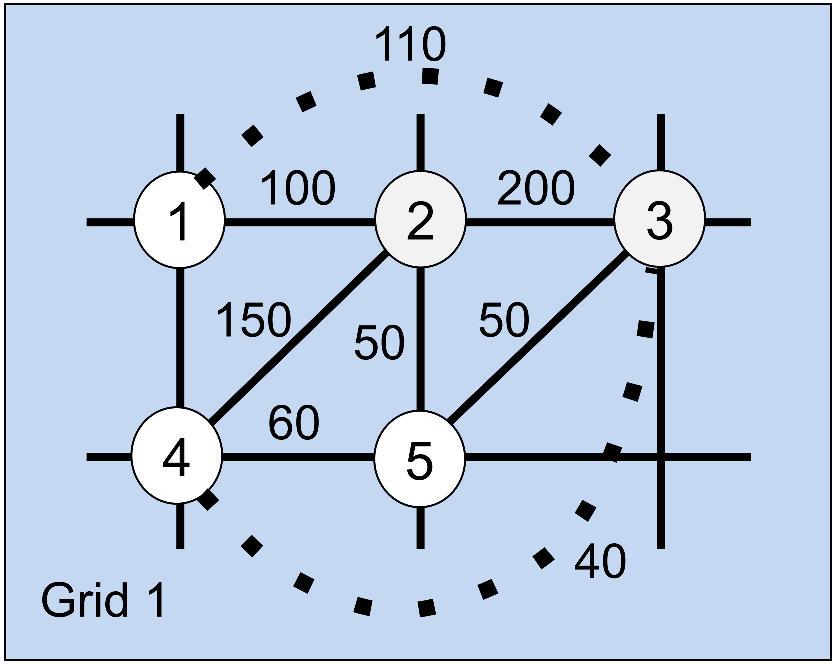
FROM/TO DEPARTMENT

Department	1	2	3	4	5
1	—	100	50		
2		—	200	50	
3	60		—	40	50
4		100		—	60
5		50			—

Block Diagramming: Example

2 ►► 3	200 loads
2 ►► 4	150 loads
1 ►► 3	110 loads
1 ►► 2	100 loads
4 ►► 5	60 loads
3 ►► 5	50 loads
2 ►► 5	50 loads
3 ►► 4	40 loads
1 ►► 4	0 loads
1 ►► 5	0 loads

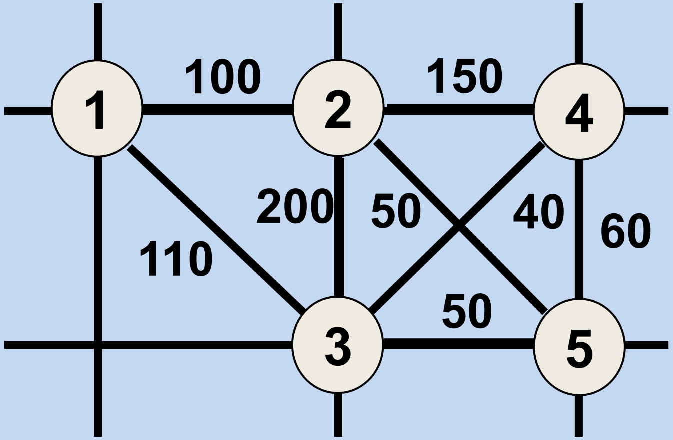
Nonadjacent Loads
110+40=150



Block Diagramming: Example

2 ►► 3	200 loads
2 ►► 4	150 loads
1 ►► 3	110 loads
1 ►► 2	100 loads
4 ►► 5	60 loads
3 ►► 5	50 loads
2 ►► 5	50 loads
3 ►► 4	40 loads
1 ►► 4	0 loads
1 ►► 5	0 loads

Nonadjacent Loads: 0

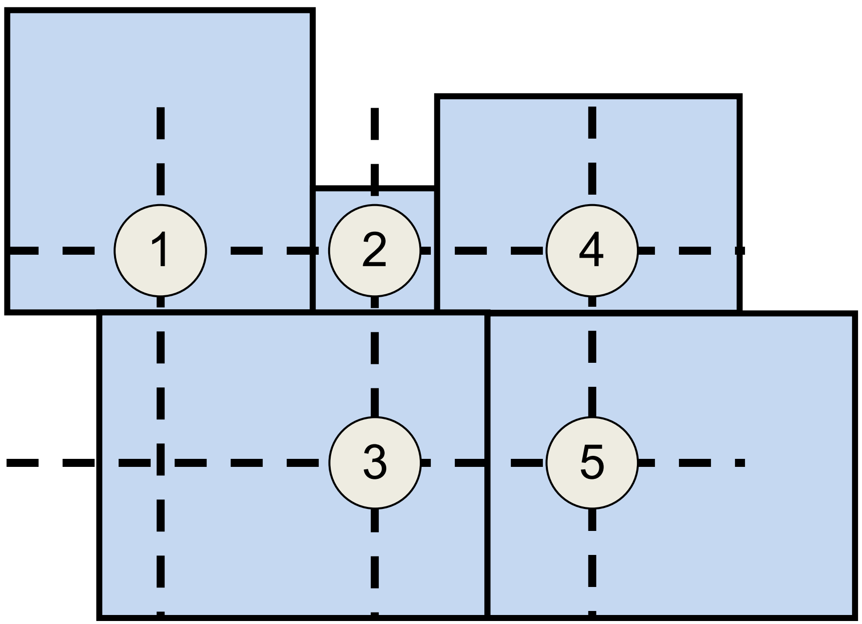


Grid 2

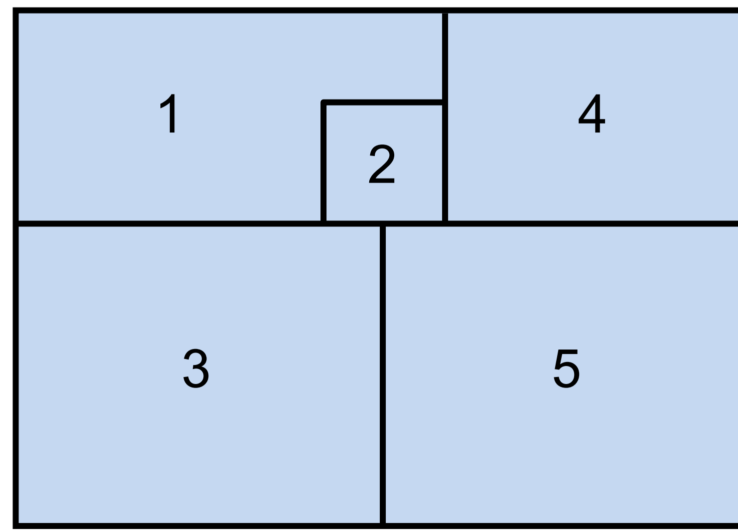
Block Diagramming: Example

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

(a) Initial block diagram



(b) Final block diagram



Block Diagramming With Excel

Example 7.1 - Process Layout

INPUT:

Load Summary Chart

	Department					
From \ To	**1**	**2**	**3**	**4**	**5**	**6**
1		100	50			
2			200	50		
3	60			40	50	
4		100			60	
5		50				
6						

Input load summary chart and trial layout

Enter departments here:

1	2	3
4	5	

Try different layout configurations

OUTPUT:

Nonadjacent loads = 150

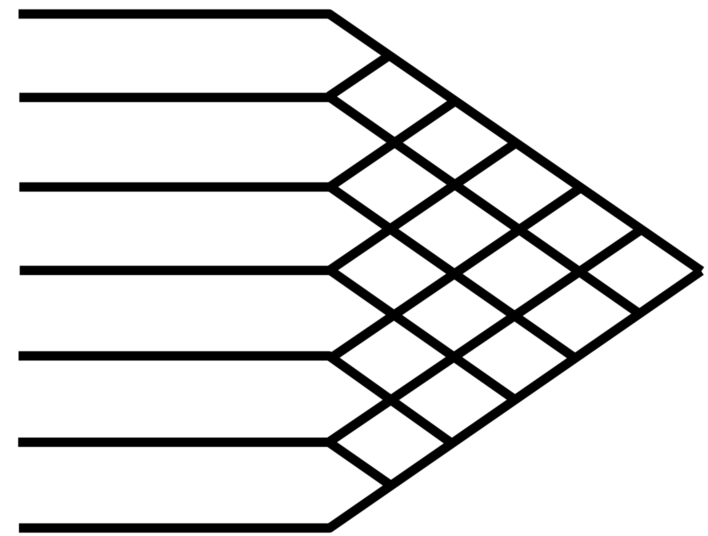
CALCULATIONS:

Composite Movements			Nonadjacent Locations				Layout
From <>	*To*	*Loads*	*1<>3*	*1<>6*	*3<>4*	*4<>6*	*Score*
1	2	100	0	0	0	0	0
1	3	110	1	0	0	0	110
1	4	0	0	0	0	0	0
1	5	0	0	0	0	0	0
1	6	0	0	0	0	0	0
2	3	200	0	0	0	0	0
2	4	150	0	0	0	0	0
2	5	50	0	0	0	0	0
2	6	0	0	0	0	0	0
3	4	40	0	0	1	0	40
3	5	50	0	0	0	0	0
3	6	0	0	0	0	0	0
4	5	60	0	0	0	0	0
4	6	0	0	0	0	0	0
5	6	0	0	0	0	0	0
							150

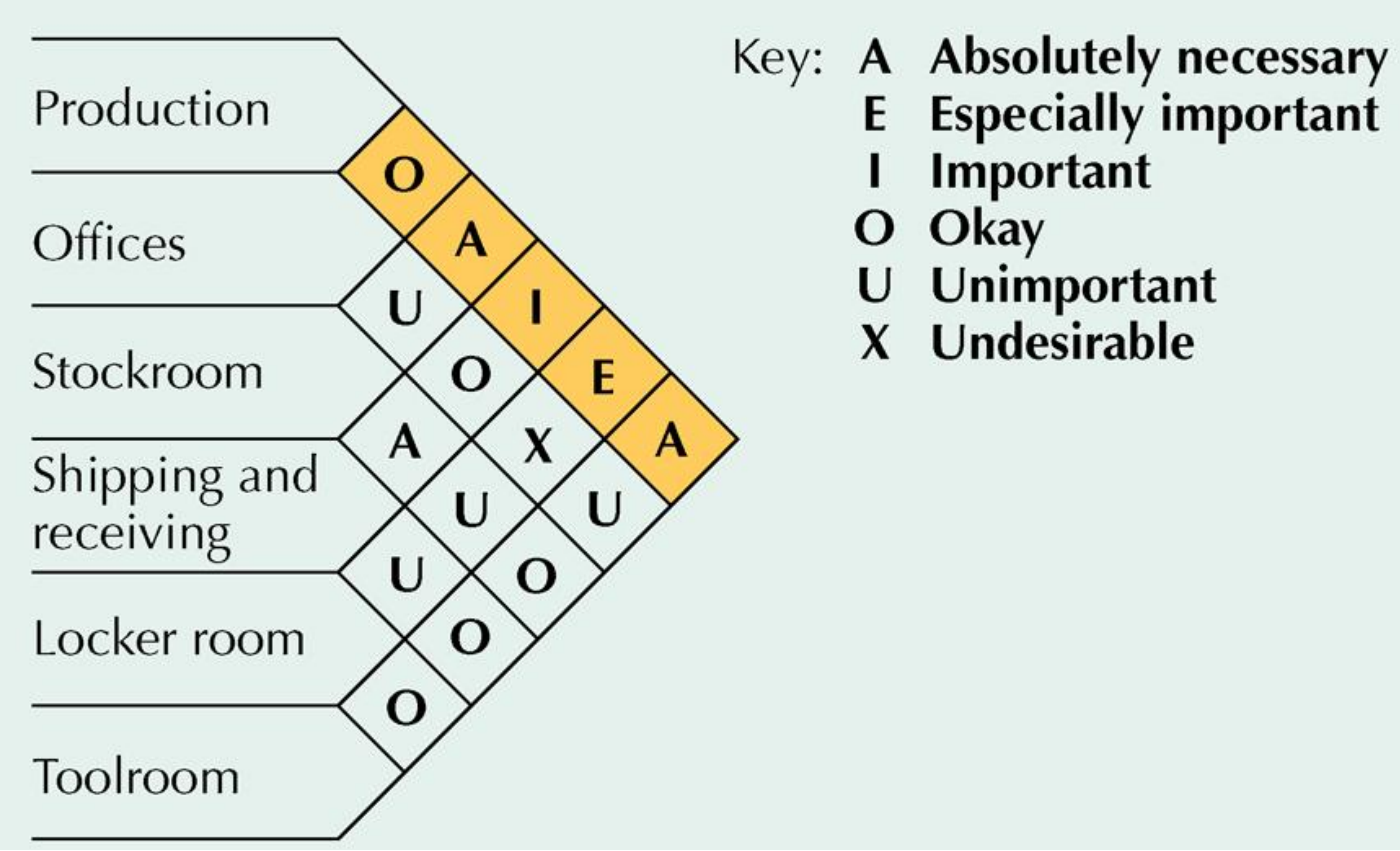
Excel will calculate composite movements and nonadjacent loads

Relationship Diagramming

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

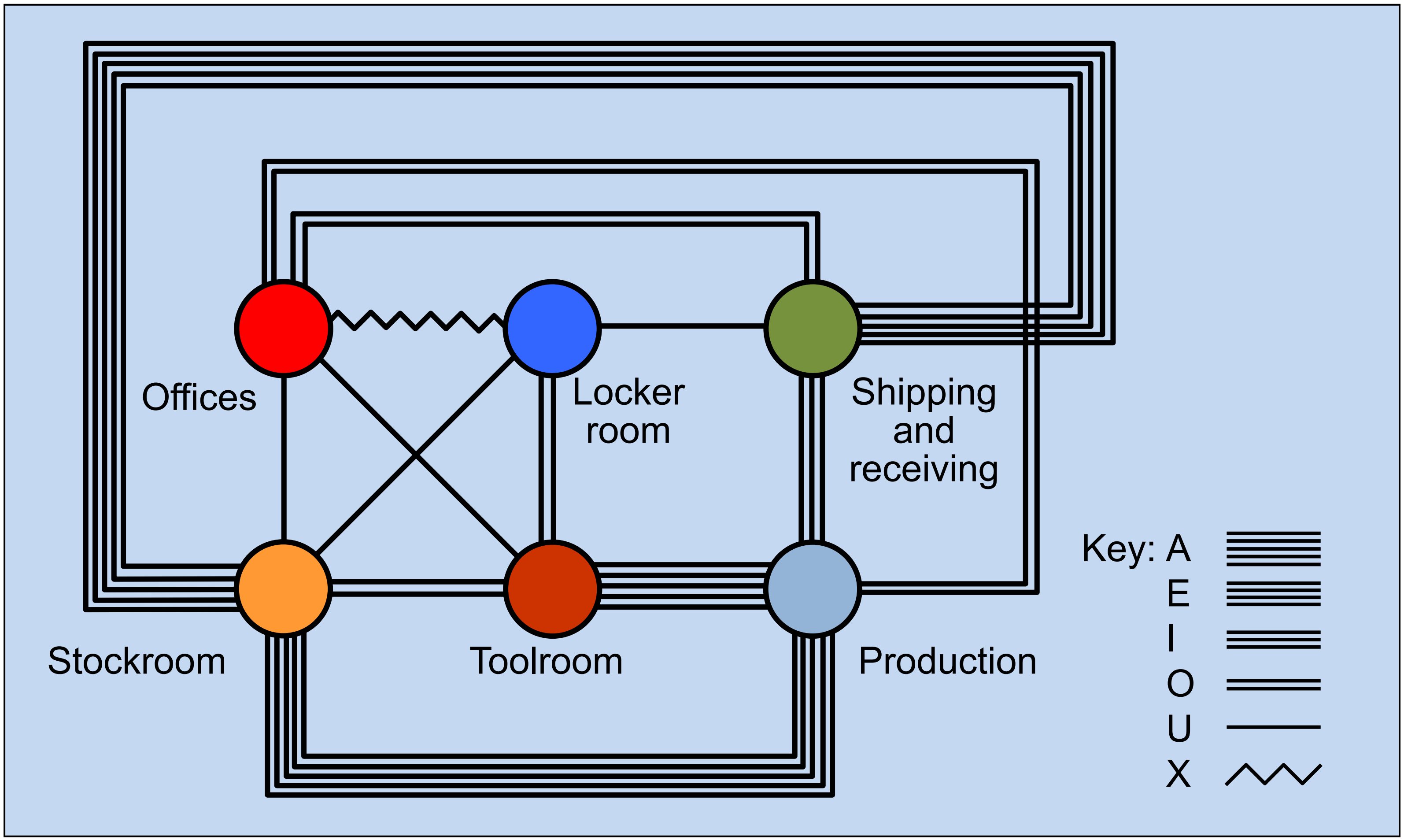


Relationship Diagramming



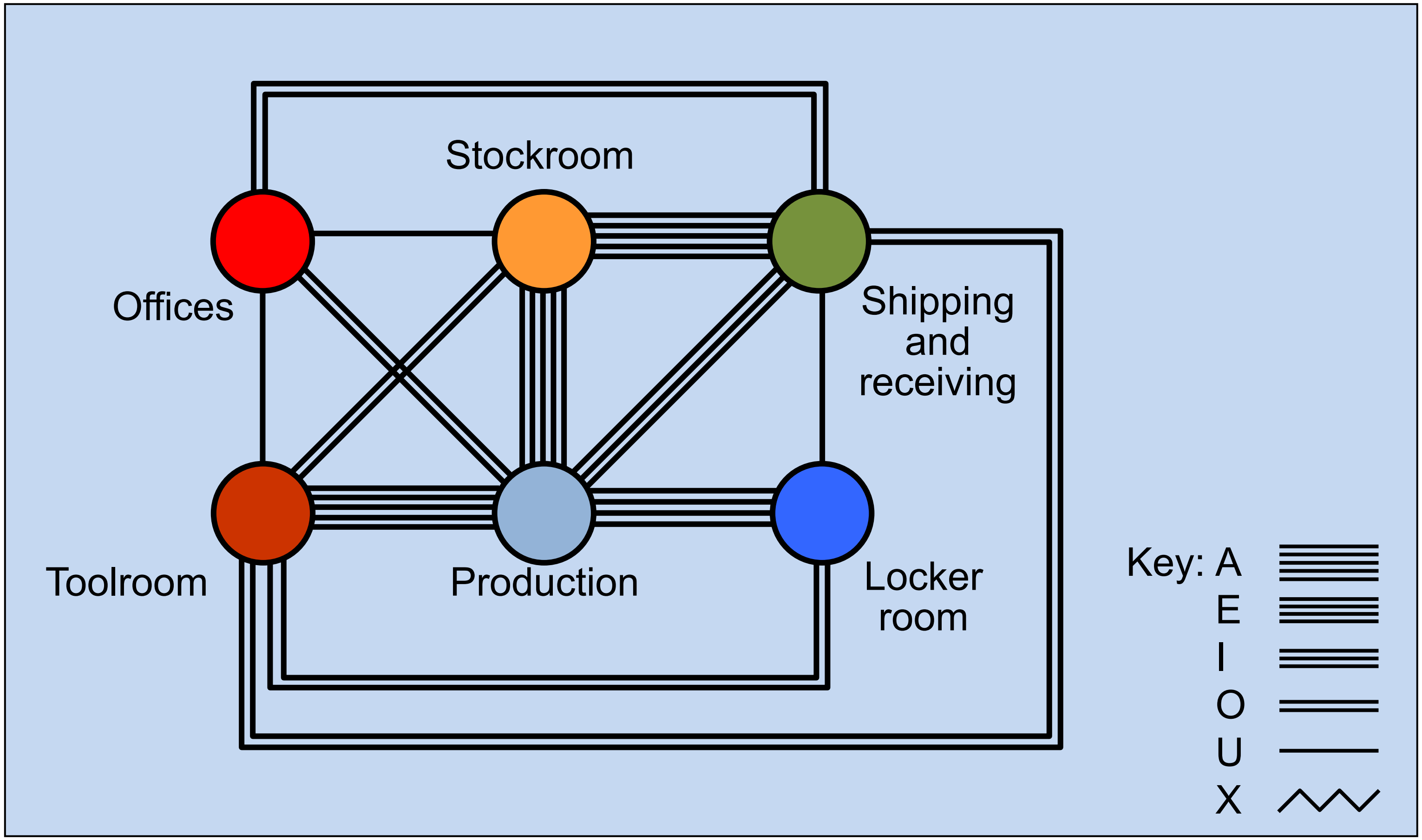
Relationship Diagramming

(a) Relationship diagram of original layout



Relationship Diagramming

(b) Relationship diagram of revised layout



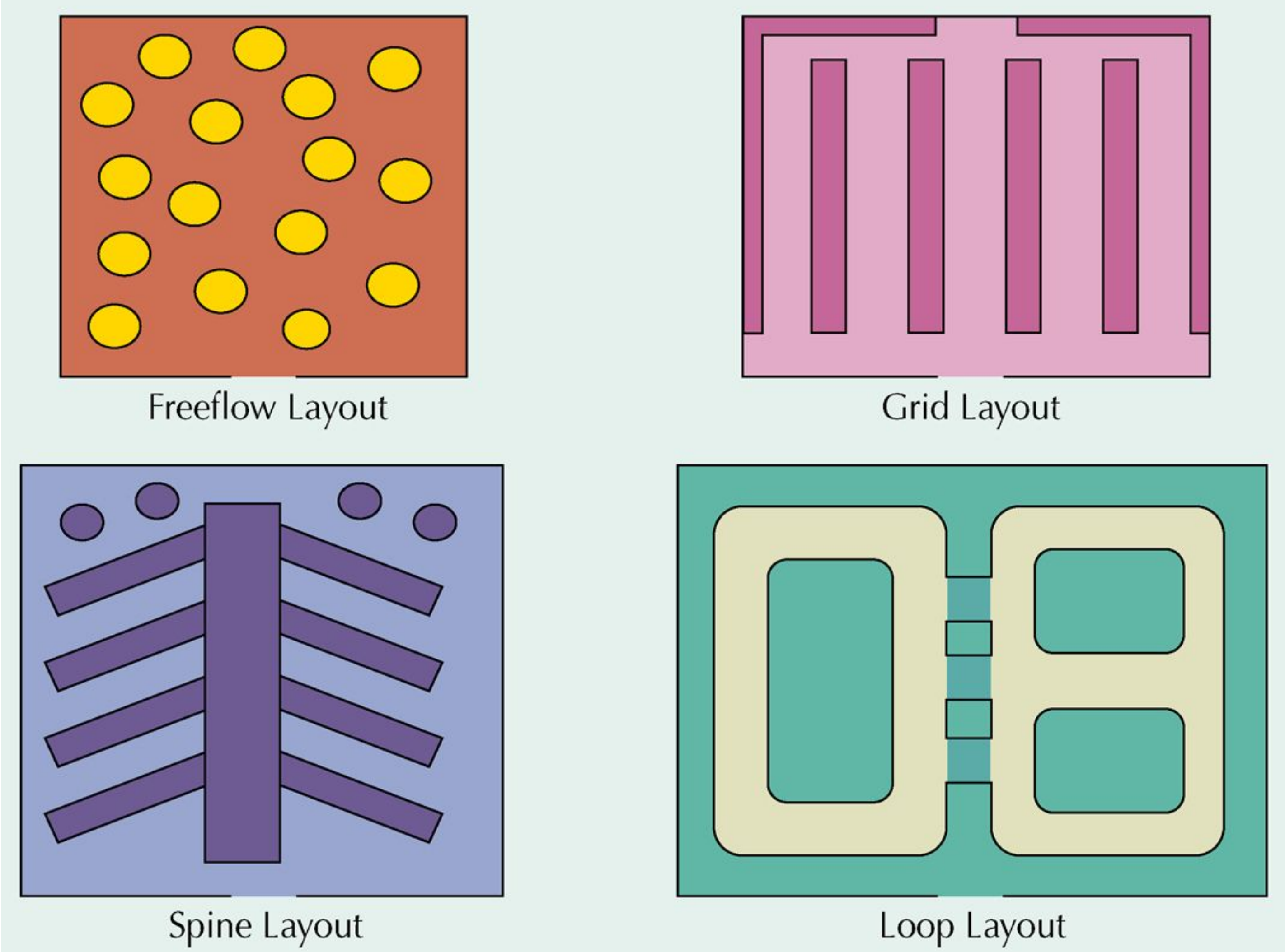
Computerized Layout Solutions

- 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



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

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

$$C_d = \frac{}{}$$

$$C_d =$$

Cycle Time Example

Produce 120 units in an 8-hour day

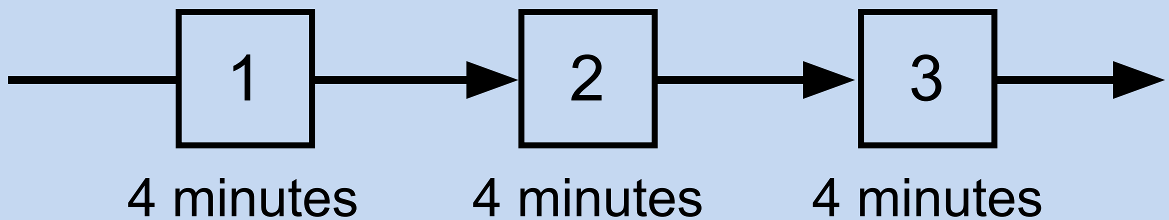
$$C_d = \frac{\text{production time available}}{\text{desired units of output}}$$

$$C_d = \frac{(8 \text{ hours x } 60 \text{ minutes / hour})}{(120 \text{ units})}$$

$$C_d = \frac{480}{120} = 4 \text{ minutes}$$

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

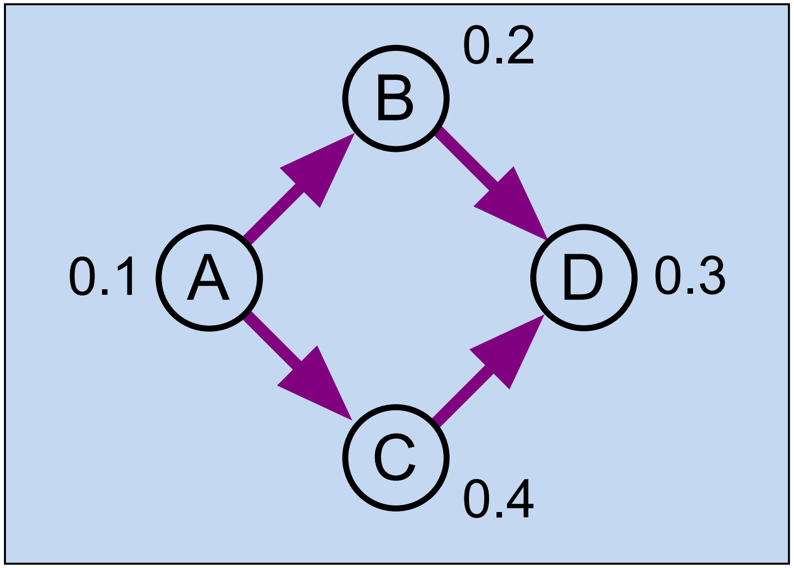
C_d = desired cycle time

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

	Work Element	Precedence	Time (Min)
A	Press out sheet of fruit	—	0.1
B	Cut into strips	A	0.2
C	Outline fun shapes	A	0.4
D	Roll up and package	B, C	0.3



Line Balancing

	Work Element	Precedence	Time (Min)
A	Press out sheet of fruit	—	0.1
B	Cut into strips	A	0.2
C	Outline fun shapes	A	0.4
D	Roll up and package	B, C	0.3

C_d =

N =

Line Balancing

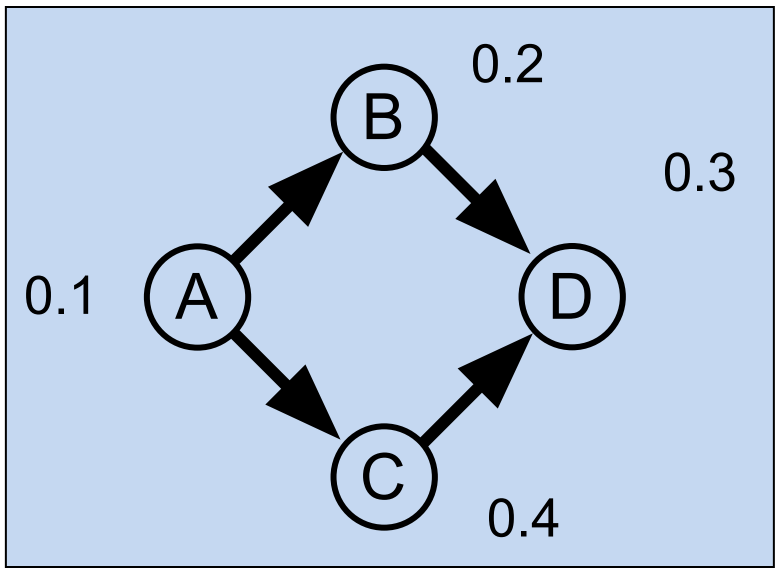
	Work Element	Precedence	Time (Min)
A	Press out sheet of fruit	—	0.1
B	Cut into strips	A	0.2
C	Outline fun shapes	A	0.4
D	Roll up and package	B, C	0.3

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

$$N = \frac{0.1 + 0.2 + 0.3 + 0.4}{0.4} = \frac{1.0}{0.4} = 2.5 \square\ 3 \text{ workstations}$$

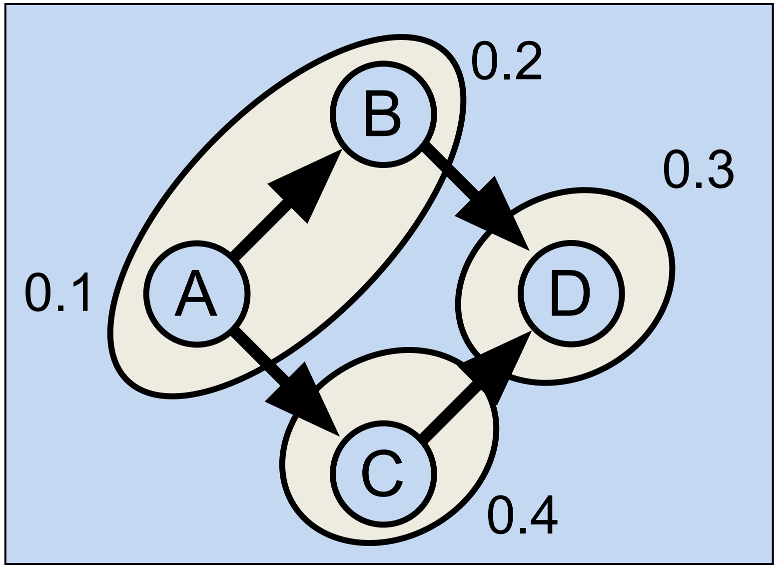
Line Balancing

Workstation	Element	Remaining Time	Remaining Elements
1			
2			
3			



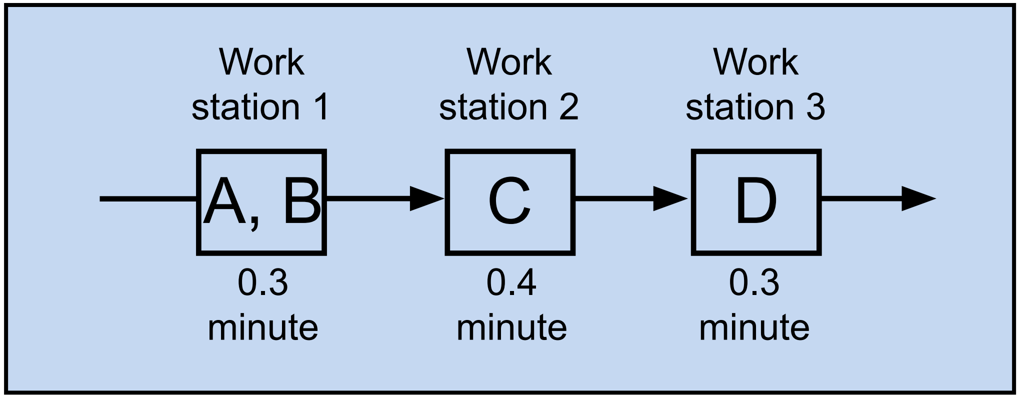
Line Balancing

Workstation	Element	Remaining Time	Remaining Elements
1	A	0.3	B, C
	B	0.1	C, D
2	C	0.0	D
3	D	0.1	none



$C_d = 0.4$
$N = 2.5$

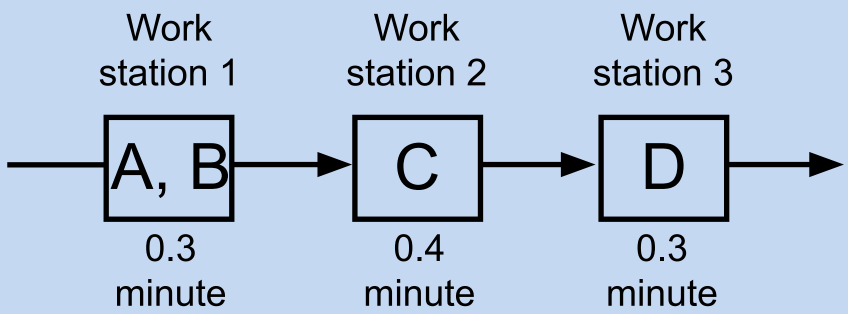
Line Balancing



$C_d = 0.4$
$N = 2.5$

$E =$

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

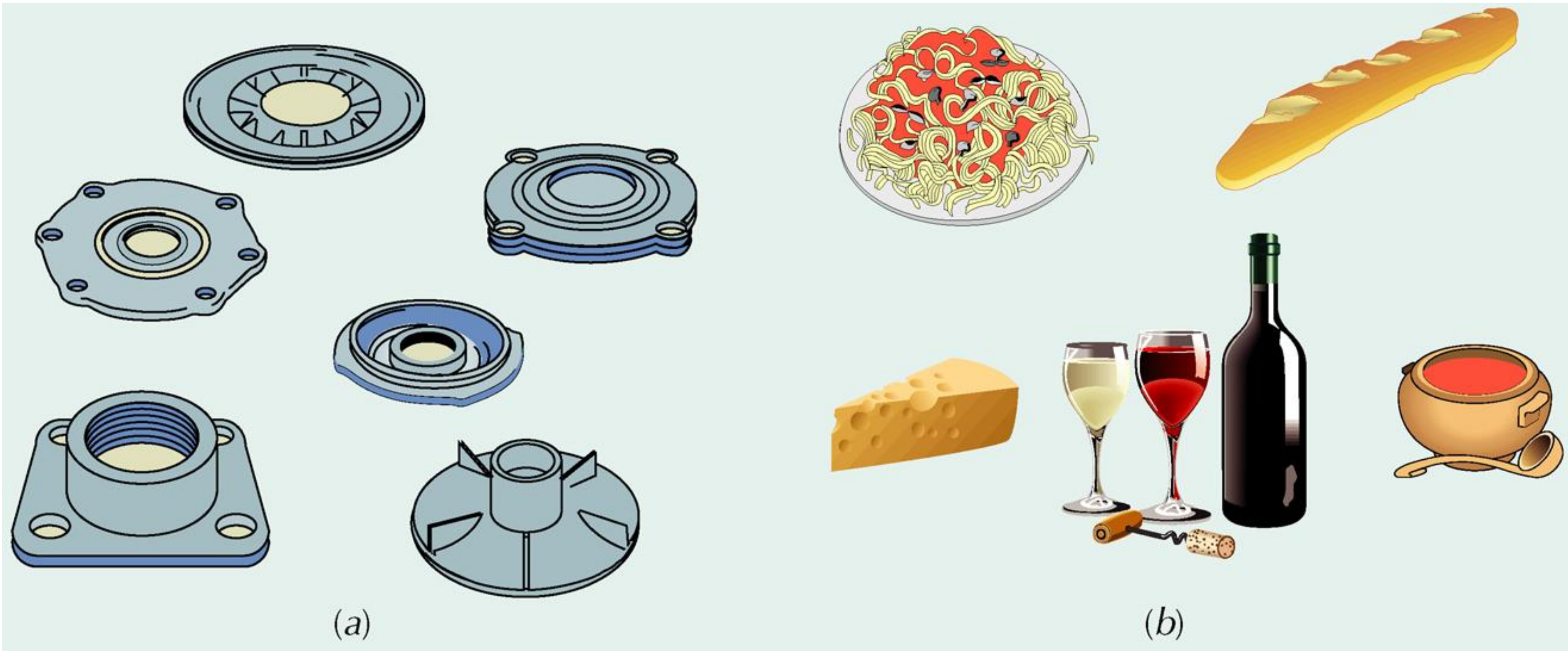
Hybrid Layouts

- 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

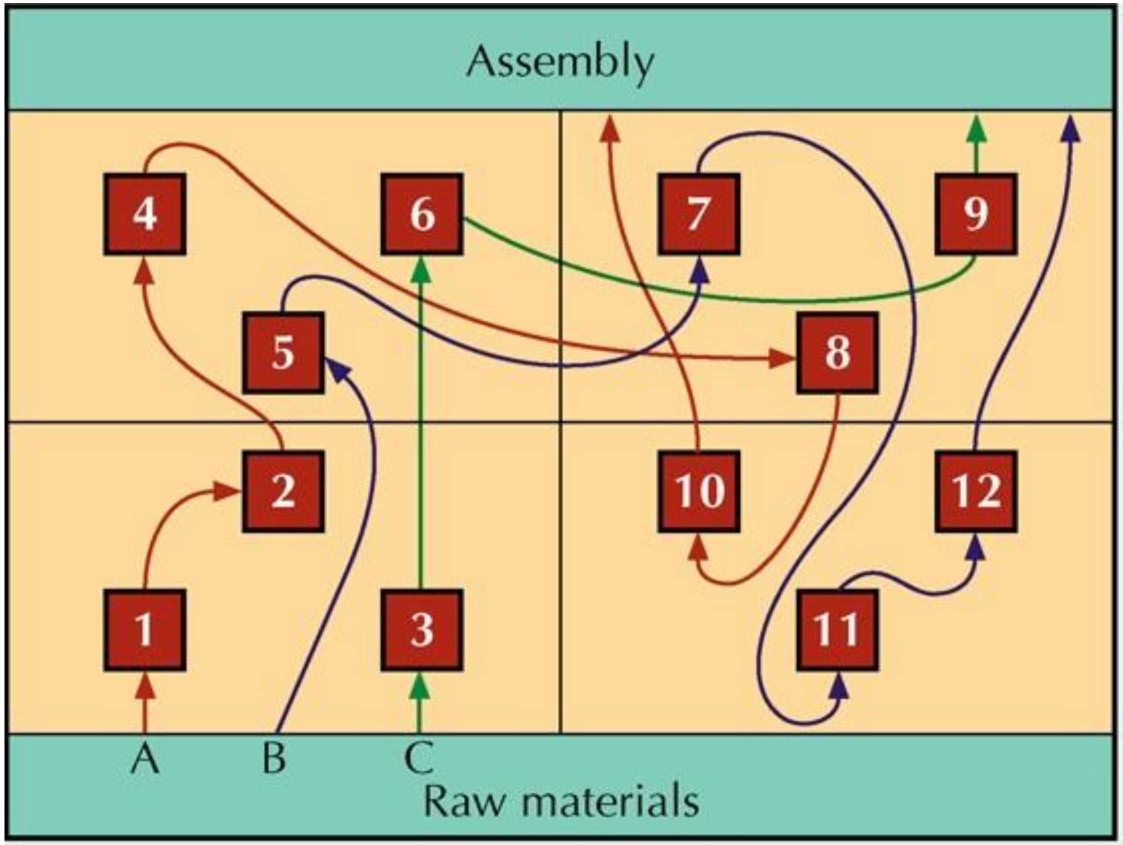
Parts Families



A family of similar parts

A family of related grocery items

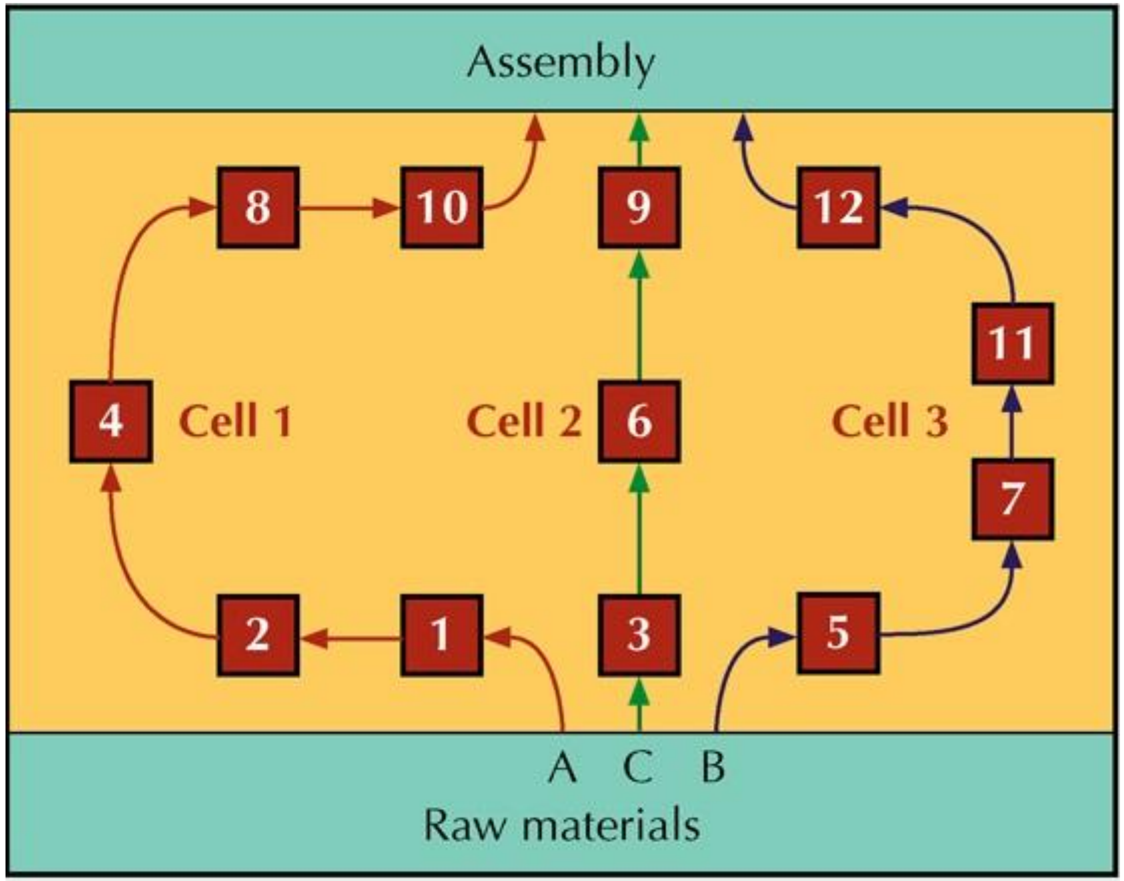
Original Process Layout



Part Routing Matrix

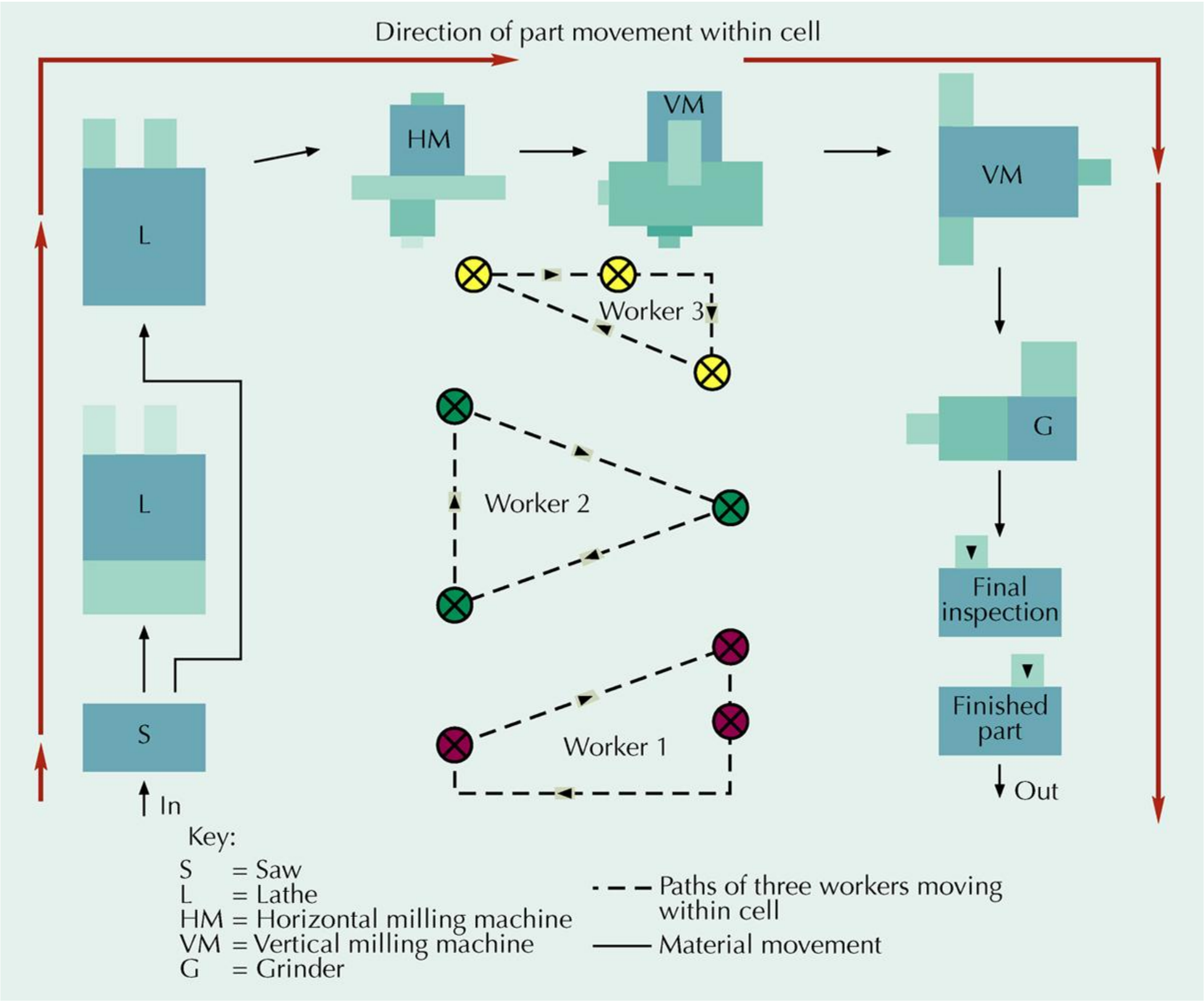
Parts	Machines 1	2	3	4	5	6	7	8	9	10	11	12
A	×	×		×				×		×		
B					×		×				×	×
C			×			×			×			
D	×	×		×				×		×		
E					×	×						×
F	×			×				×				
G			×			×			×			×
H							×				×	×

Revised Cellular Layout



Reordered Routing Matrix

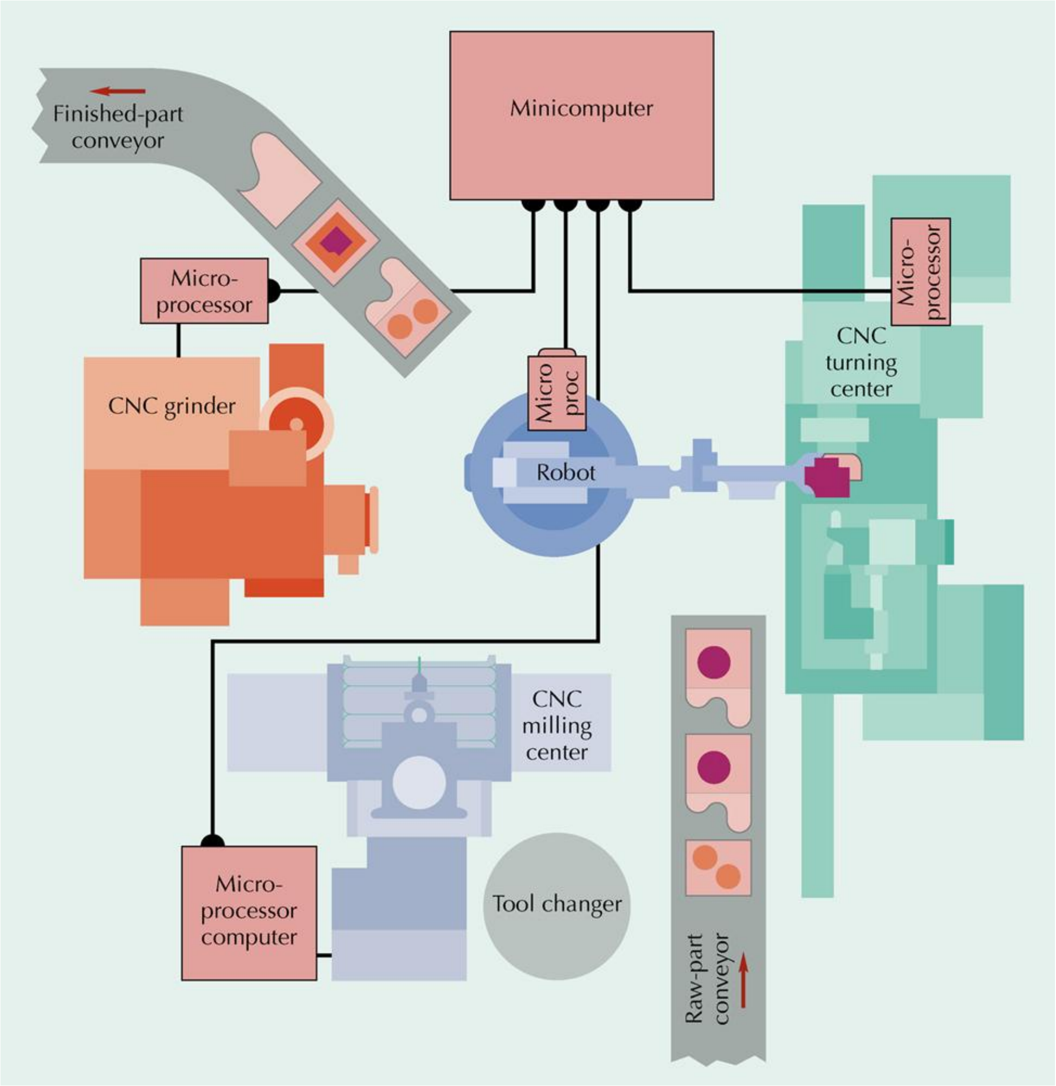
	Machines											
Parts	1	2	4	8	10	3	6	9	5	7	11	12
A	×	×	×	×	×							
D	×	×	×	×	×							
F	×		×	×								
C						×	×	×				
G						×	×	×				×
B									×	×	×	×
H										×	×	×
E							×		×			×


Direction of part movement within cell
HM
VM
VM
L
Worker 3
G
L
Worker 2
Final inspection
Worker 1
Finished part
S
In
Out
Key:
S = Saw
L = Lathe
HM = Horizontal milling machine
VM = Vertical milling machine
G = Grinder
Paths of three workers moving within cell
Material movement

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

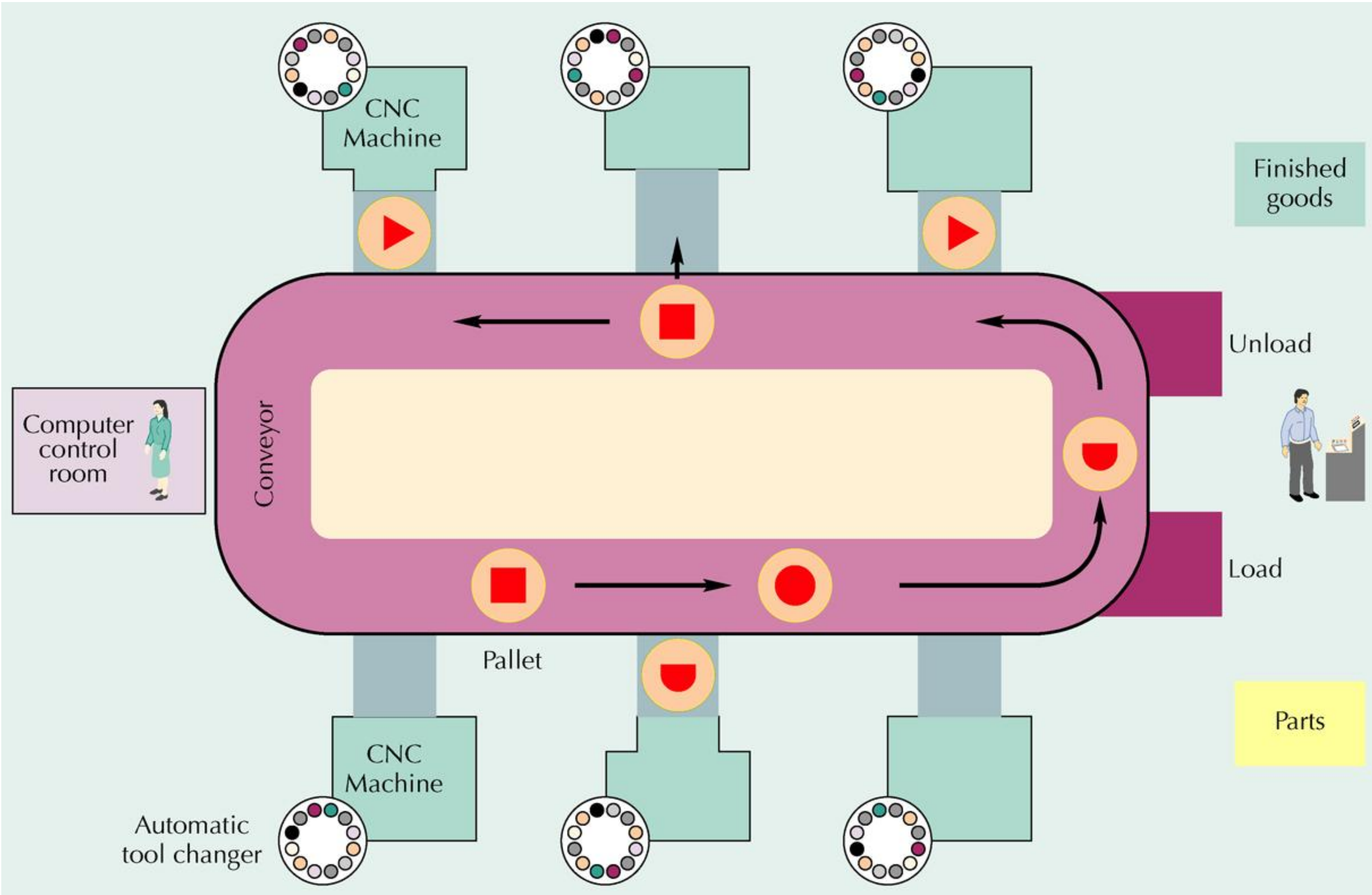
Automated Manufacturing Cell



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