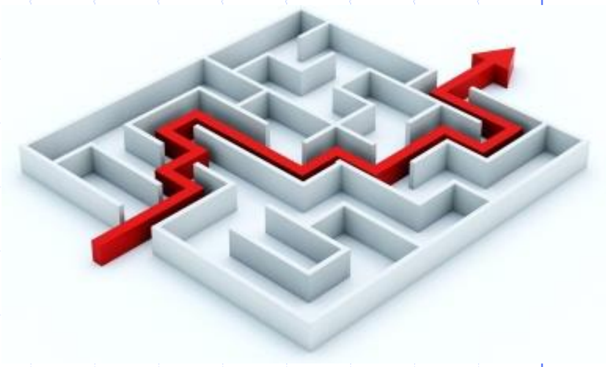
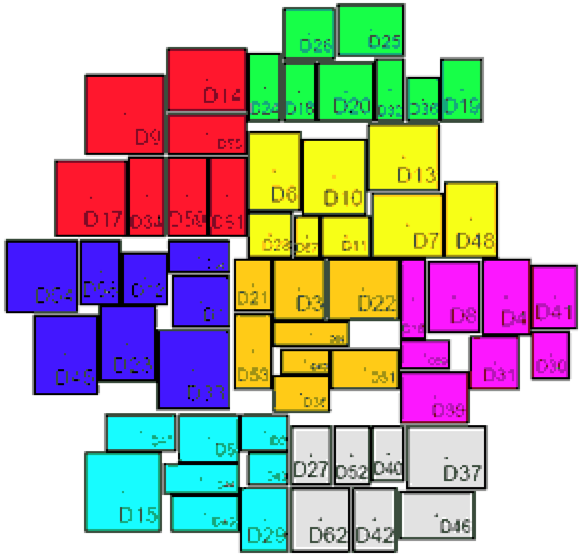
Chapter 3

Flow Systems, Activity Relationships, and Space Requirements

Introduction



- **Flow**
  - Flow of materials, people, equipment, information, money, etc.
  - Flow into, within and from manufacturing facility



- **Space**
  - The amount of space required in the facility
  - Workstation specification, department specification and other space requirements
- **Activity relationships**
  - Activity relationship is the key input in facilities design
  - Defined by flow relationships, organizational relationships, environmental relationships, process relationships and control relationships

Introduction (Contd.)

- Data Needed for Layouts:

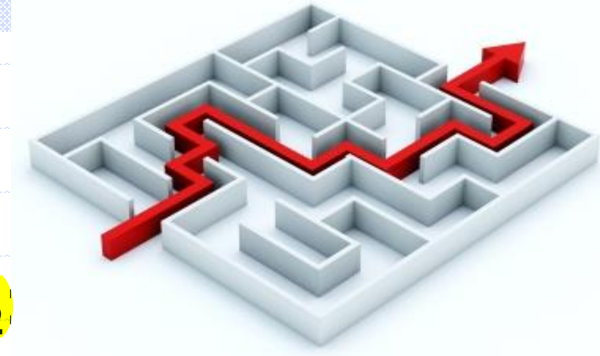
- Frequency of trips or flows of materials measure the interaction between facilities
  - Flow

- Floor space available and space requirements
  - Space

- Adjacency requirements between pairs of activities
  - Activity relationships

- Shape and size and Location **restrictions** for facility

Flow Systems



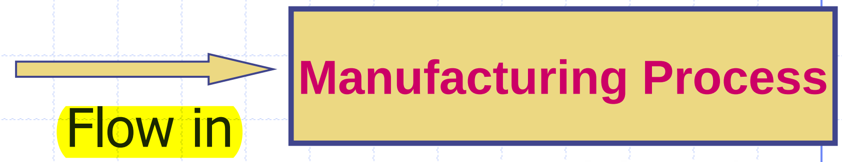
Flow process have three characteristics

1. Subject or item to be processed.
2. Resources required for processing or transportation.
3. Communication: procedures that coordinate the resources.

Types of Manufacturing Flows:

1. Flow into the facility (Material Management System)
2. Flow within the facility (**Material Flow System**)
3. Flow out of the facility (Physical Distribution System)

Flow Systems (contd.)



1. Flow into the facility:

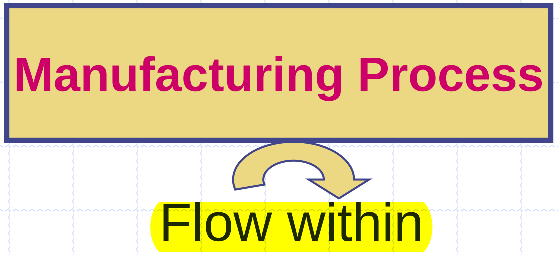
<u>Resources</u>:

- Production control and purchasing functions
- Vendors
- Transportation and material handling to move the material or parts
- Receiving and storage

<u>Communication</u>:

- Production forecasts
- Inventory records
- Purchase order
- Move tickets
- Electronic data Interchange (EDI)
- Kanbans
- Etc.

Flow Systems (contd.)



2. Flow within the facility:

- Determined by the type of departments.

Resources:

- Production control and quality control depts.
- Manufacturing, assembly, and storage depts.
- Material handling to move materials, parts, supplies.
- Warehouse

Communication:

- Production schedules
- Work order release
- Move tickets
- Kanbans
- Route sheets
- Warehouse records

Flow Systems (contd.)

Manufacturing Process → Flow out

3. Flow out of the facility:

<u>Resources</u>:

- The customer.
- Sales and accounting departments and warehouses.
- The material handling system and transportation equipment.
- Distributors of the finished product.

<u>Communication</u>:

- Sales orders
- Shipping reports and releases
- EDI invoices
- etc

Material Flow Systems

Patterns of flow may be viewed from the perspective of flow within workstations, within departments, and between departments.

1. **Flow within workstation:**
   - Motions studies and ergonomics considerations are important in establishing the flow within workstations.
   - For example, flow within workstations should be simultaneous, symmetrical, natural, rhythmical, and habitual.

Material Flow Systems (contd.)

2. **Flow within department:**

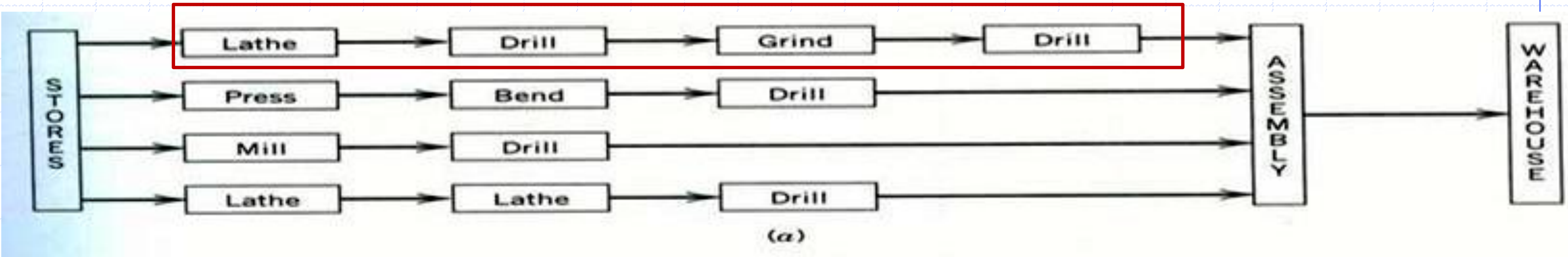
- Examples:

  Locating machines within a department

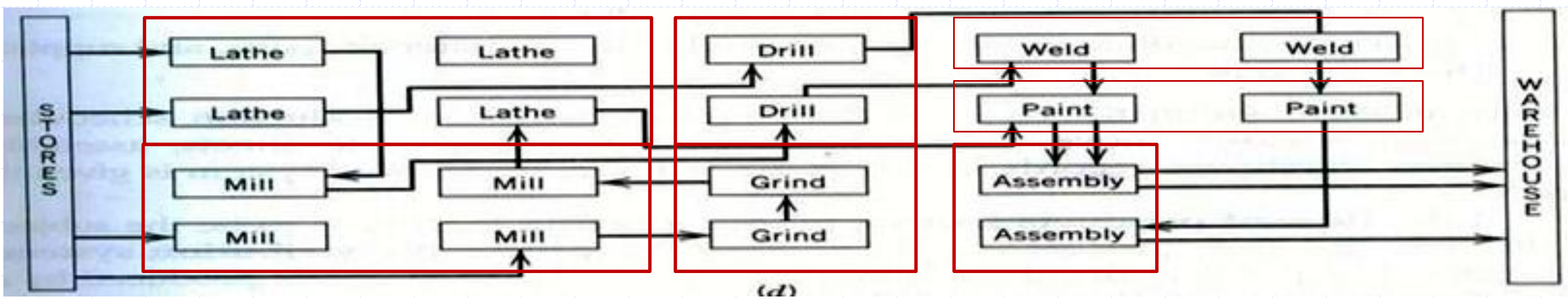
  Laying out a hospital emergency room.

- Dependent on the type of department (process or product department).

- For a product department, the flow will follow the layout of the machines. The possible flow patterns are:
  - End-to-end, back-to-back
  - Front-to-front
  - Circular

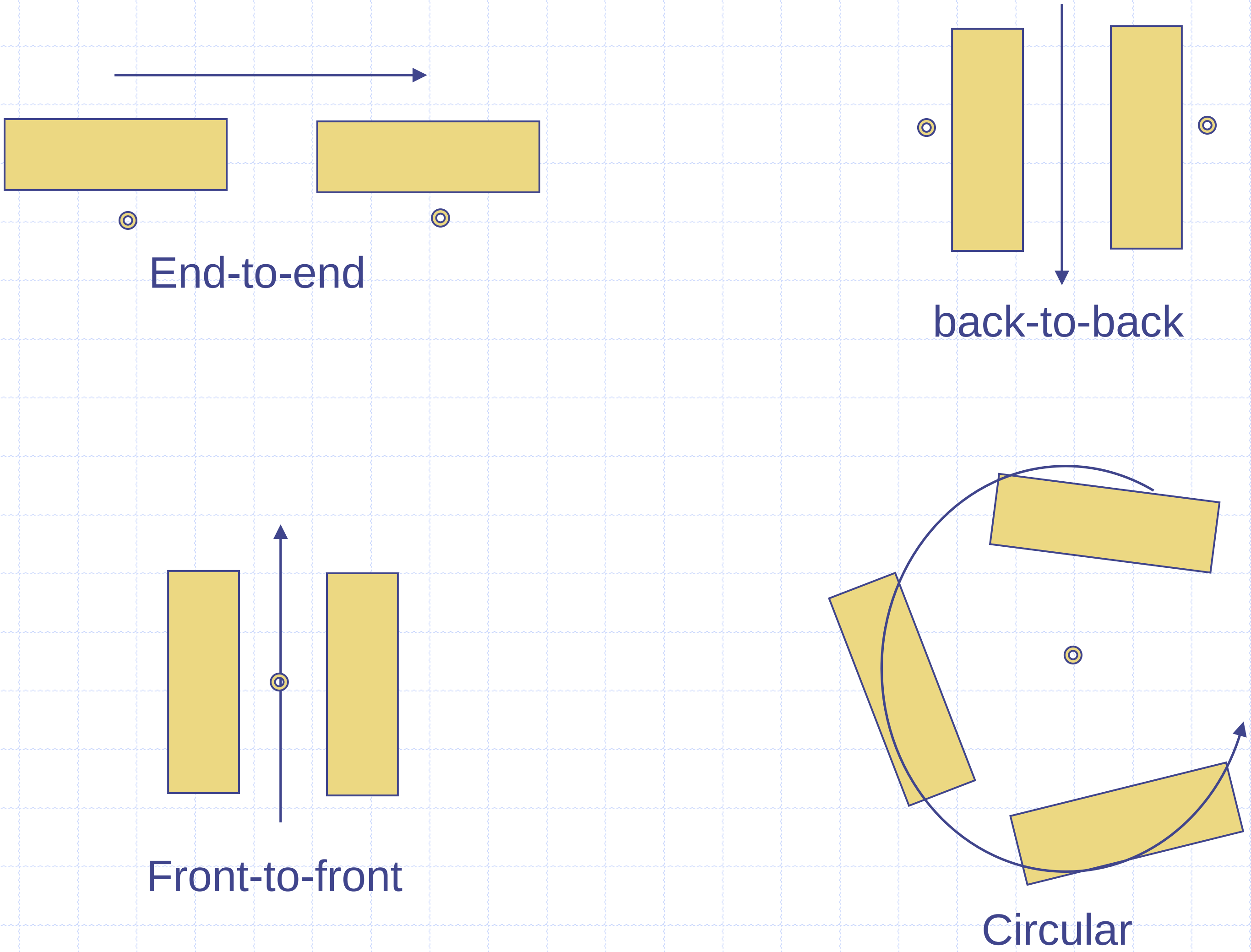


Product Department



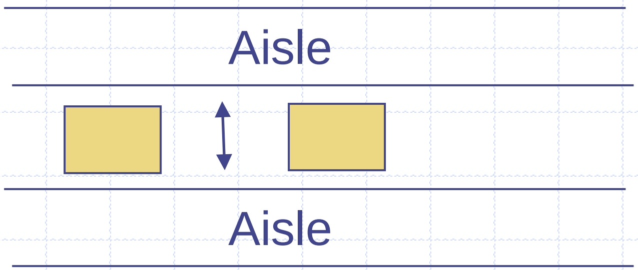
Process Department

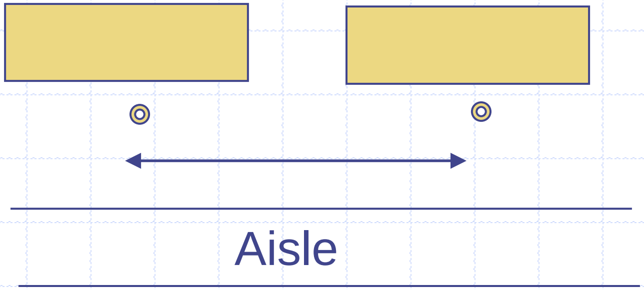
Material Flow Systems (contd.)

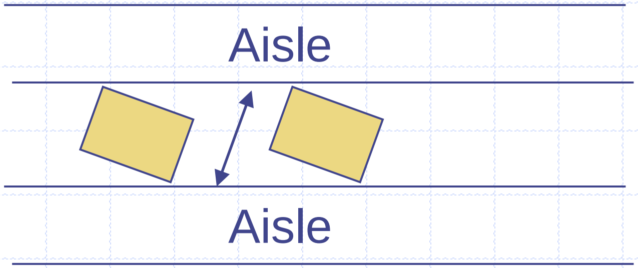


Material Flow Systems (contd.)

- For a process department, little intradepartmental flow. Most is between the department and aisles.
- Three examples of configurations:
  - Parallel
  - Perpendicular
  - Diagonal (not used often, assume one way aisles which are not common)







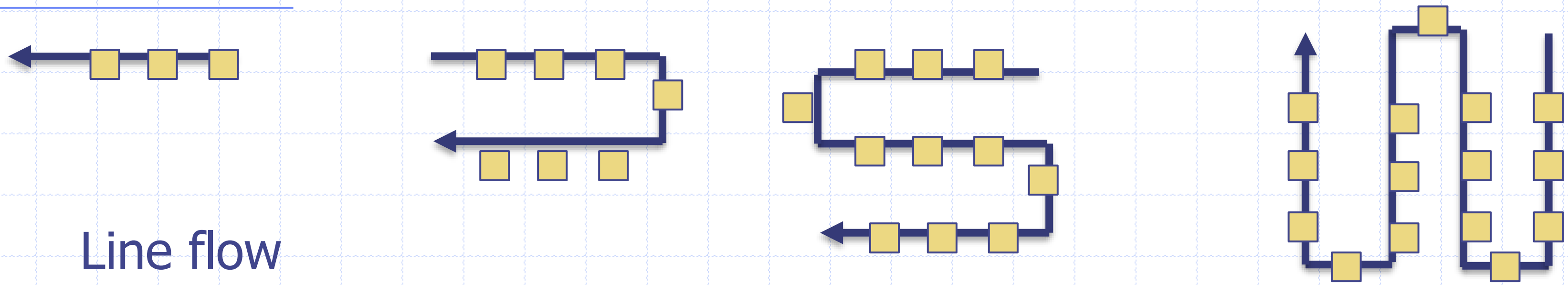
Material Flow Systems (contd.)

- In the case of mechanized and automated systems involving the use of continuously running conveyors, shuttle carts, automated guided vehicles, robots, and others.

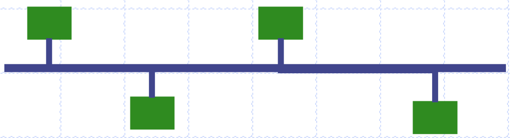
- Several primitive flow structures or patterns:

1. The line flow pattern:
    - Straight-line
    - U-shaped
    - S-shaped
    - W-shaped
2. The spine flow pattern
3. The loop flow pattern
4. The tree flow pattern

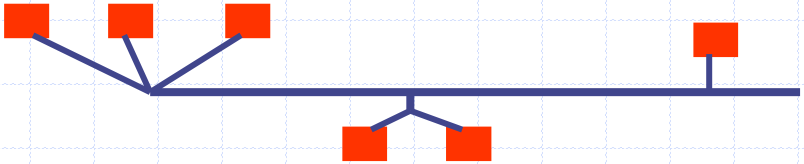
Material Flow Systems (contd.)



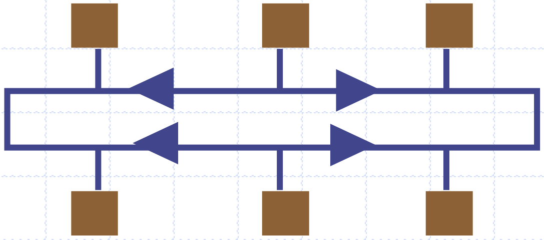
Line flow



Spine flow



Tree flow



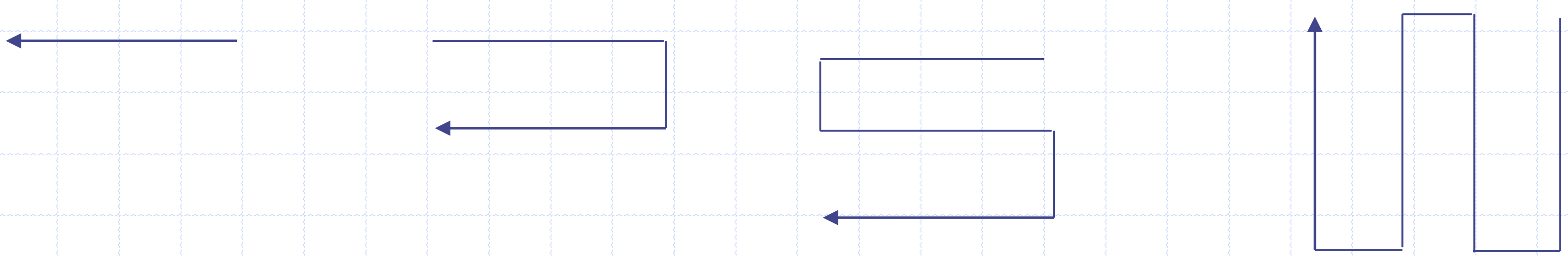
Inner loop

Material Flow Systems (contd.)

3. Flow between departments:

Flow typically consists of a combination of the four general flow patterns:

- Straight-line
- U-shaped
- S-shaped
- W-shaped



Material Flow Systems (contd.)

- An important consideration in combining the general flow patterns is the location of the entrance (receiving department) and exit (shipping department).
- Often these locations are fixed due to building construction
- Flow within facility should conform to the restricted locations of the entrance and exit.
- Examples, see Figure 3.25:
  - Entrance and exit can be: at the same location, on adjacent sides, same side but opposite ends, and on opposite sides

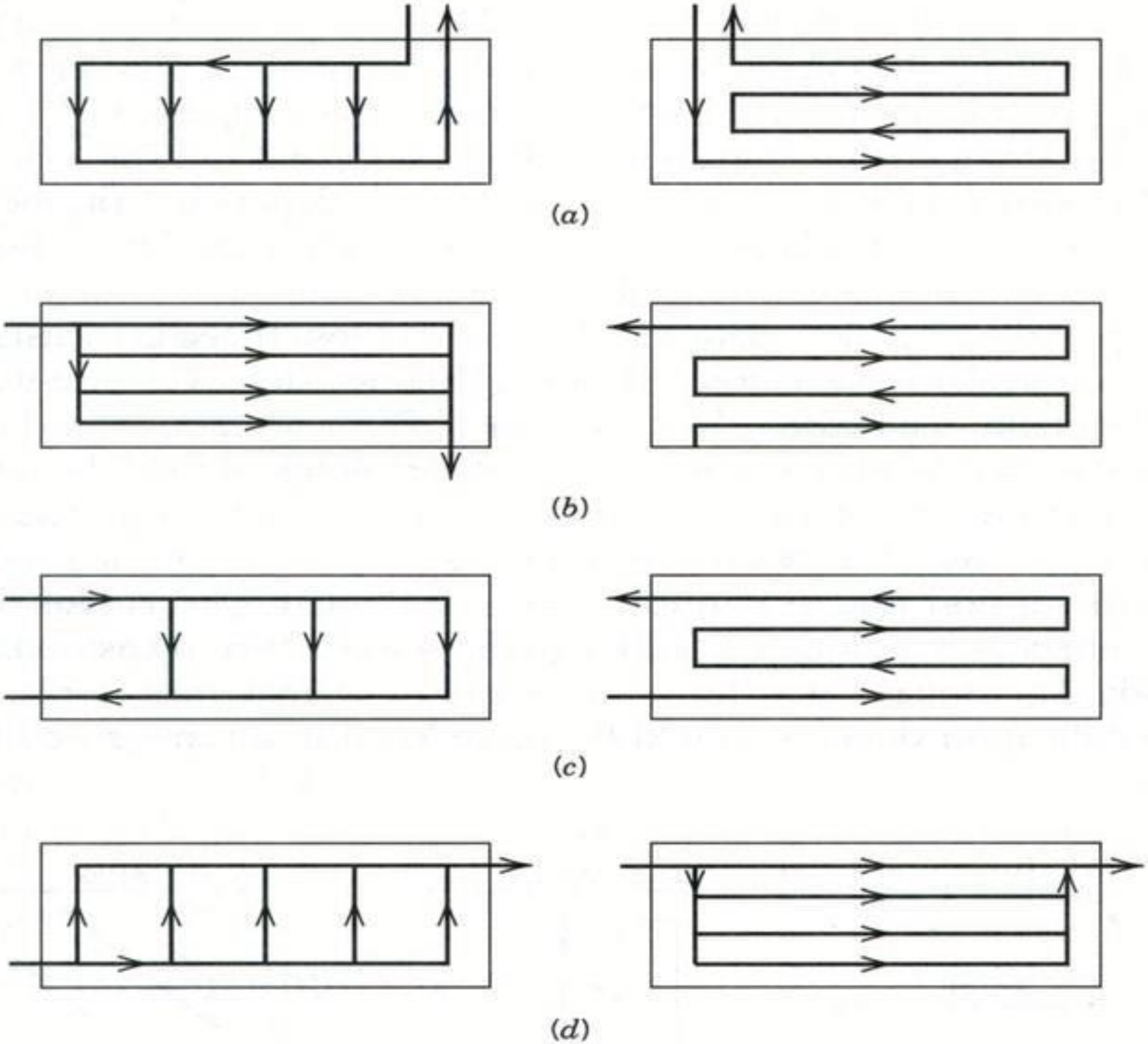
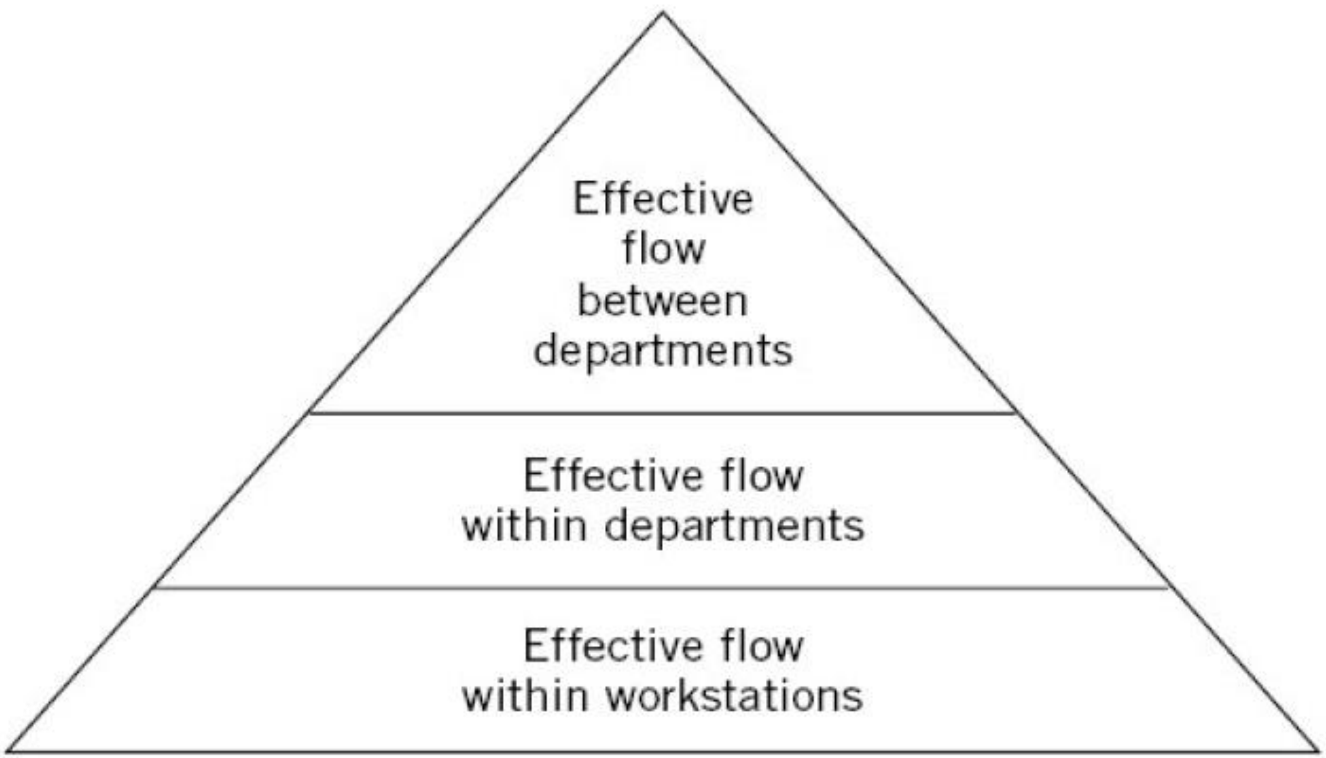


Figure 3.25 Flow within a facility considering the locations of the entrance and exit. (*a*) At the same location. (*b*) On adjacent sides. (*c*) On the same side but at opposite ends. (*d*) On opposite sides.

Material Flow Systems (contd.)
Flow Planning

- Effective flow planning is a hierarchal planning process.
- Effective flow between departments depends on effective flow within departments, which in turn depends on effective flow within workstations.



Material Flow Systems (contd.)
Flow Planning

- **Flow planning principles:**

1. Maximize direct flow path:

- Maximize directed uninterrupted flow paths. That is, the path does not intersect with other paths.
- Avoid backtracking which increases the length of the flow.

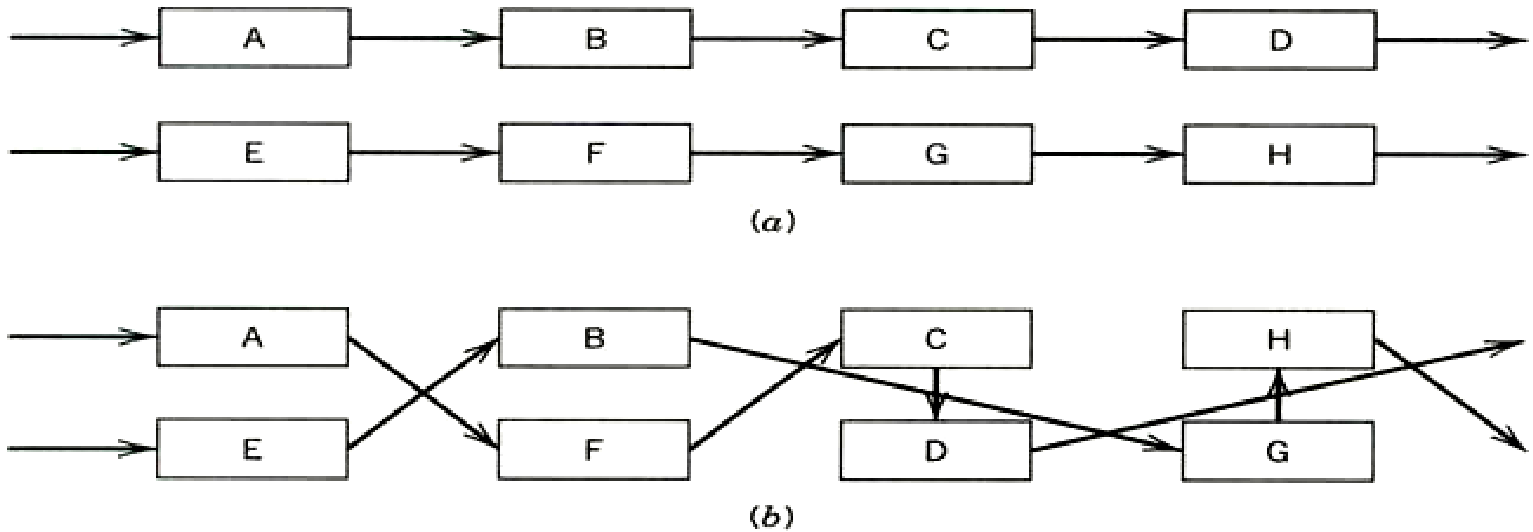


Figure 3.27 The impact of interruptions on flow paths. (*a*) Uninterrupted flow paths. (*b*) Interrupted flow paths.

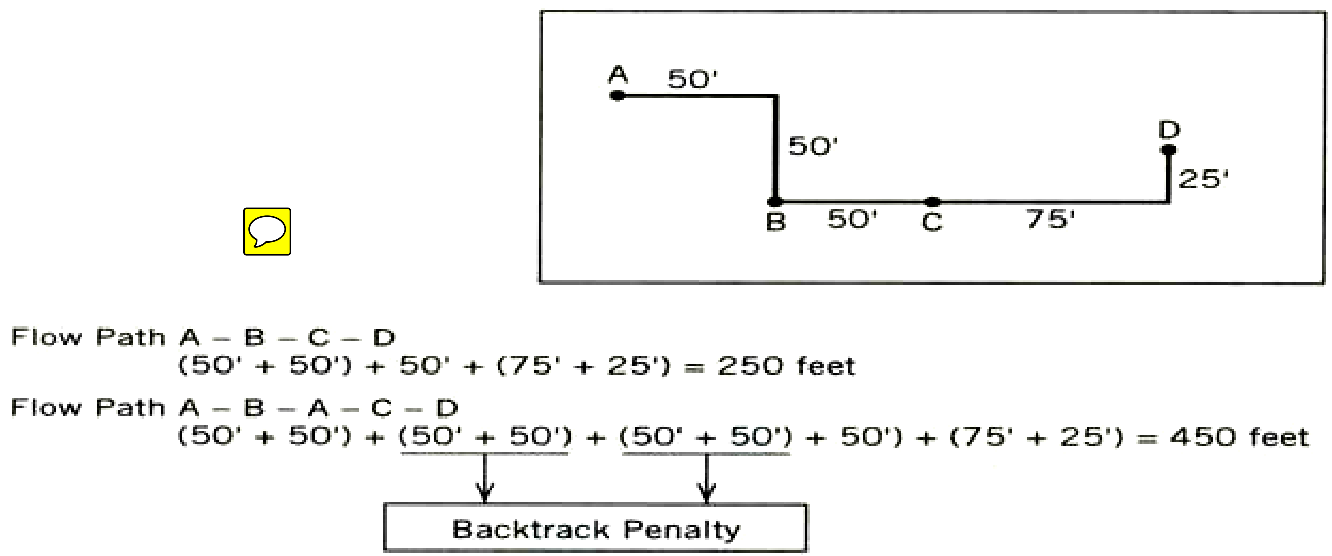


Figure 3.28 Illustration of how backtracking impacts the length of flow paths.

Material Flow Systems (contd.)
Flow Planning

2. **Minimize flow: work simplification approach**

   1. Eliminating flow by delivering materials, information, or people directly to the point of ultimate use and therefore eliminate intermediate steps.

   2. Plan for the flow between two consecutive points to require as few movements as possible – preferably one.

   3. Combine flows or operations where possible. Plan for the movement of material, information, or people to occur simultaneously with processing.

Material Flow Systems (contd.)

Flow Planning

3. **Minimize the cost of the flow:**

   1. Minimize manual handling by minimizing walking, manual travel distances, and motions.

   2. Eliminate manual handling by automation or mechanizing the flow . This lets workers devote their time to their operations – not material handling.

Material Flow Systems (contd.)
Flow Planning

- Possible indicators that the flow needs improvement:

1. Many units on carts, shelves, or conveyors waiting to be assembled.
2. Parts on the floor in bulk containers waiting to be assembled.
3. Shelving along the walls full of rejected parts or other items that may not have been disposed of.
4. Numerous rework benches, or a large amount of rework being performed on production benches.
5. Expensive machinery that is idle.
6. People expediting high-priority work orders.
7. Production status meetings being held every day.
8. Trash on the floor.
9. Anything in the aisles except people and transport equipment.
10. Operators making partial assemblies because of a part shortage.

Material Flow Systems (contd.)
Flow Planning

- Signs of a good general flow pattern:
  - A flow starts at receiving and terminates at shipping.
  - Straight and short lines of flow
  - Minimum backtracking
  - Materials moved directly to point of use
  - Minimum WIP
  - Flow pattern is easily expandable, new processes can easily be merged in

Departmental Planning

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Department Planning

- Concerned with **forming** planning department (production, service, support ,..etc.)

- Production Planning departments are collections of workstations to grouped together during the facility layout process.

- As a general rule, planning department needs to combine workstations that perform “like” functions.
- “Like‟ Functions
  - Similar products
  - Similar components
  - Similar processes

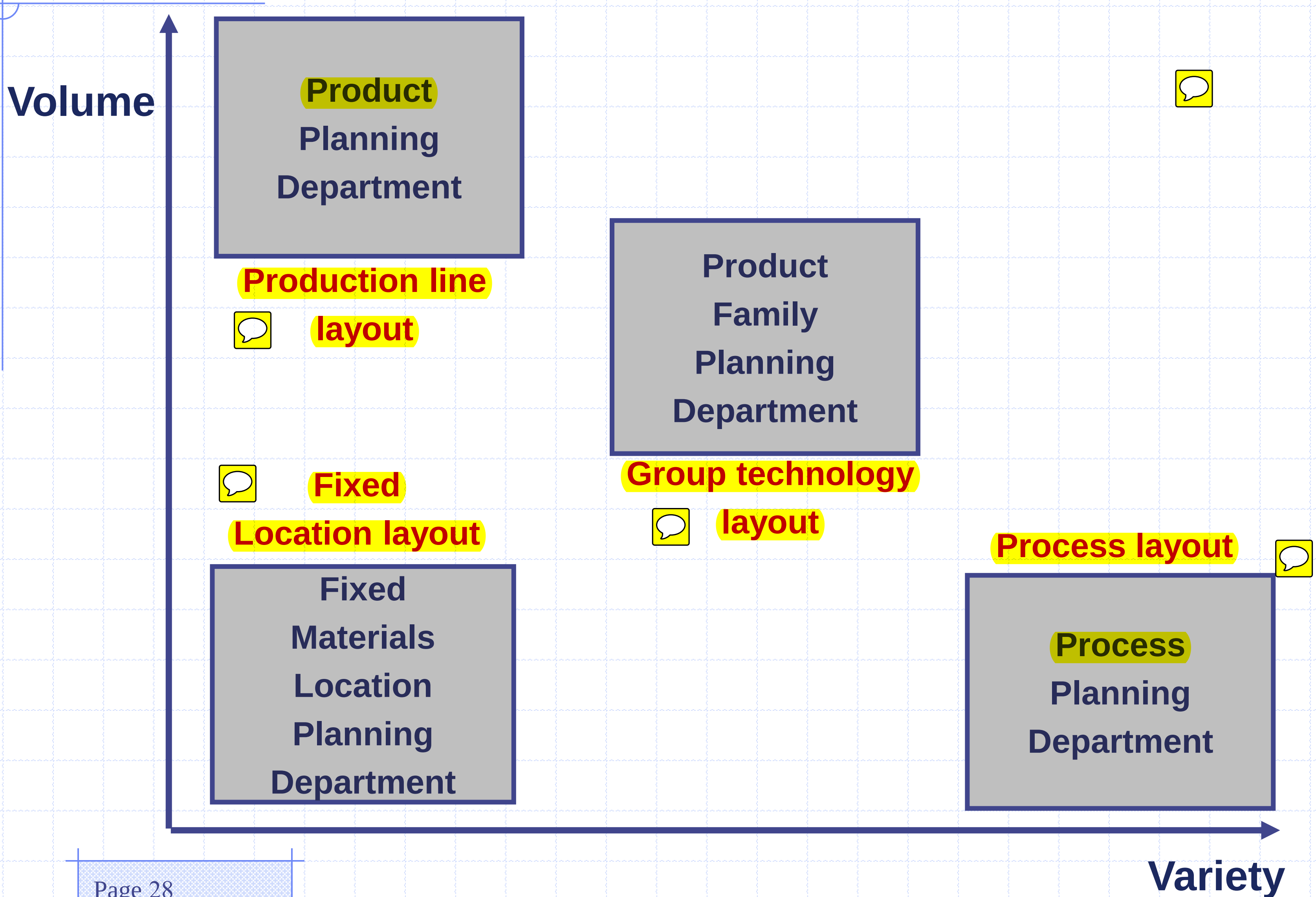
Department Planning (contd.)

General Types of Layouts

- Production line layout –
  - Large stable demand for a standardized product (engine, automobile)
- Fixed position layout –
  - Demand exists for large, awkward, difficult to move product such as aircraft
- Product family layout –
  - Medium demand for medium number of similar components
- Process layout –
  - Combine workstations that perform similar processes
- Hybrid layout –
  - Composition of several of the different types of layouts

Department Planning (contd.)

Volume/Variety Classification



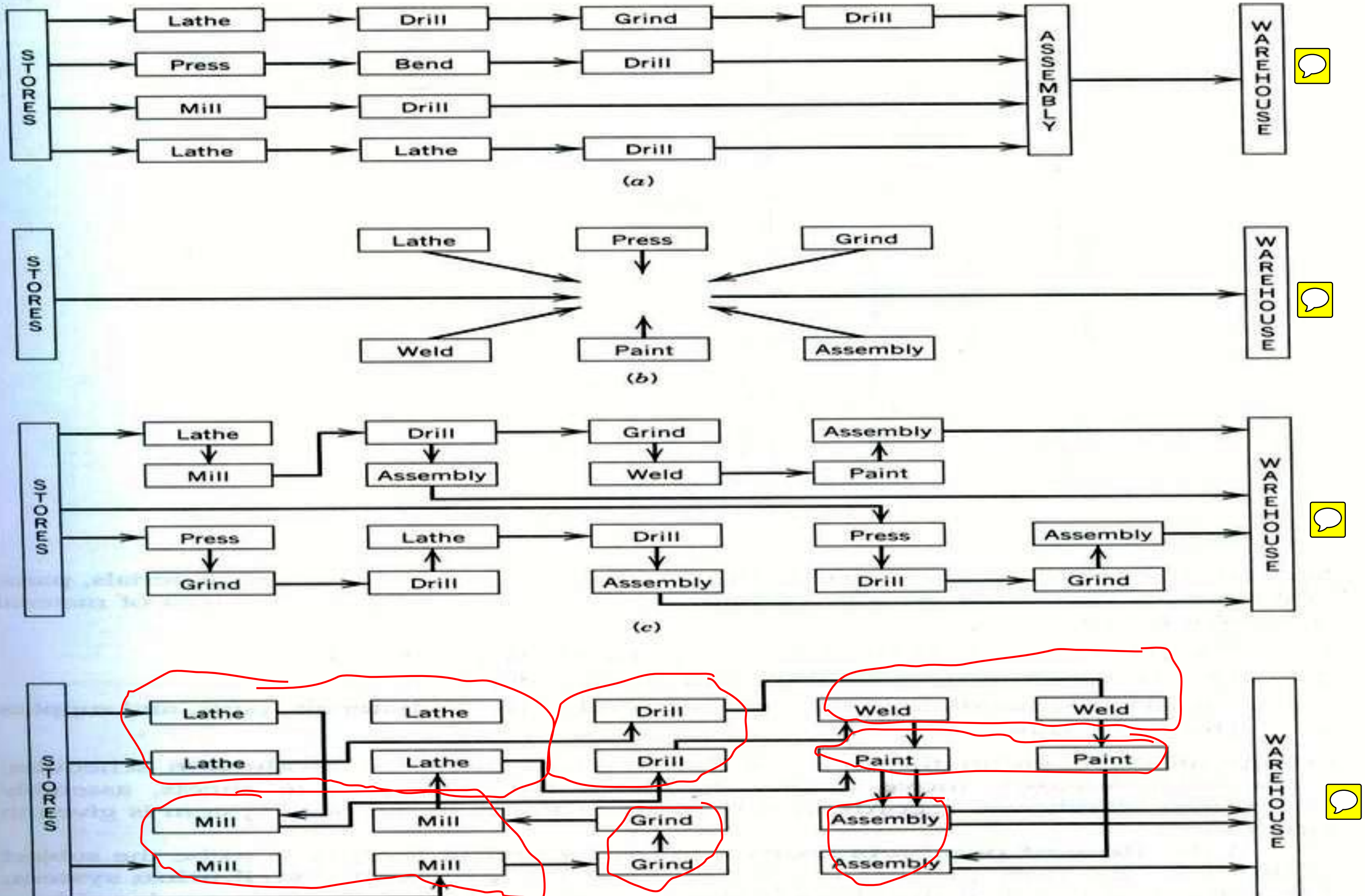


Figure 3.18 Material flow systems for various types of departments. (*a*) Product planning departments. (*b*) Fixed materials location planning departments. (*c*) Product family planning departments. (*d*) Process planning departments.

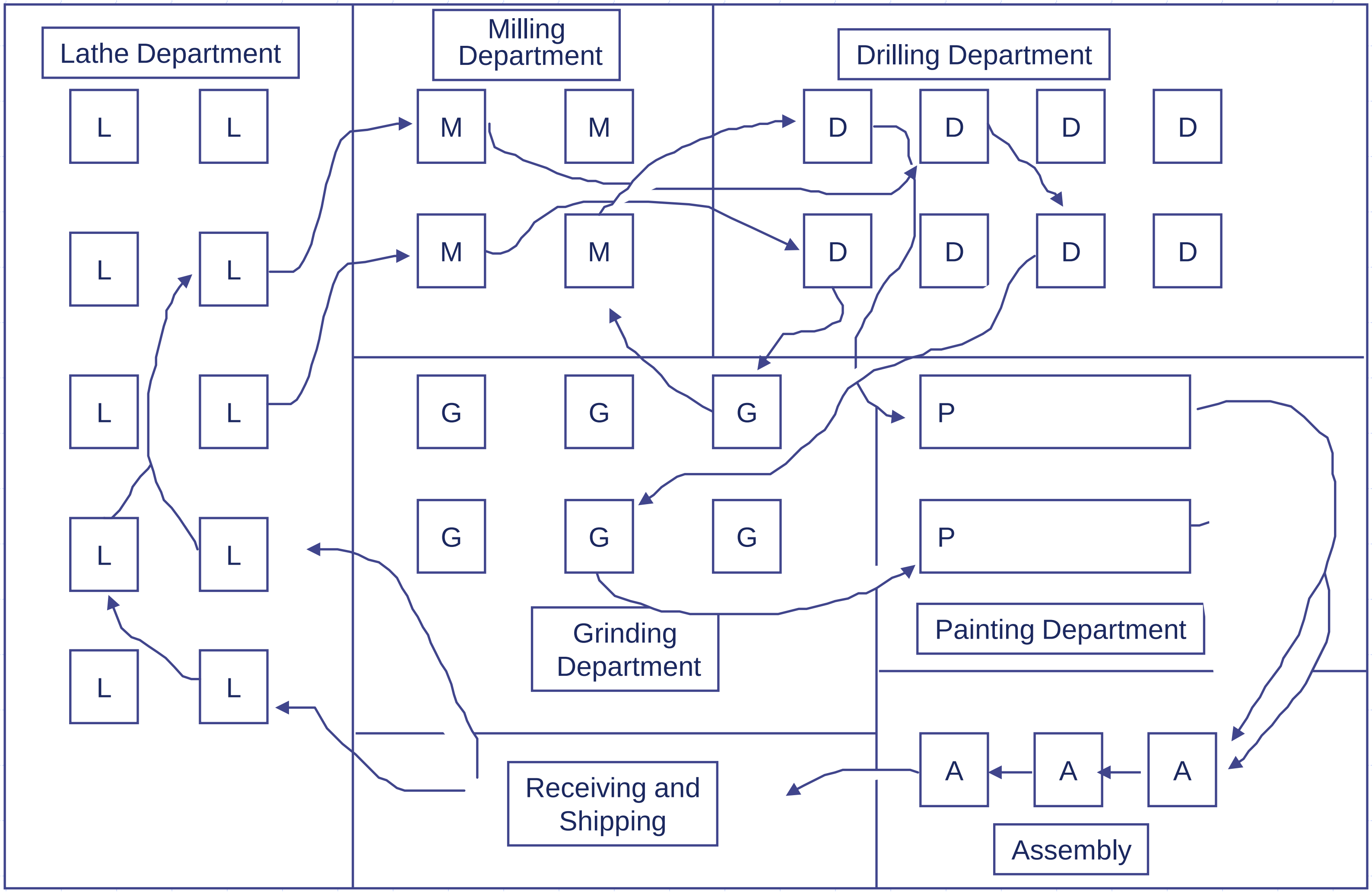
Guide for Combining Workstations Table 3.1

Table ***Procedural Guide for Combining Workstations in Planning Departments***

If the Product Is	The Type of Planning Department Should Be	And the Method of Combining Workstations into Planning Departments Should Be
Standardized and has a large stable demand.	Production line, product department.	Combine all workstations required to produce the product.
Physically large, awkward to move, and has a low sporadic demand	Fixed materials location, product department	Combine all workstations required to produce the product with the area required for staging the product
Capable of being grouped into families of similar parts that may be produced by a group of workstations	Product family, product department	Combine all workstations required to produce the family of products
None of the above	Process department	Combine identical work stations into initial planning departments and attempt to combine similar initial planning departments without obscuring important interrelationships within departments

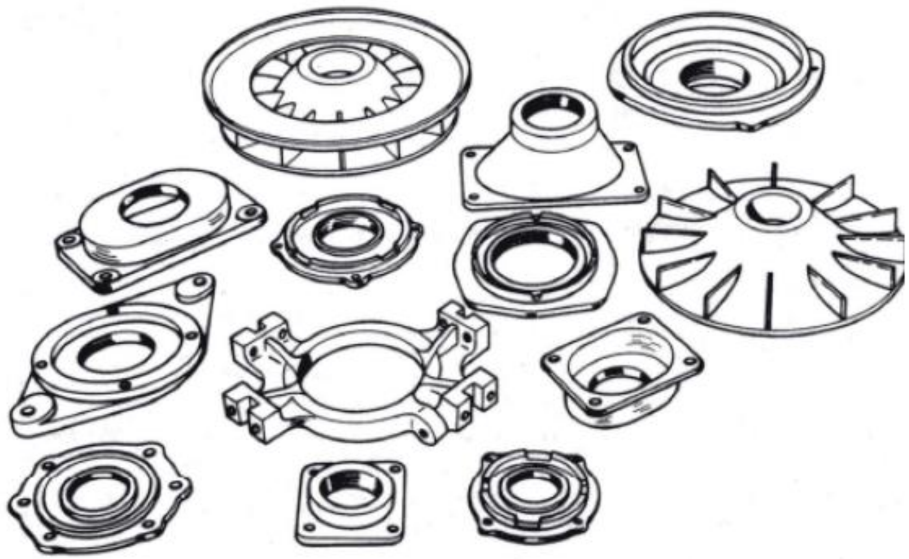
Support, administrative, and service planning departments have been traditionally treated as "process" departments, because similar activities are performed

Process Layout Example

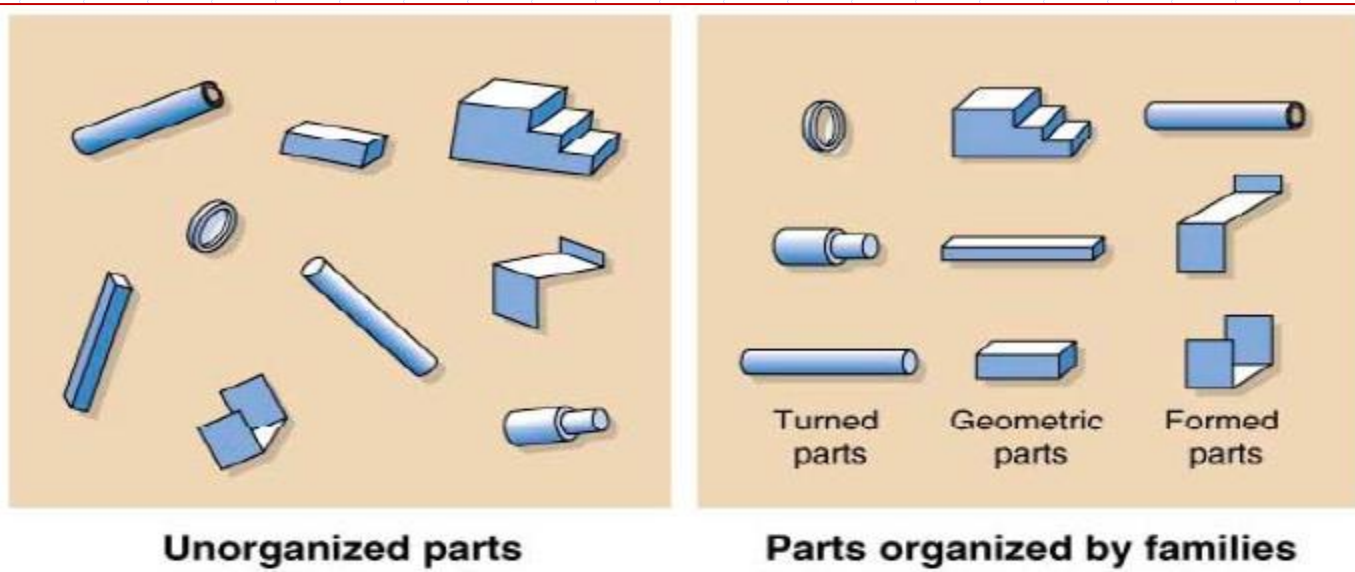


Product Family Departments
Manufacturing cells (Group Technology)

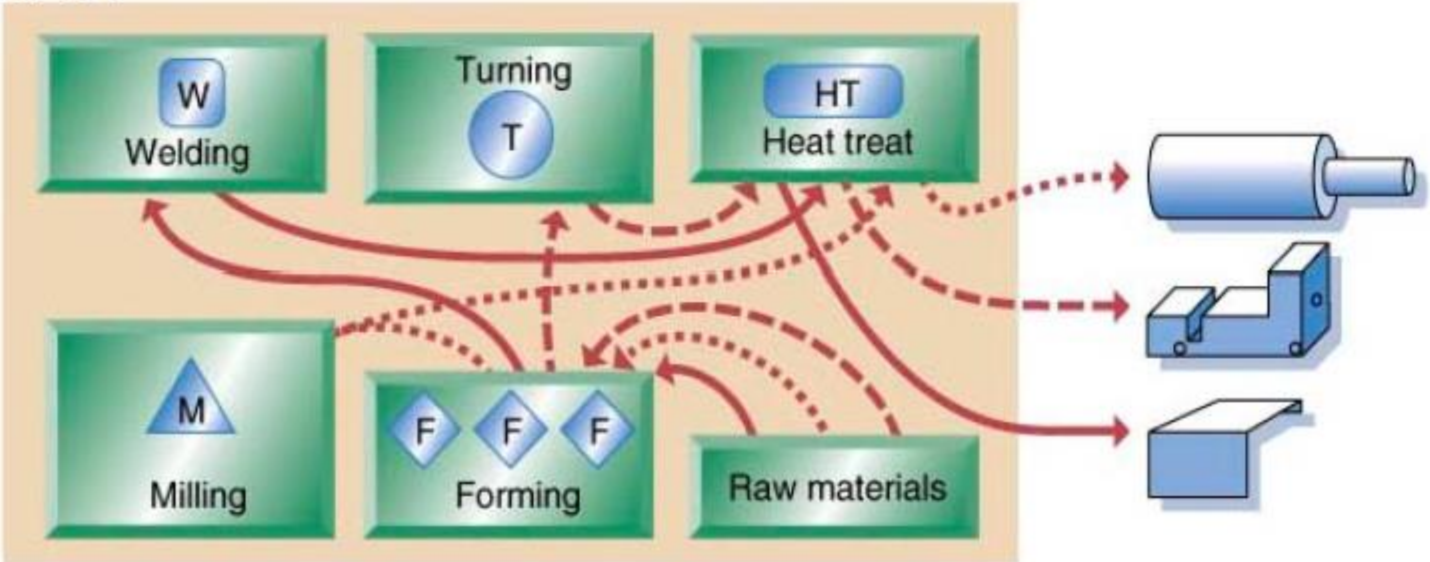
- *Product Family* or *Group Technology departments* aggregates medium volume-variety parts into families.
- Machines required to manufacture the part family are grouped to form cells (*cellular manufacturing*)
- Cells are formed in different ways based on similarity
  - Machines
  - Employees
  - Materials
  - Tooling



Different design attributes,
similar manufacturing requirements



Before GT



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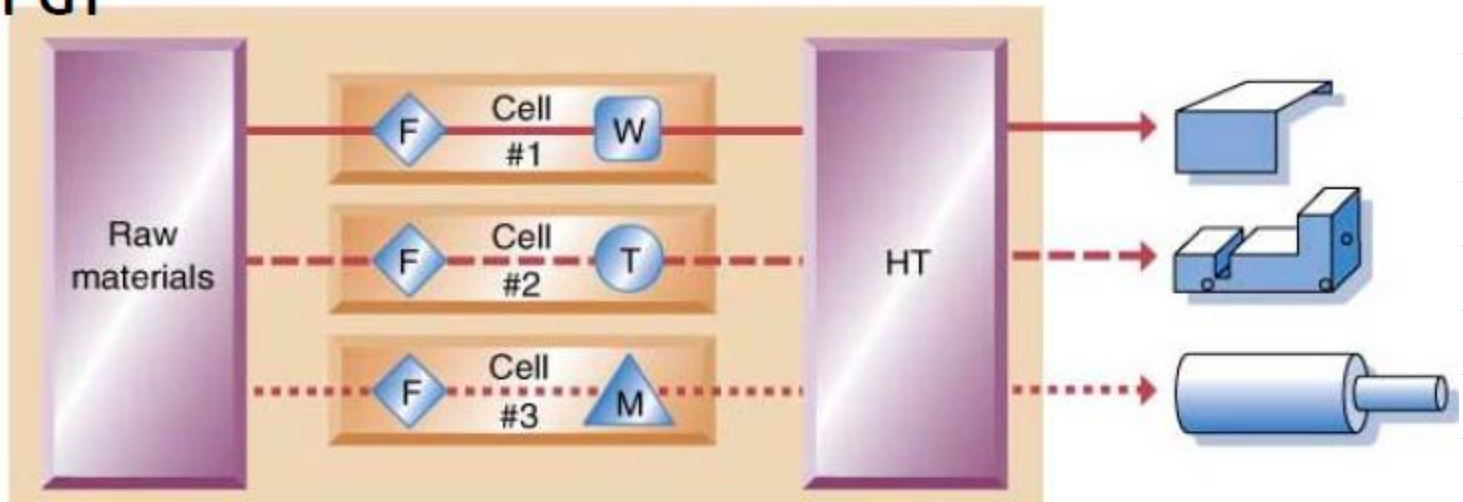
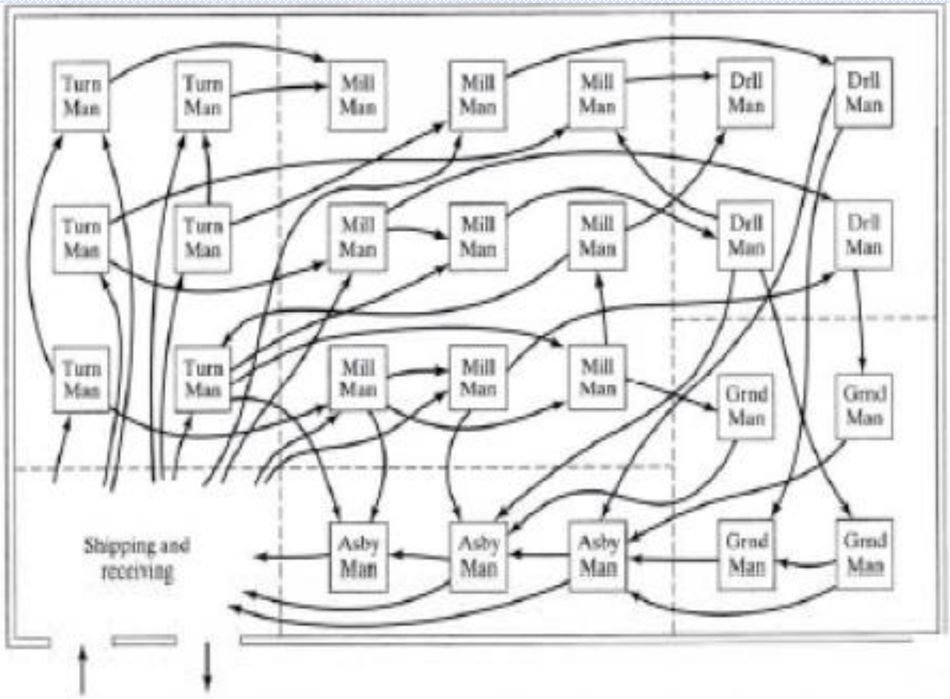


- Before GT



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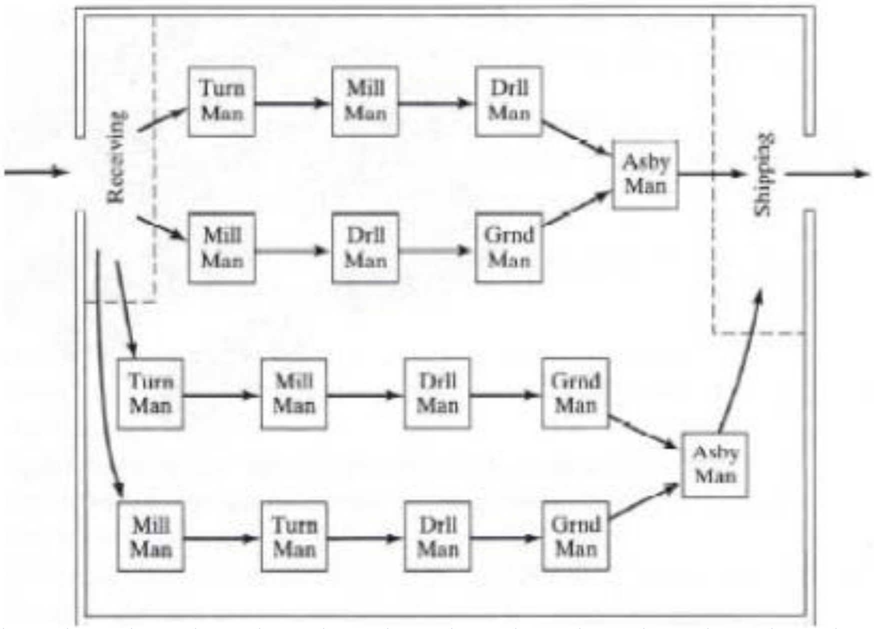


Product Family Departments
Manufacturing cells (Group Technology) (contd.)

- Manufacturing cell operation needs minimum external Support.
- Often designed, controlled and operated using *JIT, TQM and Lean manufacturing concepts*

- Benefits of cell manufacturing:
  - Reduction: inventories, space, paperwork, equipment, transportation, etc.
  - Simplification: communication, handling, scheduling, etc.
  - Improvement: productivity, flexibility, quality, customer satisfaction, etc.

Product Family Departments
Manufacturing cells (Group Technology) (contd.)

- Successful implementation of cells requires addressing:
  - Selection: identification of machine and part types for cell
  - Design: layout, production and material handling requirements
  - Operation: determining lot sizes, scheduling, number of operators
  - Control: methods used to measure the performance of the cell
- Several approaches for selection issues e.g. heuristics, mathematical models and **clustering techniques**.
- Different ways of clustering algorithms
  - One simple clustering techniques is called direct clustering algorithm (DCA)
  - Example of DCA : see page 102 (text book)

Direct Clustering Algorithm (DCA)

1. Sum the 1s in each column and each row of the machine-part matrix.
2. Order the rows (top to bottom) in descending order of the number of 1s in the rows.
3. Order the columns (left to right) in ascending order of the number of 1s in each.
4. Sort the columns. Beginning with the first row of the matrix, shift to the left all columns having a 1 in the first row. Continue row-by-row until no further opportunity exists for shifting columns.
5. Sort the rows. Beginning with the leftmost column, shift rows upward when opportunities exist to form blocks of 1s.
6. Form cells such that all processing for each part occurs in a single cell.

Example 3.1:

Applying the DCA method to group 5 machines

Step 1

machine #

part #	1	2	3	4	5	**# of 1s**
1	1		1			2
2	1					1
3		1		1	1	3
4	1		1			2
5		1				1
6				1	1	2
# of 1s	3	2	2	2	2	

Steps 2&3

machine #

part #	5	4	3	2	1	# of 1s
3	1	1		1		3
6	1	1				2
4			1		1	2
1			1		1	2
5				1		1
2					1	1
# of 1s	2	2	2	2	3	

Step 4

machine #

part #	5	4	2	3	1	# of 1s
3	1	1	1			3
6	1	1				2
4				1	1	2
1				1	1	2
5			1			1
2					1	1
# of 1s	2	2	2	2	3	

Step 5

machine #

part #	5	4	2	3	1	# of 1s
3	1	1	1			3
6	1	1				2
5			1			2
4				1	1	2
1				1	1	1
2					1	1
# of 1s	2	2	2	2	3	

Step 6

machine #

part #	5	4	2	3	1	# of 1s
3	1	1	1			3
6	1	1				2
5			1			2
4				1	1	2
1				1	1	1
2					1	1
# of 1s	2	2	2	2	3	

Product Family Departments
Manufacturing cells (Group Technology) (contd.)

- "Bottleneck" machines in cellular manufacturing are those bind two cells together.

- When bottleneck condition exist:
  - Locate bottleneck machines at the boundary between cells.
  - Duplicate machines
  - Consider redesign of parts
  - Consider outsourcing processing

"Bottleneck" machines

Part # \ Machine #	5	4	2	3	1
3	1	1	1		
6	1	1			
5			1	1	
4				1	1
1				1	1
2					1

(a)

Part # \ Machine #	5	4	2	3	1
3	1	1	1		
6	1	1			
5			1	1	
4				1	1
1				1	1
2					1

(b)

Part # \ Machine #	5	4	2	3	1
3	1	1	1		
6	1	1			
5			1	1	
4				1	1
1				1	1
2					1

(c)

What can we do?

Product Family Departments
Manufacturing cells (Group Technology) (contd.)

- The design of the cellular manufacturing system can be *Decoupled cells* *or* *Integrated cells* :

1. **Decoupled cells**:
   - uses a storage area to store parts after the cell has finished with them
   - that acts as a decoupler (making the cells and departments independent of each other).
   - If another cell needs them, it would retrieve them from there.
   - This lead to excessive material handling and poor responsiveness.

Product Family Departments
Manufacturing cells (Group Technology) (contd.)

2. **Integrated cells**:
   - Cells and departments are linked through the use of Kanbans or cards.
   - **Production cards (POK)**: to authorize production of more components or subassemblies.
   - **Withdrawal cards (WLK)**: to authorize delivery of more components, subassemblies, or raw materials.

- Kanban:
  - means "signal" and commonly uses cards to signal the supplying workstation that is consuming workstation requests more parts

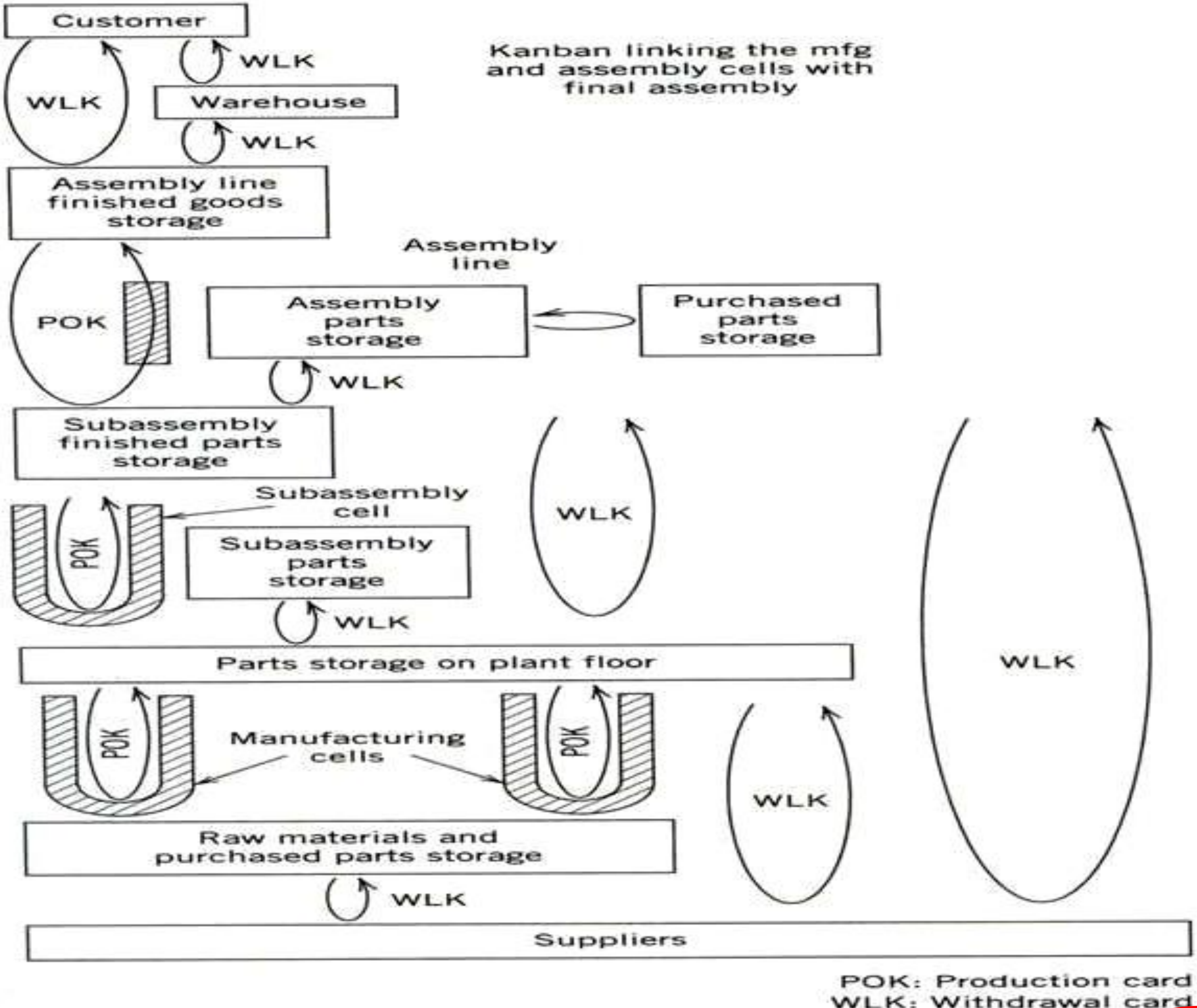


Figure 3.15 Integrated cellular manufacturing system.

Product Family Departments
Manufacturing cells (Group Technology) (contd.)

- In general there are two types of production control systems:

1. "Push" production control system:
   - When workstation completes its set of operations, it pushes its finished parts to next workstation. If the supplying workstation operates faster than consuming workstation, parts will begin to build up.
2. "Pull" production control system:
   - Supplying workstation did not produce any parts until its consuming workstation requested parts. This system called Kanban which means signal.

- The final step is the layout of each cell:

U-shaped arrangement of workstations significantly enhance visibility.

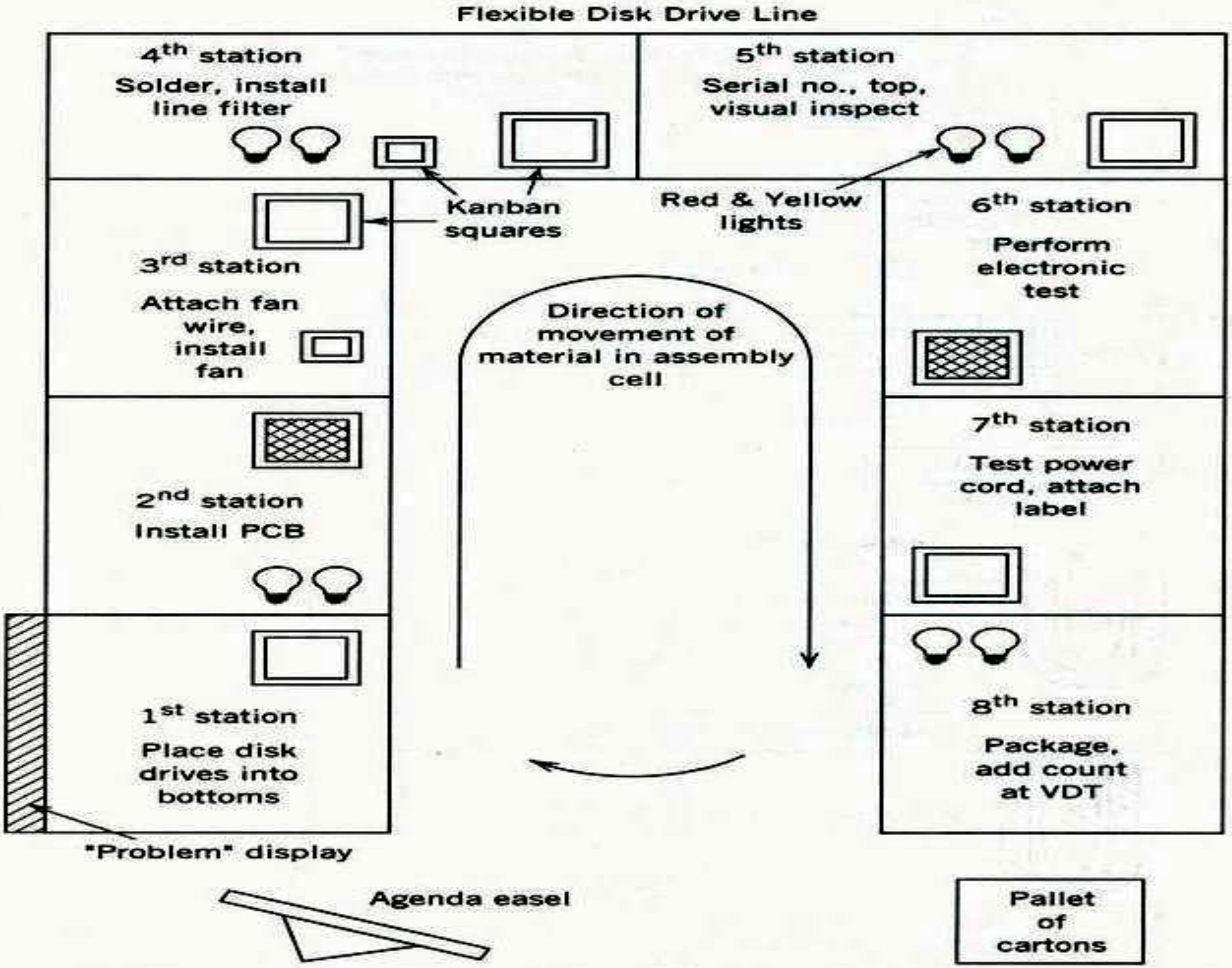


Figure 3.16 An assembly cell for disk drives, designed by workers at Hewlett-Packard, Greely Division.

Activity Relationships

Activity Relationships

Five main types:

- Organizational relationships – influenced by span of control and reporting relationships.
- Flow relationships – including the flow of material, people, equipment, information, and money.
- Control relationships – level of automation, centralized vs. decentralized material control.
- Environment relationships – including safety considerations like temp, noise, humidity, and dust.
- Other process relationships - such as floor loading, water required by machines, etc.

Measuring Flow

- Measuring flow is very important in evaluating alternative arrangement of departments within a facility.

- Quantitative: If large volumes of materials, information, and people moving between departments.

- Qualitative: If not a lot of physical movement between departments, but significant communication or organizational relationships.

Measuring Flow

- Quantitative flow measurement:
- **Mileage chart:**
  - distance between departments ← AB ≠ BA
  - Note the diagonal values are zero
  - Not necessarily symmetric: one way aisles, different entry and exit points in the department.
  - Measures of distance
    - Euclidean, Squared Euclidean, Rectilinear, Aisle Distance, Adjacency, Shortest path
  - We will discuss them in detail later.

	A	B	C
A		12	18
B	6		6
C	18	14	

Example of Mileage chart

Measuring Flow

- Quantitative flow measurement:
- **From-to chart:**
  - Flow between departments. ← AB = BA
  - does not have to be symmetric (Example: No definite reason for the flows from stores to milling to be the same as the flows from milling to stores)

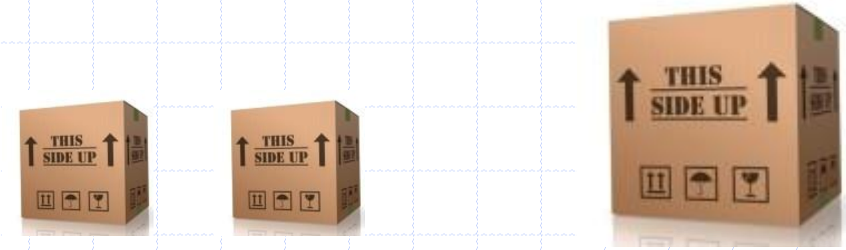
From \ To	A	B	C
A		420	125
B	60		350
C	75	25	

Measuring Flow

- A From-to chart is constructed as follows:

1. List departments in logical sequence.
2. Establish a measure of flow for the facility that accurately indicates equivalent flow volumes. (Some common unit of measure).
3. Based on the flow paths for the items to be moved and the established measure of flow, record the flow volumes on the from-to chart.

Measuring Flow



- <u>Example:</u>

  A firm produces three products, 1, 2, and 3. Product 1 and 2 are of the same size and weight, while product 3 is twice as the size of products 1 and 2 and requires twice effort to move it.

  - The departments include five departments A, B, C, D and E.
  - The overall quantities to be produce daily and routes are
  - Product 1 : 30; A →C → B →D →E
  - Product 2 : 12; A → B → D → E
  - Product 3 : 7; A → C → D →B →E

- Construct the from –to matrix.

Measuring Flow

- Example (contd.). From-to matrix

From \ To	A	B	C	D	E
A		12	30+2*7=44	0	0
B	0		0	30+12=42	2*7=14
C	0	30		2*7=14	0
D	0	0	0		30+12=42
E	0	0	0	0	

Measuring Flow

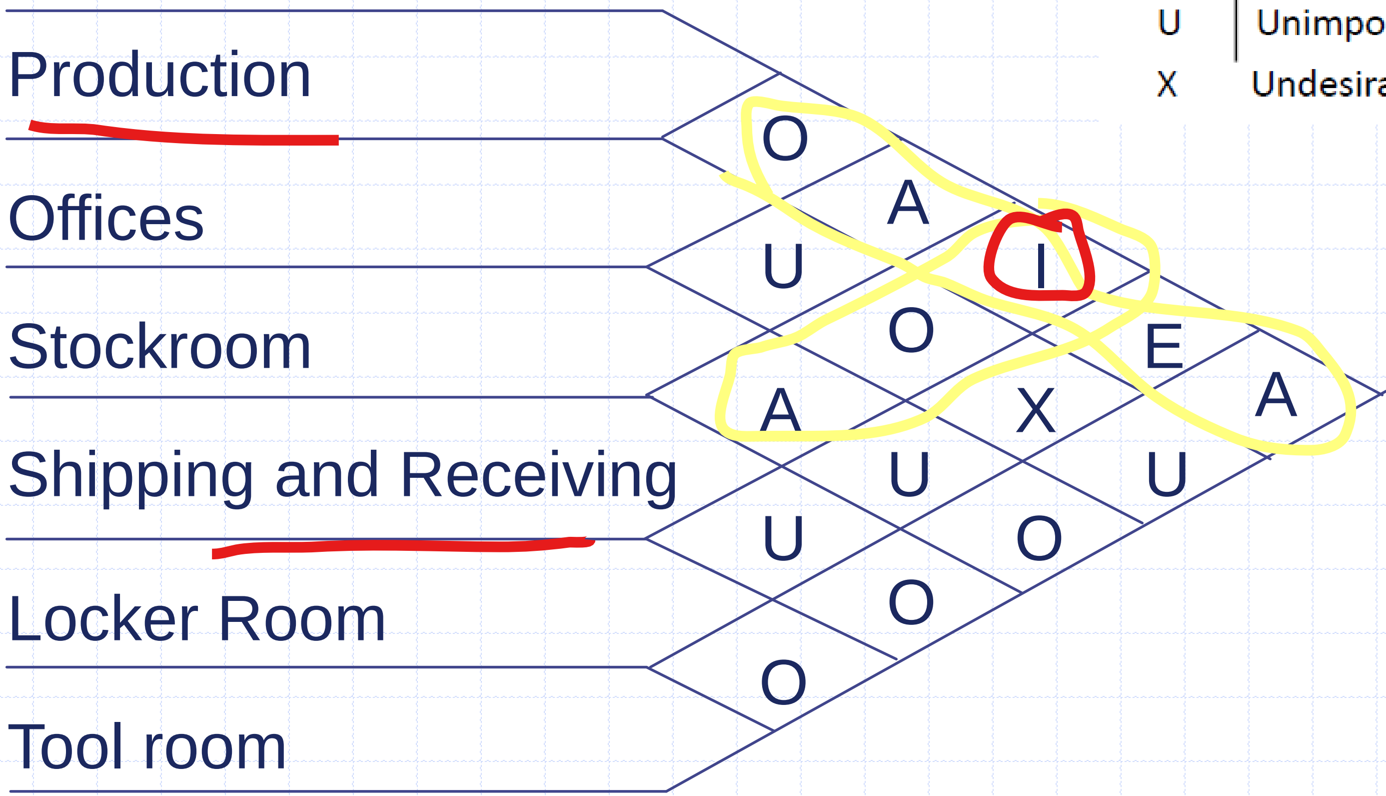
- Qualitative flow measurement:
- **Relationship chart:**
  - Determine the relative importance of different departments being close to each other.
  - 6 Closeness Relationship Values:

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

Measuring Flow

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

Example of Relationship chart:



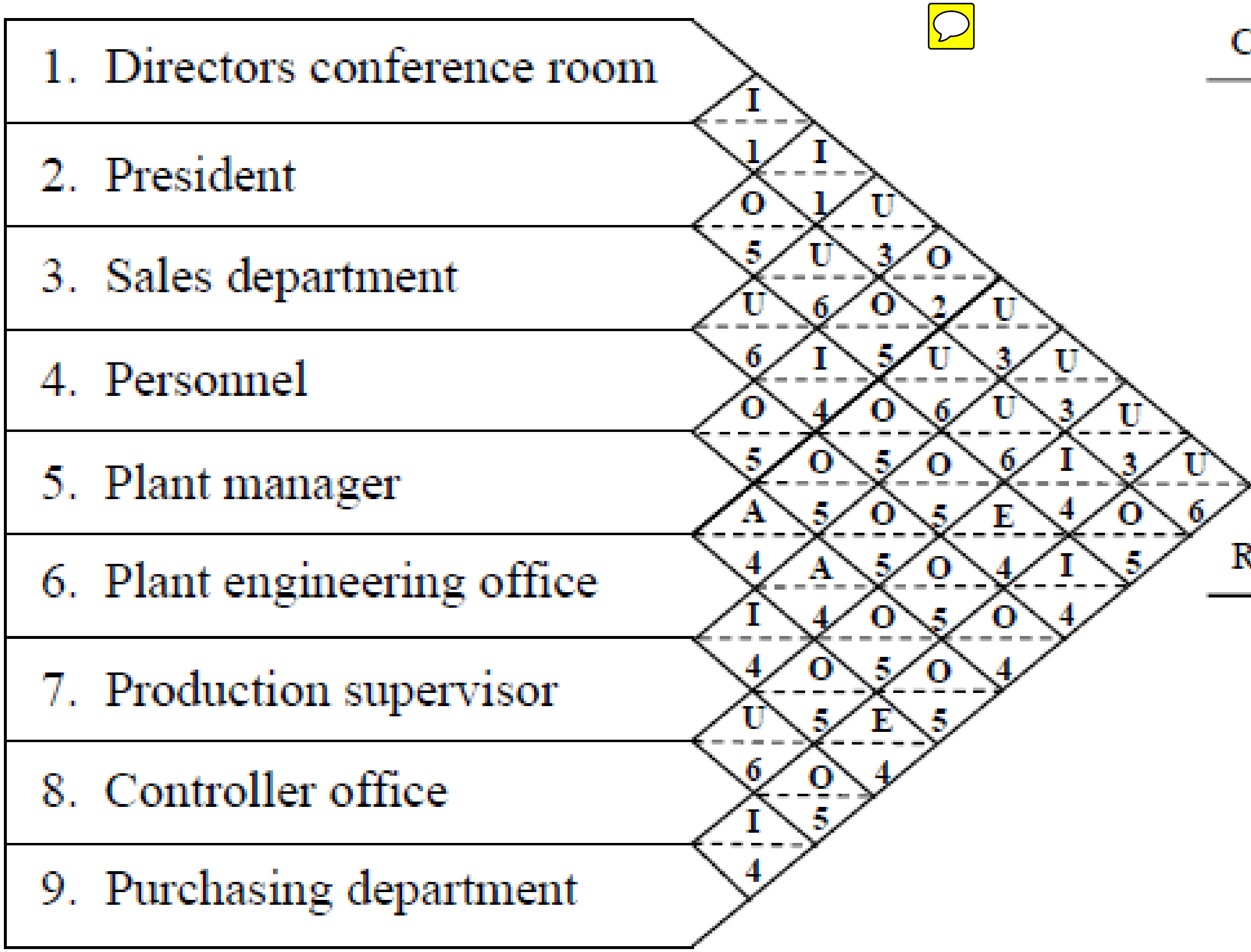
Measuring Flow

- To construct the Relationship chart:

1. List all the departments.
2. Get closeness information. How to get this information.
3. Define the criteria for assigning closeness values and itemize and record this information on the chart. (example: frequency of use high, medium, low)
4. Get feedback from sources of information.

Avoid too many A's and X's.

Relationship Chart may include the closeness values in conjunction with reasons for the value



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

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

Converting From-to chart to Relationship chart

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	–	–	–	–	–	–	–

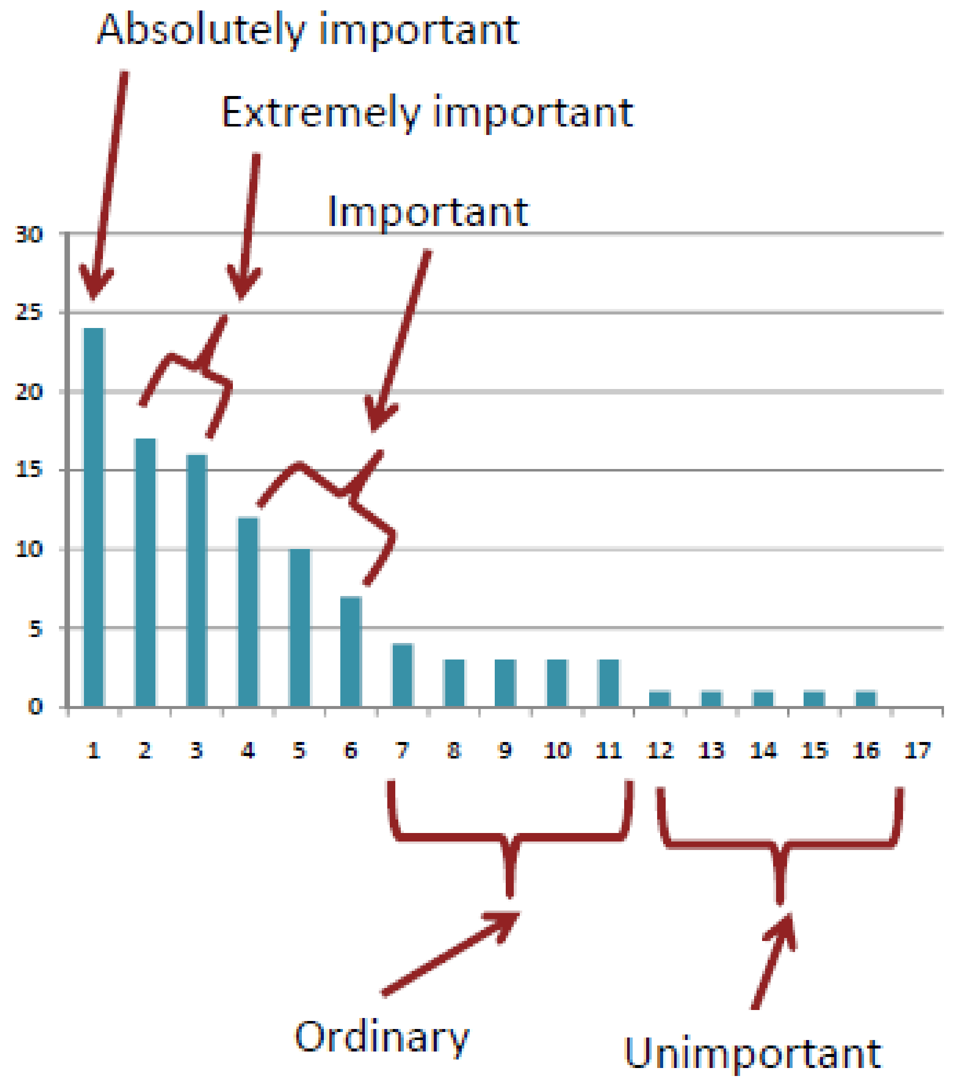
Frequency table

	Departments	*Frequency*
1	Stores-Milling	24
2	Milling Plate	14+3=17
3	Stores-Press	16
4	Stores-Turning	12
5	Stores-Assembly	8+2=10
6	Turning-Plate	8+2=10
7	Assembly-Warehouse	7
8	Plate-Assembly	4
9	Milling-Assembly	3
10	Turning- Milling	3
11	Press-Plate	3
12	Plate-Warehouse	3
13	Stores-Plate	1
14	Milling -Warehouse	1
15	Turning-Warehouse	1
16	Press-Assembly	1
17	Press-Warehouse	1

Converting From-to chart to Relationship chart

Frequency table

	Departments	*Frequency*
1	Stores-Milling	24
2	Milling-Plate	14+3=17
3	Stores-Press	16
4	Stores-Turning	12
5	Stores-Assembly	8+2=10
6	Turning-Plate	8+2=10
7	Assembly-Warehouse	7
8	Plate-Assembly	4
9	Milling-Assembly	3
10	Turning- Milling	3
11	Press-Plate	3
12	Plate-Warehouse	3
13	Stores-Plate	1
14	Milling -Warehouse	1
15	Turning-Warehouse	1
16	Press-Assembly	1
17	Press-Warehouse	1



Space Requirements

Space Requirements

- The amount of space required in the facility is difficult to estimate because:

1. Uncertainty: change in demand, change in product mix, new technology, new methods.

2. Department managers tend to overstate their needs.

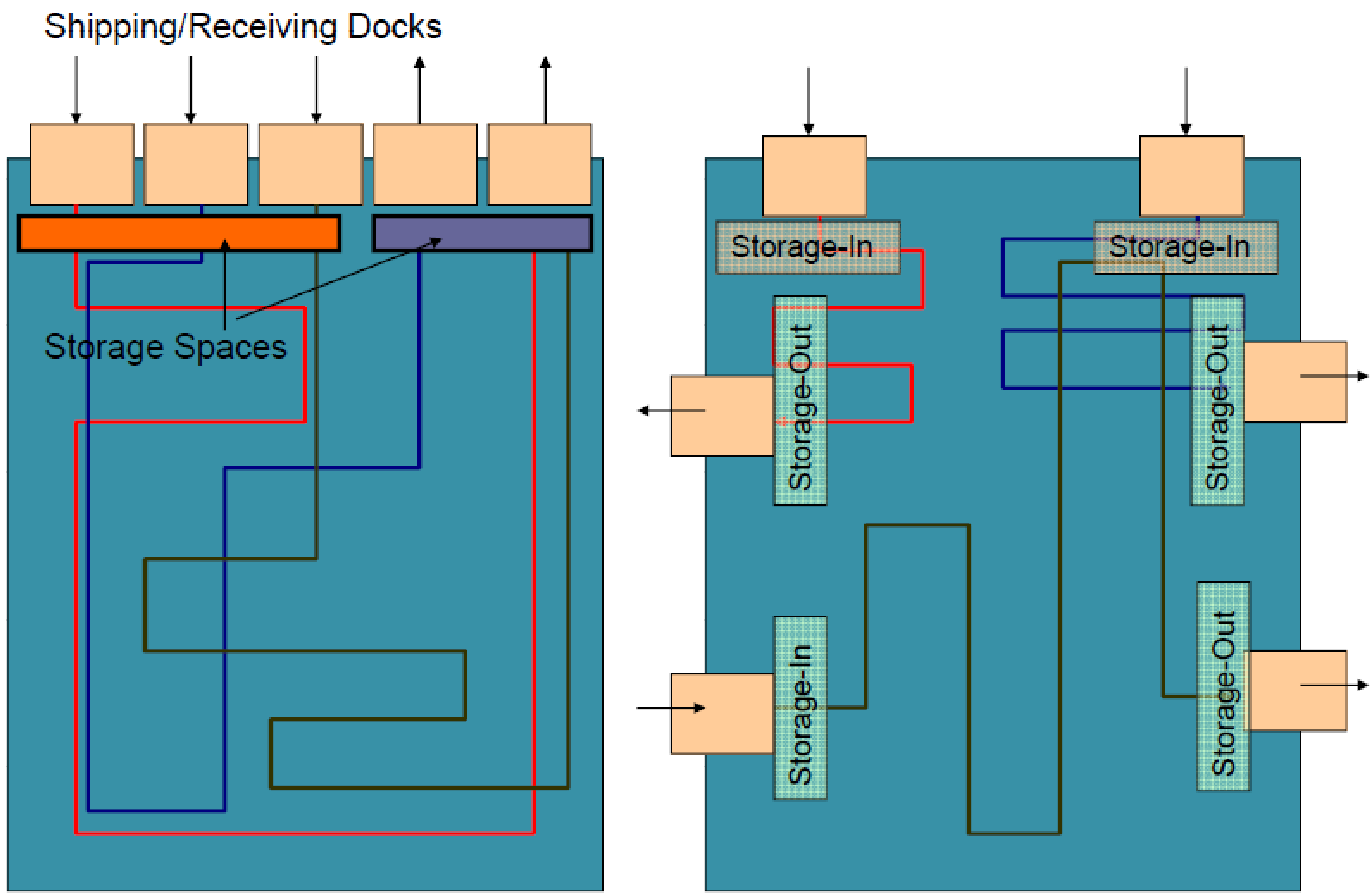
3. Parkinson's Law: Department expands to fill up its space.

Space Requirements (contd.)

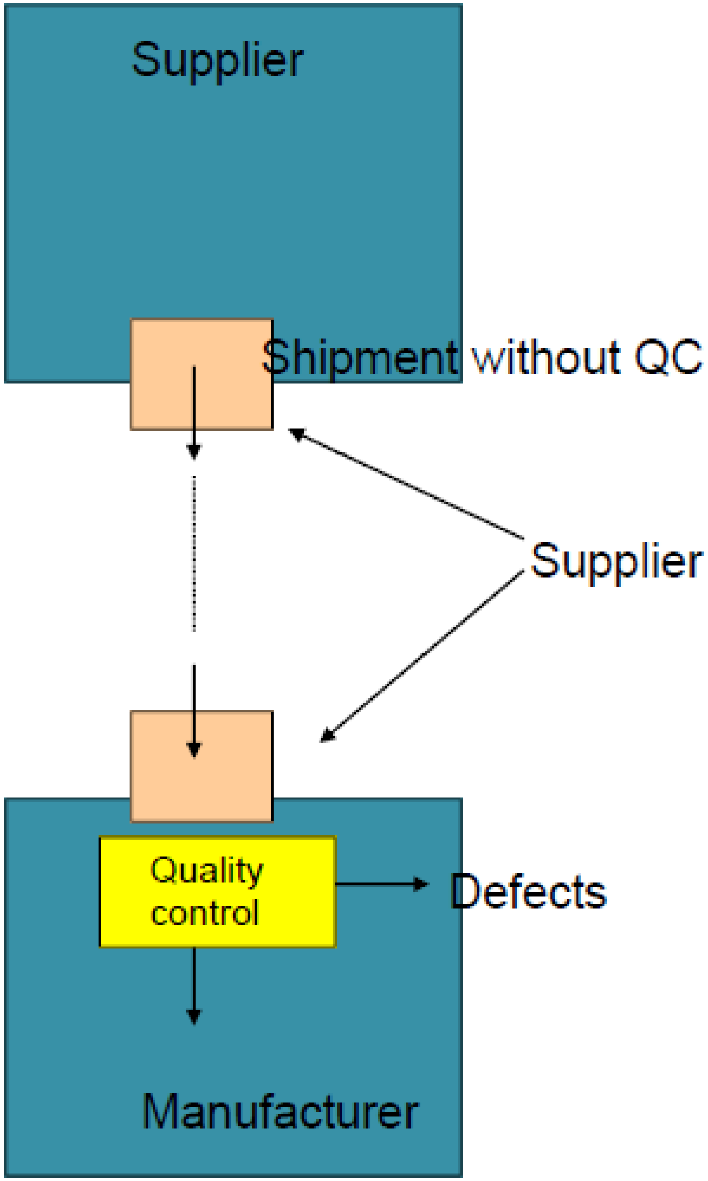
- Modern Manufacturing methods are reducing space requirements:
  - Product are delivered to point of use in small batches.
  - Decentralized storage.
  - Less inventory (products are pulled with Kanbans).
  - More efficient layout arrangements (manufacturing cells).
  - Quality control at the source
  - Companies are downsizing (leaner organizations, focused factories, outsourcing, etc.)
  - Offices are shared

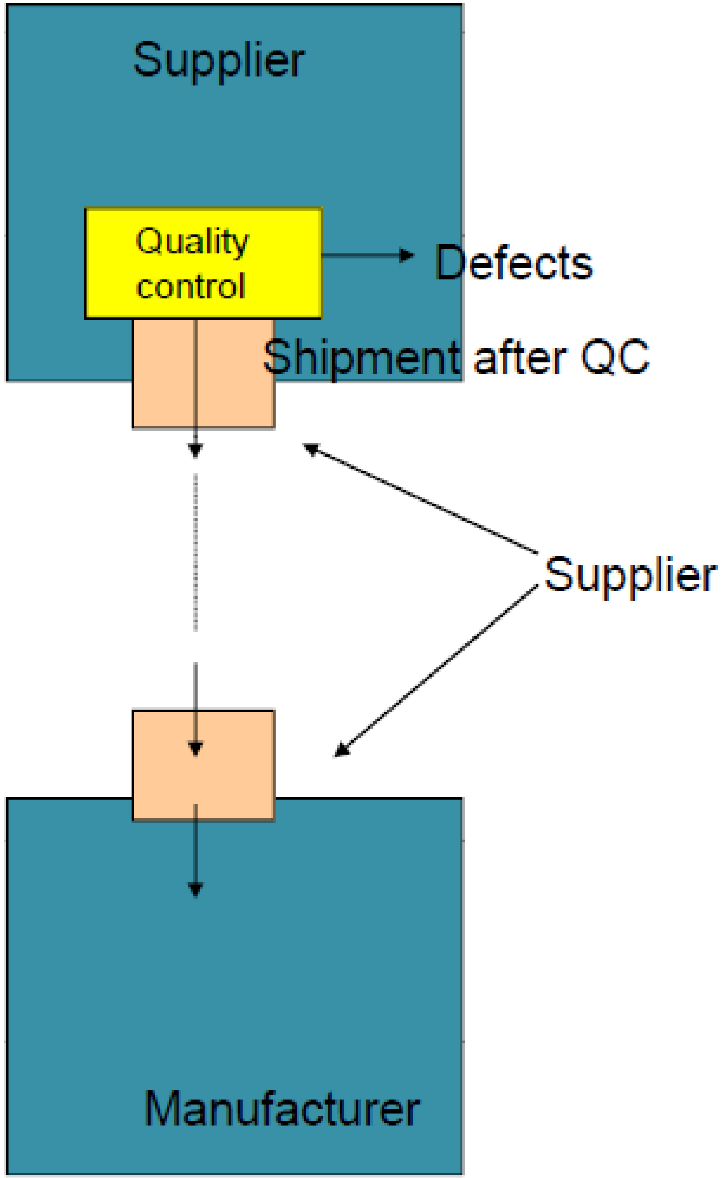
For **manufacturing**: Start with the **workstations**, then **departments**

Manufacturing methodologies change



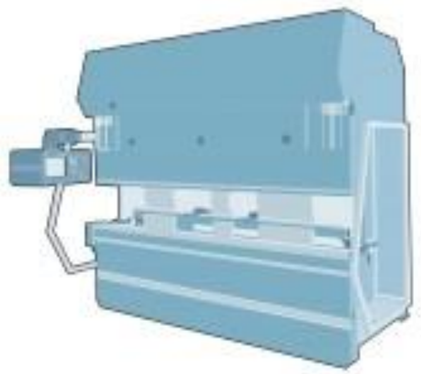
Manufacturing methodologies change





Space Requirements
Workstation Specification

- Three components: Equipment, materials, personnel:
- **Equipment:**
  - Footprint of machines (machinery data sheets)
  - Machine travel (all directions)
  - Machine Maintenance
  - Plant services



- **Materials:**
  - Receiving area (and storing inbound materials)
  - Holding In-process materials (WIP)
  - Storing outbound materials
  - Waste and scrap
  - Tools, Fixtures, jigs, dies, and maintenance materials.

Space Requirements
Workstation Specification

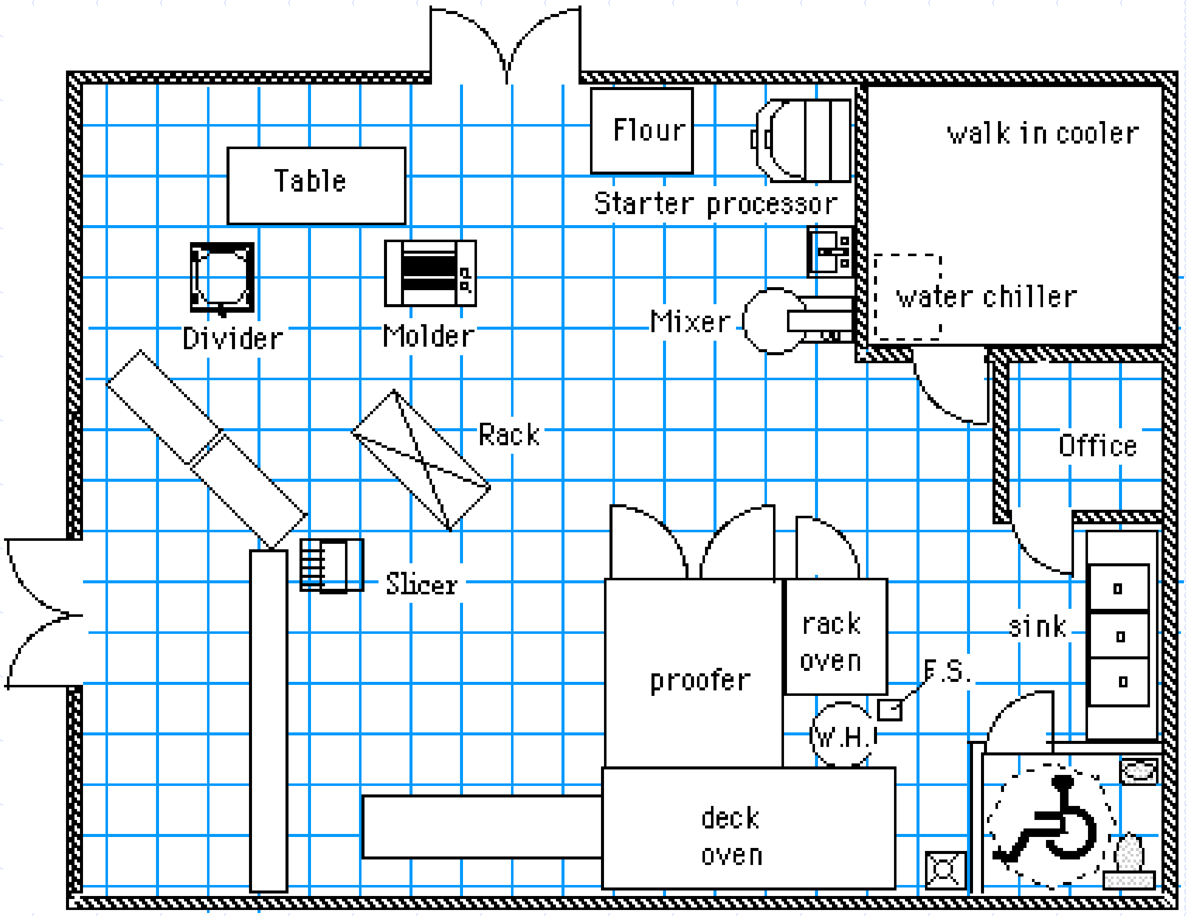
- **Personnel:**
  - The operator
  - Material handling
  - Operator ingress and egress

- For the first two points consider ergonomic principles:
  - No long reaches
  - Minimize manual handling
  - Safety
- For operator ingress and egress:
  - Min 30 inch aisle if two stationary objects.
  - Min 36 inch aisle if one stationary and one working machine.
  - Min 42 inch aisle if two working machines.

Usually a good idea to simulate operator tasks to verify the validity of estimates.

Space Requirements
Department Specification

- Departmental area requirements are not simply the sum of the areas of the individual workstations.



Bakery – Production department

Space Requirements
Department Specification

- Some areas can be shared between workstations:
  - tools, housekeeping items, storage areas, operators, Kanban boards, etc.
- Additional space is required for material handling, WIP buffers, storage cabinets, office areas, visual displays, aisles, etc.
- For both workstation and department often end up with a range on space estimates. (allowance factor)

Space Requirements
Aisle Specification

Two types:
- Main – this is the current focus
- Departmental (Aisle allowance estimate – see table 3.4)

- Want the aisle to promote effective flow
- How wide depends on how big the moving things. See table 3.5 in the book for examples.
- Do people and material need to be pass at the same time. Two way flow?
- Minimize curves, non-right angle intersections, and dead ends.
- Aisles should lead to doors if possible.
- Be certain to note where columns are located so that they are not located in the aisles.

Table 3.4

Table 3. 4 *Aisle Allowance Estimates*

If the Largest Load Is	Aisle Allowance Percentage Is[a]
Less than 6 ft^2	5-10
Between 6 and 12 ft^2	10-20
Between 12 and 18 ft^2	20-30
Greater than 18 ft^2	30-40

[a]Expressed as a percentage of the net area required for equipment, material, and personnel.

Table 3.5

Recommended Aisle Widths for Various Types of Flow

Type of Flow	Aisle Width (feet)
Tractors	12
3-ton Forklift	11
2-ton Forklift	10
1-ton Forklift	9
Narrow aisle truck	6
Manual platform truck	5
Personnel	3
Personnel with doors opening into the aisle from one side	6
Personnel with doors opening into the aisle from two sides	8