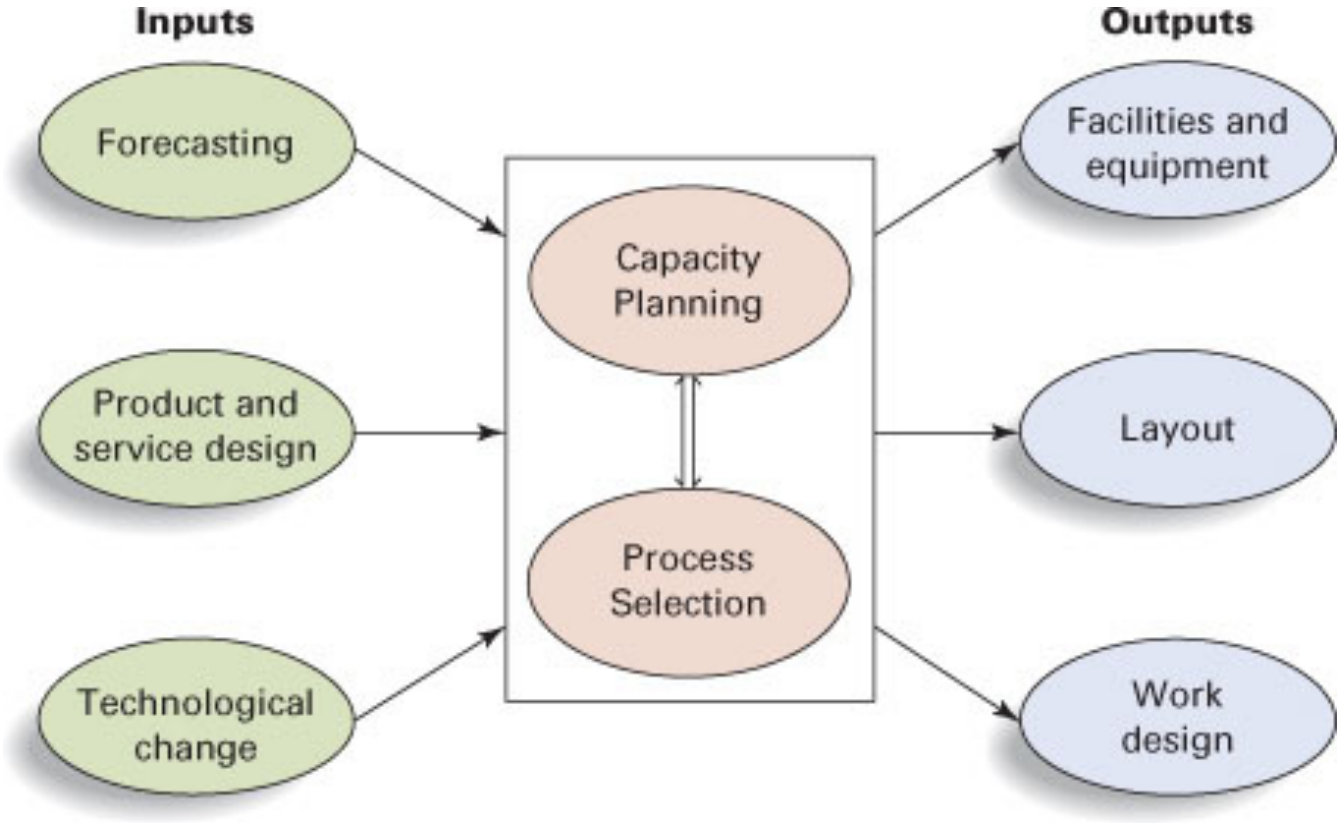
Process Selection and Facility Layout

Chapter 6

Introduction

Process selection and capacity planning influence system design



- Capital intensity
- Process flexibility

Technology

Refers to applications of scientific discoveries to the development and improvement of goods and services and/or the processes that produce or provide them.

Three kinds of technology (impact on costs, productivity, and competitiveness):

- **Product and service technology** is the discovery and development of new products and services.
- **Process technology** includes methods, procedures, and equipment used to produce goods and provide services.
- **Information technology (IT)** is the science and use of computers and other electronic equipment to store, process, and send information.

Technology as a Competitive Advantage

Technoly Acquisition

Process Selection

How much **variety** in products or services will the system need to handle?
What degree of equipment **flexibility** will be needed?
What is the expected **volume** of output?

Process Types:

- Job Shop
- Batch
- Repetitive
- Continuous
- (Project)

Job Shop

- Relatively small scale
- Low volume of high-variety goods or services
- Processing is **intermittent**
- High flexibility of equipment

Manufacturing example: A tool and die shop that is able to produce one-of-a-kind tools.

Service example: A veterinarian's office, which is able to process a variety of animals and a variety of injuries and diseases.

Batch

- Moderate volume of moderate variety products or services.
- The equipment need not be as flexible as in a job shop, but processing is still intermittent.
- The skill level of workers doesn't need to be as high as in a job shop because there is less variety in the jobs being processed.

Manufacturing example: Bakeries, which make bread, cakes, or cookies in batches

Service example: Movie theaters, which show movies to groups (batches) of people, and airlines, which carry planeloads (batches) of people from airport to airport.

Repetitive

- Higher volumes of more standardized goods or services
- Slight flexibility of equipment
- Skill of workers is generally low.

Manufacturing example: Automobiles, television sets, pencils, and computers.

Service example: Automatic carwash, cafeteria lines and ticket collectors at sports events and concerts.

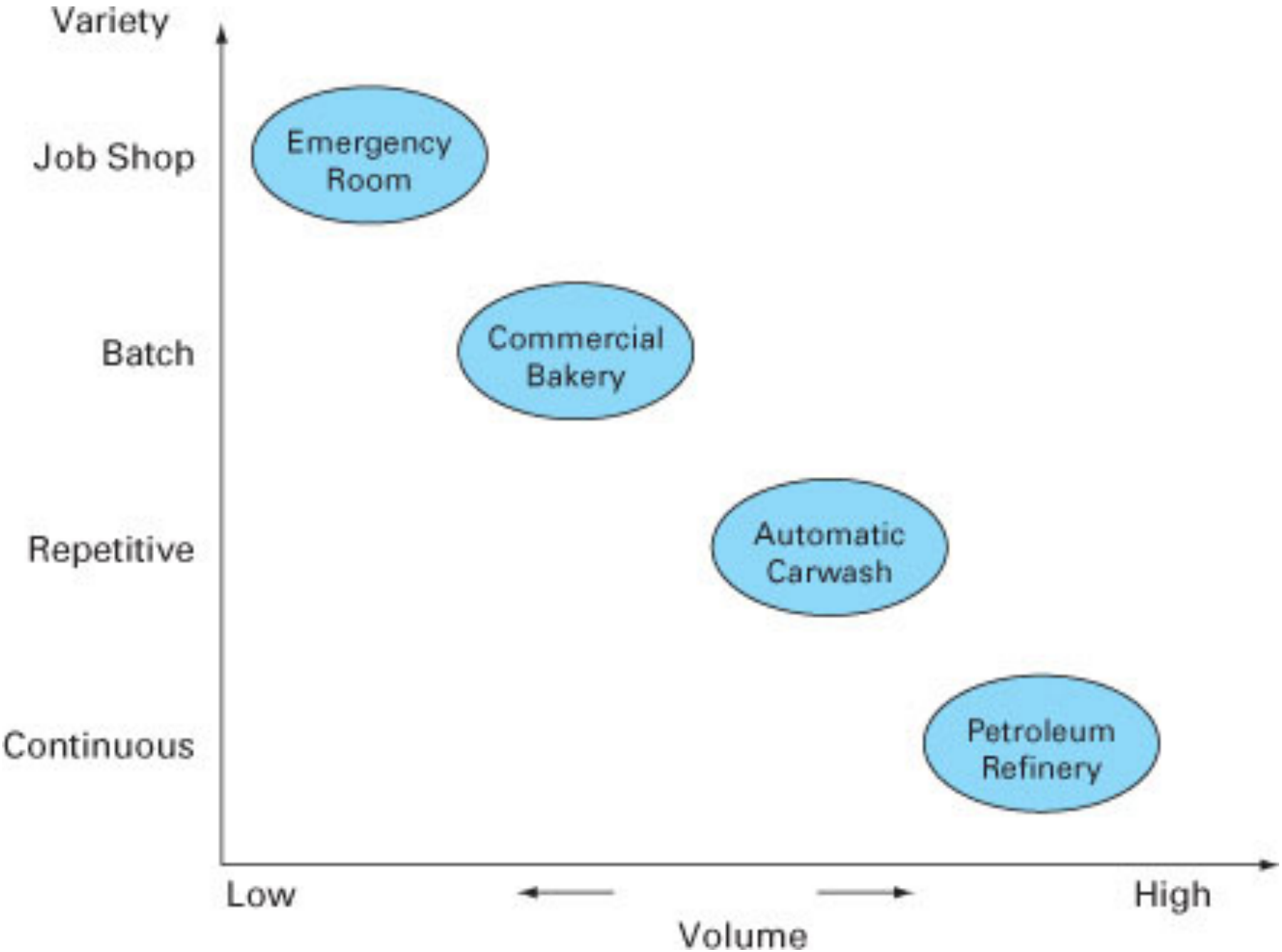
Continuous

- Very high volume of nondiscrete, highly standardized output is desired
- No variety in output
- No need for equipment flexibility.

Manufacturing example: Petroleum products, steel, sugar, flour, and salt.

Service example: Air monitoring, supplying electricity to homes and businesses, and the Internet.

	Job Shop	Batch	Repetitive/ Assembly	Continuous
Description	Customized goods or services	Semi-standardized goods or services	Standardized goods or services	Highly standardized goods or services
Advantages	Able to handle a wide variety of work	Flexibility	Low unit cost, high volume, efficient	Very efficient, very high volume
Disadvantages	Slow, high cost per unit, complex planning and scheduling	Moderate cost per unit, moderate scheduling complexity	Low flexibility, high cost of downtime	Very rigid, lack of variety, costly to change, very high cost of downtime


Variety
Job Shop
Batch
Repetitive
Continuous
Emergency Room
Commercial Bakery
Automatic Carwash
Petroleum Refinery
Low
High
Volume

Project

- Nonroutine work
- Unique set of objectives
- Limited time frame
- Equipment flexibility and worker skills can range from low to high.

Example: Consulting, making a motion picture, launching a new product or service, publishing a book, building a dam, and building a bridge.

Activity/ Function	Job Shop	Batch	Repetitive	Continuous	Projects
Cost estimation	Difficult	Somewhat routine	Routine	Routine	Simple to complex
Cost per unit	High	Moderate	Low	Low	Very high
Equipment used	General purpose	General purpose	Special purpose	Special purpose	Varied
Fixed costs	Low	Moderate	High	Very high	Varied
Variable costs	High	Moderate	Low	Very low	High
Labor skills	High	Moderate	Low	Low to high	Low to high
Marketing	Promote capabilities	Promote capabilities; semi-standardized goods and services	Promote standardized goods/services	Promote standardized goods/services	Promote capabilities
Scheduling	Complex	Moderately complex	Routine	Routine	Complex, subject to change
Work-in-process inventory	High	High	Low	Low	Varied

Product and Service Profiling

Product or service profiling can be used to avoid any inconsistencies by identifying key product or service dimensions and then selecting appropriate processes.

Key dimensions often relate to the range of products or services that will be processed, expected order sizes, pricing strategies, expected frequency of schedule changes, and order-winning requirements.

Automation

Automation is machinery that has sensing and control devices that enable it to operate automatically.

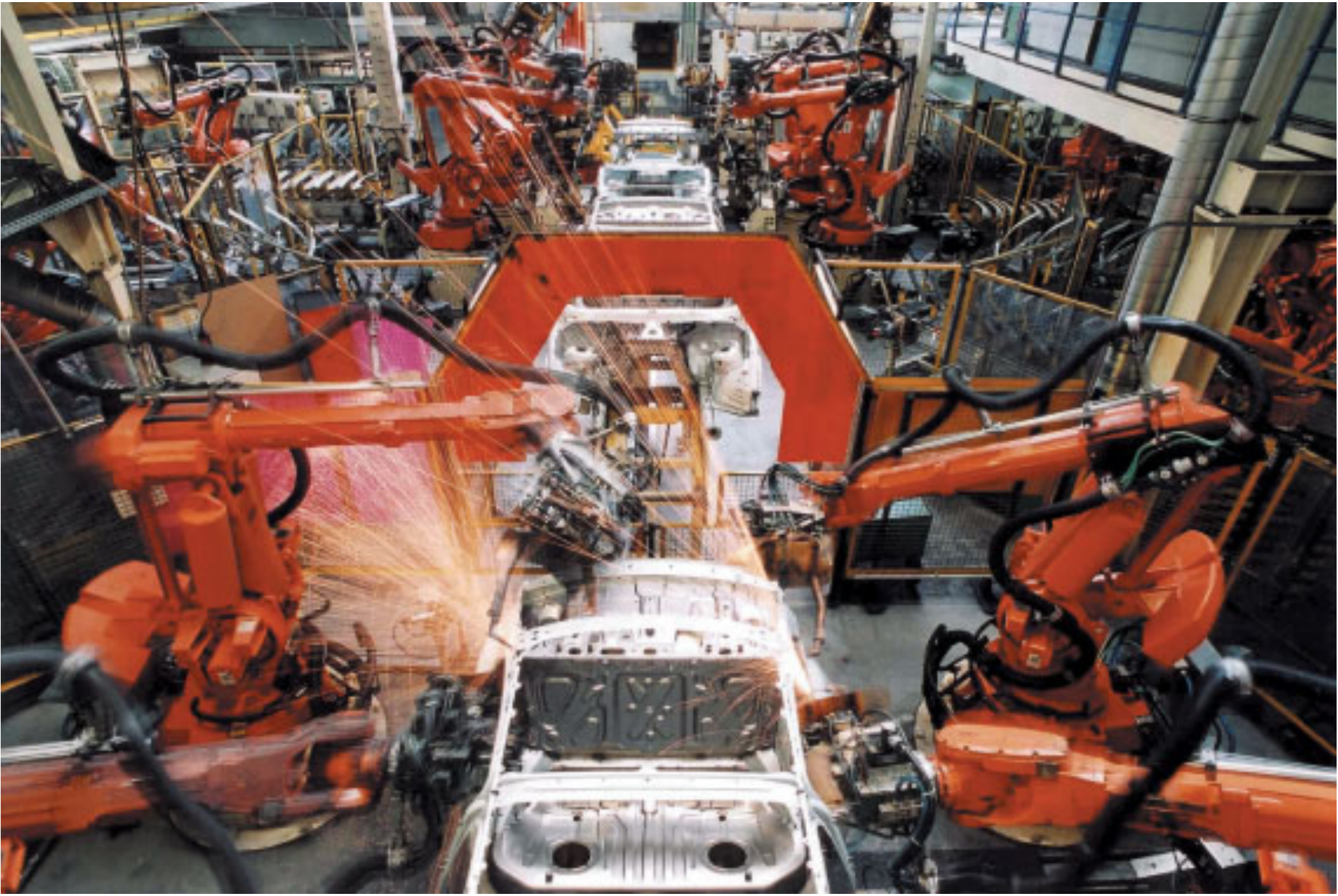
Advantages over human labor:

- Machines do not get bored or distracted, nor do they go out on strike, ask for higher wages, or file labor grievances.
- Reduction of variable costs.

Fixed automation

Programmable automation

Flexible automation



Computer-aided manufacturing (CAM) refers to the use of computers in process control, ranging from robots to automated quality control.

Numerically controlled (N/C) machines are programmed to follow a set of processing instructions based on mathematical relationships that tell the machine the details of the operations to be performed.

Individual machines may have their own computer; this is referred to as ***computerized numerical control (CNC)***. Or one computer may control a number of N/C machines, which is referred to as ***direct numerical control (DNC)***.

Facilities Layout

Layout refers to the configuration of departments, work centers, and equipment, with particular emphasis on movement of work (customers or materials) through the system.

Layout decisions are important for three basic reasons:

- require **substantial investments** of money and effort;
- **involve long-term commitments,** which makes mistakes difficult to overcome; and
- have a **significant impact** on the cost and efficiency of operations.

The basic objective of layout design is to facilitate a smooth flow of work, material, and information through the system. Supporting objectives generally involve the following:

- To facilitate attainment of product or service quality.
- To use workers and space efficiently.
- To avoid bottlenecks.
- To minimize material handling costs.
- To eliminate unnecessary movements of workers or materials.
- To minimize production time or customer service time.
- To design for safety.

Product layouts are most conducive to repetitive processing

Process layouts are used for intermittent processing

Fixed-position layouts are used when projects require layouts

The three basic types of layout are product, process, and fixed-position.

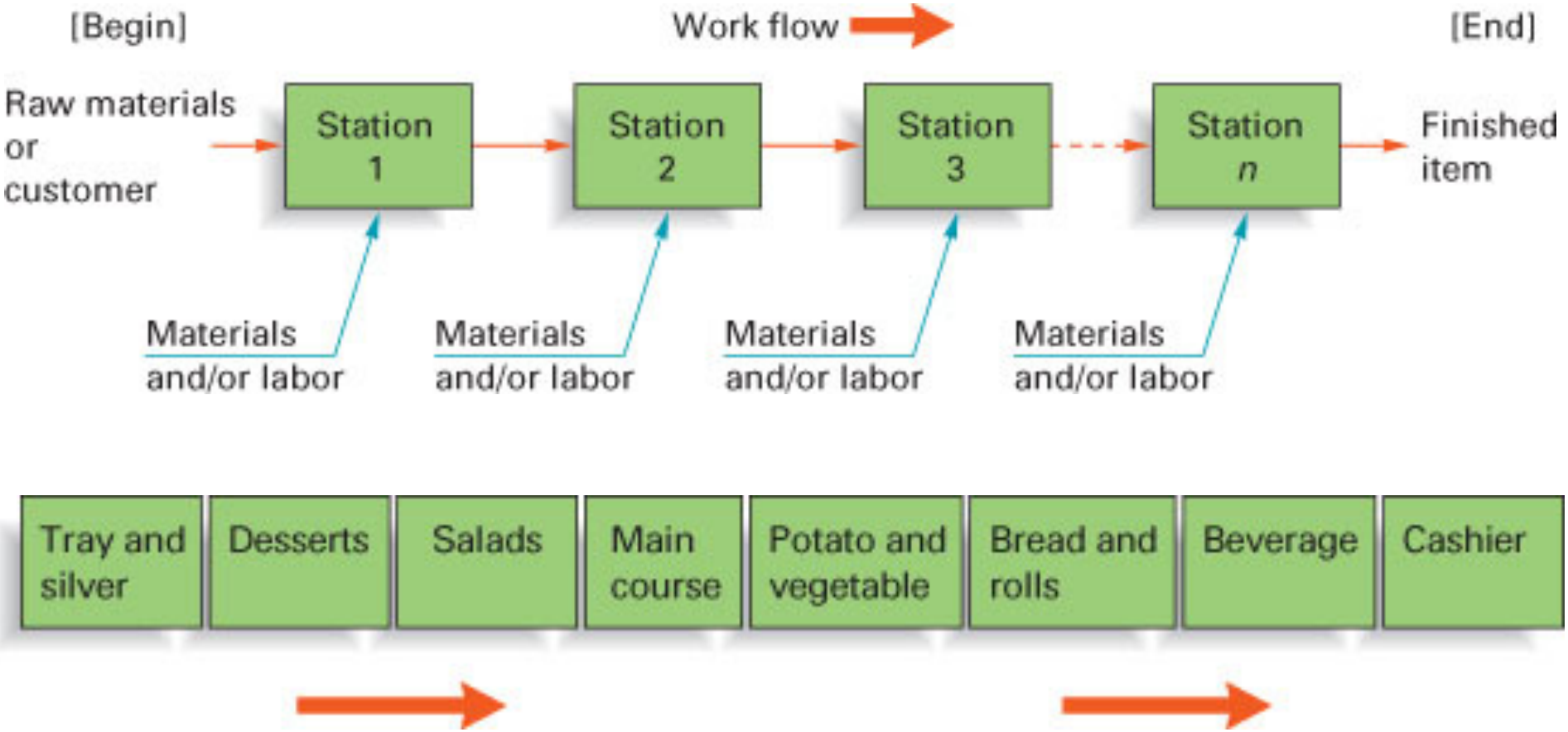
Product layouts are most conducive to repetitive processing

Process layouts are used for intermittent processing

Fixed-position layouts are used when projects require layouts

Repetitive Processing: Product Layouts

Product layouts are used to achieve a smooth and rapid flow of large volumes of goods or customers through a system.



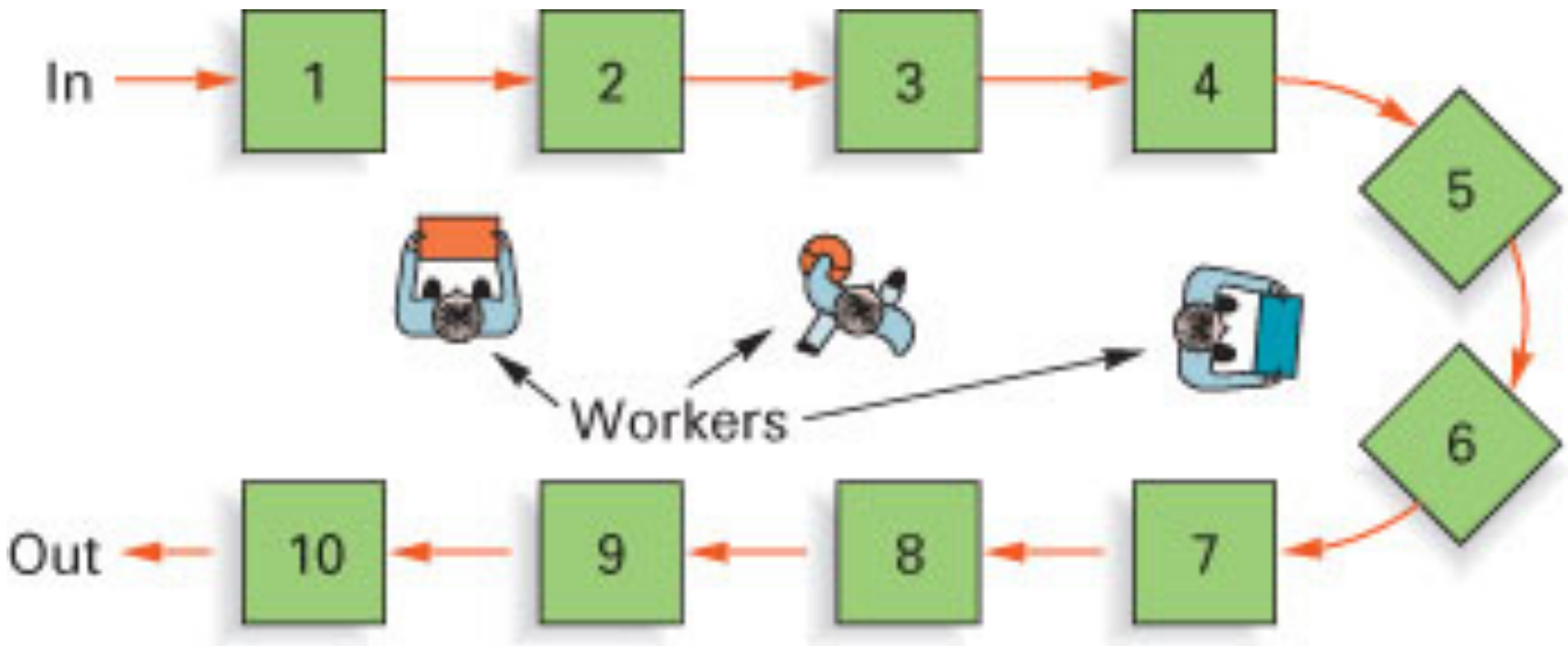
Advantages

- A high rate of output
- Low unit cost due to high volume
- Labor specialization
- Low material-handling cost per unit
- A high utilization of labor and equipment
- The establishment of routing and scheduling in the initial design of the system
- Fairly routine accounting, purchasing, and inventory control

Disadvantages

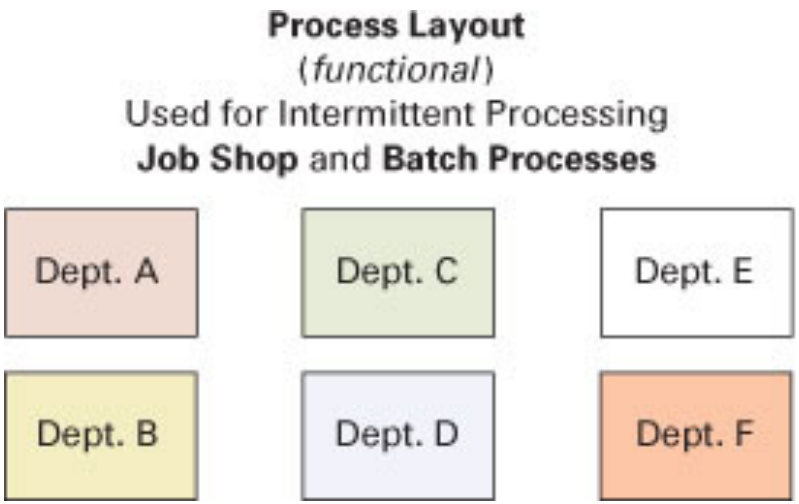
- Morale problems and to repetitive stress injuries.
- Lack of maintaining equipment or quality of output.
- Inflexible for output or design
- Highly susceptible to shutdowns
- A high utilization of labor and equipment
- Preventive maintenance, the capacity for quick repairs, and spare-parts inventories are necessary expenses
- Incentive plans tied to individual output are impractical

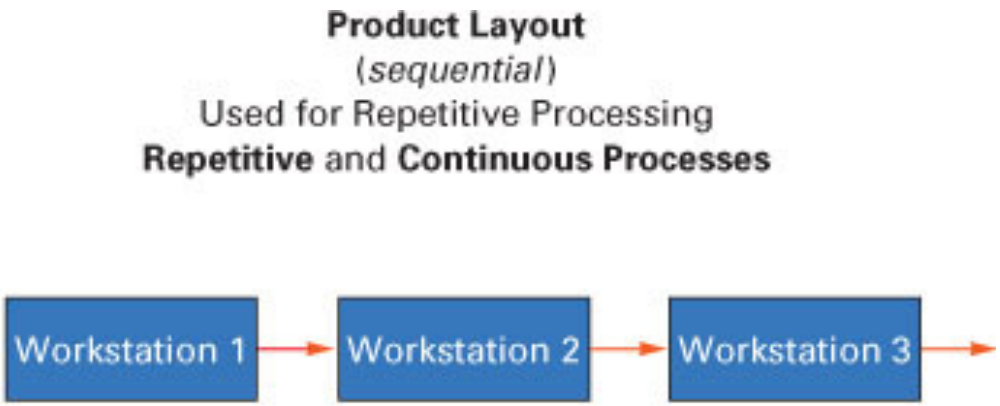
U-Shaped Layouts



Nonrepetitive Processing: Process Layouts

Process layouts are designed to process items or provide services that involve a variety of processing requirements.





Advantages

- Handle a variety of processing requirements
- Not vulnerable to equipment failures
- General-purpose equipment is less costly and is easier and less costly to maintain
- Possible to use individual incentive systems

Disadvantages

- In-process inventory costs can be high
- Routing and scheduling pose continual challenges
- Equipment utilization rates are low
- Material handling is slow and inefficient, and more costly per unit
- Job complexities reduce the span of supervision and result higher supervisory costs
- Special attention necessary for each product or customer and low volumes result in higher unit costs
- Accounting, inventory control, and purchasing are much more involved

Fixed-Position Layouts

In **fixed-position layouts,** the item being worked on remains stationary, and workers, materials, and equipment are moved about as needed.

Fixed-position layouts are widely used in farming, firefighting, road building, home building, remodeling and repair, and drilling for oil. In each case, compelling reasons bring workers, materials, and equipment to the "product's" location instead of the other way around.


CHANTIERS DE L'ATLANTIQUE

Combination Layouts

Supermarket layouts are essentially process layouts, yet we find that most use fixed-path material-handling devices such as roller-type conveyors in the stockroom and belt-type conveyors at the cash registers.

Hospitals also use the basic process arrangement, although frequently patient care involves more of a fixed-position approach, in which nurses, doctors, medicines, and special equipment are brought to the patient.

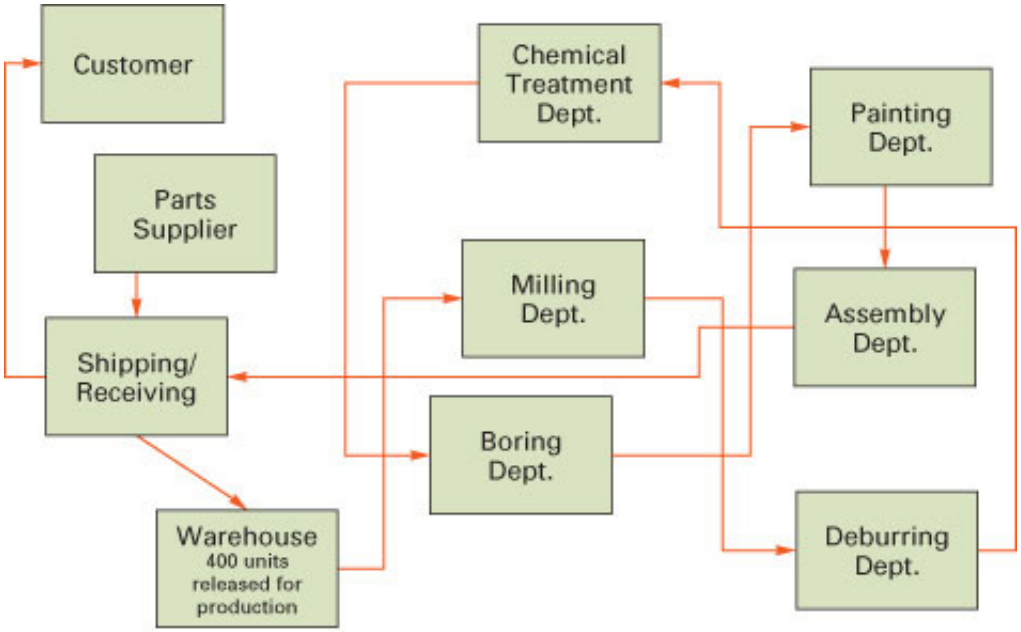
Faulty parts made in a product layout may require off-line reworking, which involves customized processing. Moreover, conveyors are frequently observed in both farming and construction activities.

Cellular manufacturing - Group technology

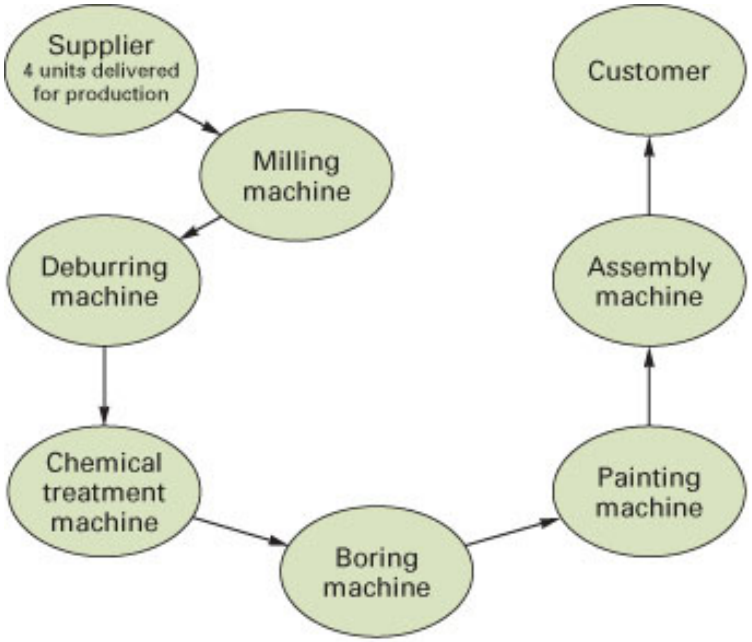
Flexible manufacturing systems

Cellular Layouts

Cellular production is a type of layout in which workstations are grouped into what is referred to as a *cell*.



A. Example of an order processed in a traditional process layout.



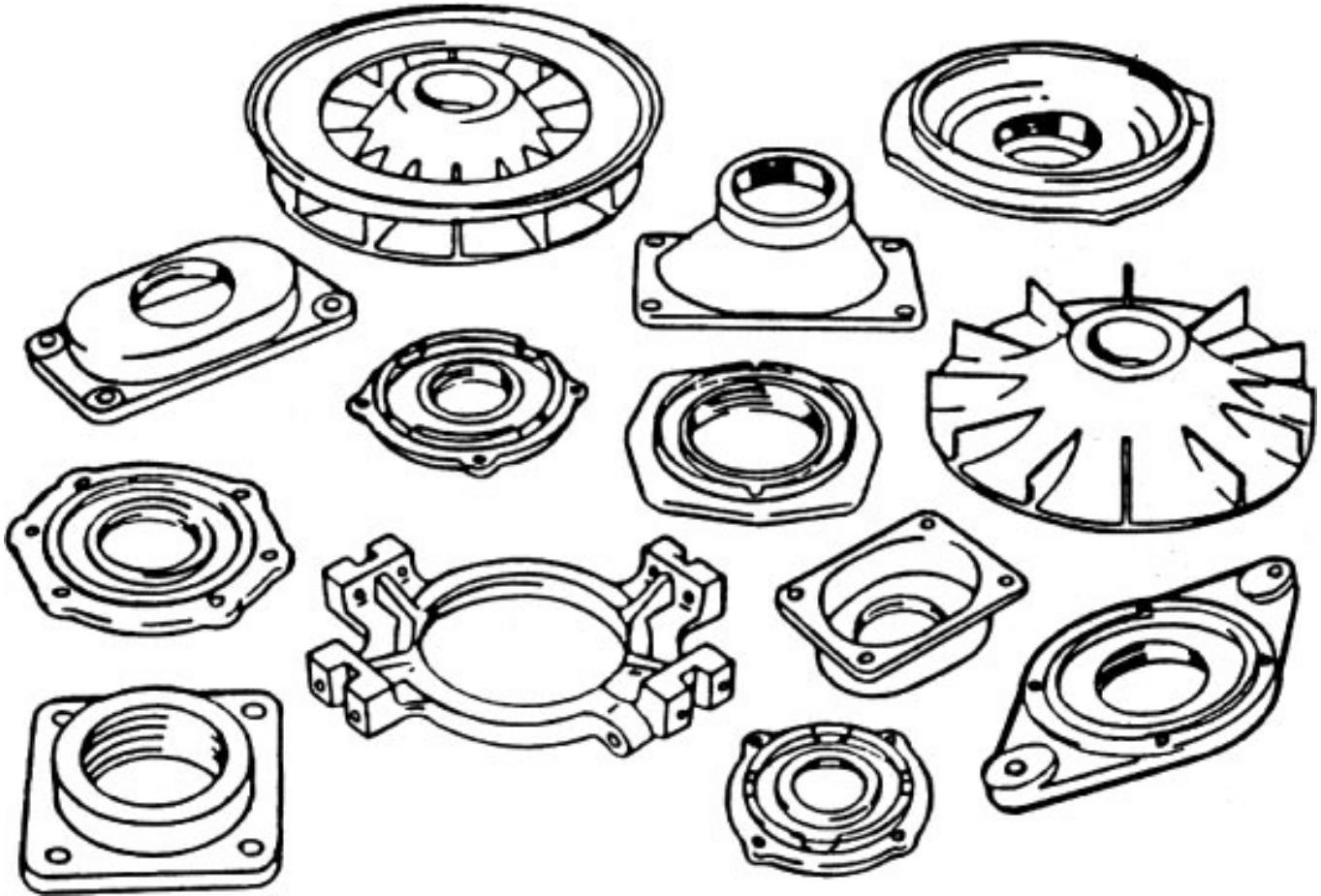
B. The same example of an order processed in a cellular layout.

Single-minute exchange of die (SMED) enables an organization to quickly convert a machine or process to produce a different (but similar) product type.

Right-sized equipment is often smaller than equipment used in traditional process layouts, and mobile, so that it can quickly be reconfigured into a different cellular layout in a different location.

Dimension	Functional	Cellular
Number of moves between departments	Many	Few
Travel distances	Longer	Shorter
Travel paths	Variable	Fixed
Job waiting time	Greater	Shorter
Throughput time	Higher	Lower
Amount of work in process	Higher	Lower
Supervision difficulty	Higher	Lower
Scheduling complexity	Higher	Lower
Equipment utilization	Lower	Higher

Effective cellular manufacturing must have groups of identified items with similar processing characteristics. This strategy for product and process design is known as **group technology** and involves identifying items with similarities in either *design characteristics* or *manufacturing characteristics,* and grouping them into *part families.*



Flexible Manufacturing Systems

A flexible manufacturing system (FMS) is a group of machines that include supervisory computer control, automatic material handling, and robots or other automated processing equipment. Reprogrammable controllers enable these systems to produce a variety of *similar* products. Systems may range from three or four machines to more than a dozen. They are designed to handle intermittent processing requirements with some of the benefits of automation and some of the flexibility of individual, or stand-alone, machines (e.g., N/C machines).

- relatively narrow range of part variety
- requires longer planning and development times
- companies sometimes prefer a gradual approach to automation, and FMS represents a sizable chunk of technology.

Computer-integrated manufacturing (CIM) is a system that uses an integrating computer system to link a broad range of manufacturing activities, including engineering design, flexible manufacturing systems, purchasing, order processing, and production planning and control.

Service Layouts

Many service organizations use process layouts because of variability in customer processing requirements.

Unlike manufacturing layouts, service layouts must be aesthetically pleasing as well as functional.

Warehouse and Storage Layouts

The design of storage facilities presents a different set of factors than the design of factory layouts.

- Frequency of order
- Correlations between items
- Widths of aisles
- The height of storage racks
- Rail and/or truck loading and unloading
- Need to periodically make a physical count of stored items.

Retail Layouts

The objectives that guide design of manufacturing layouts often pertain to

- Cost minimization
- Product flow
- Traffic patterns
- Traffic flow

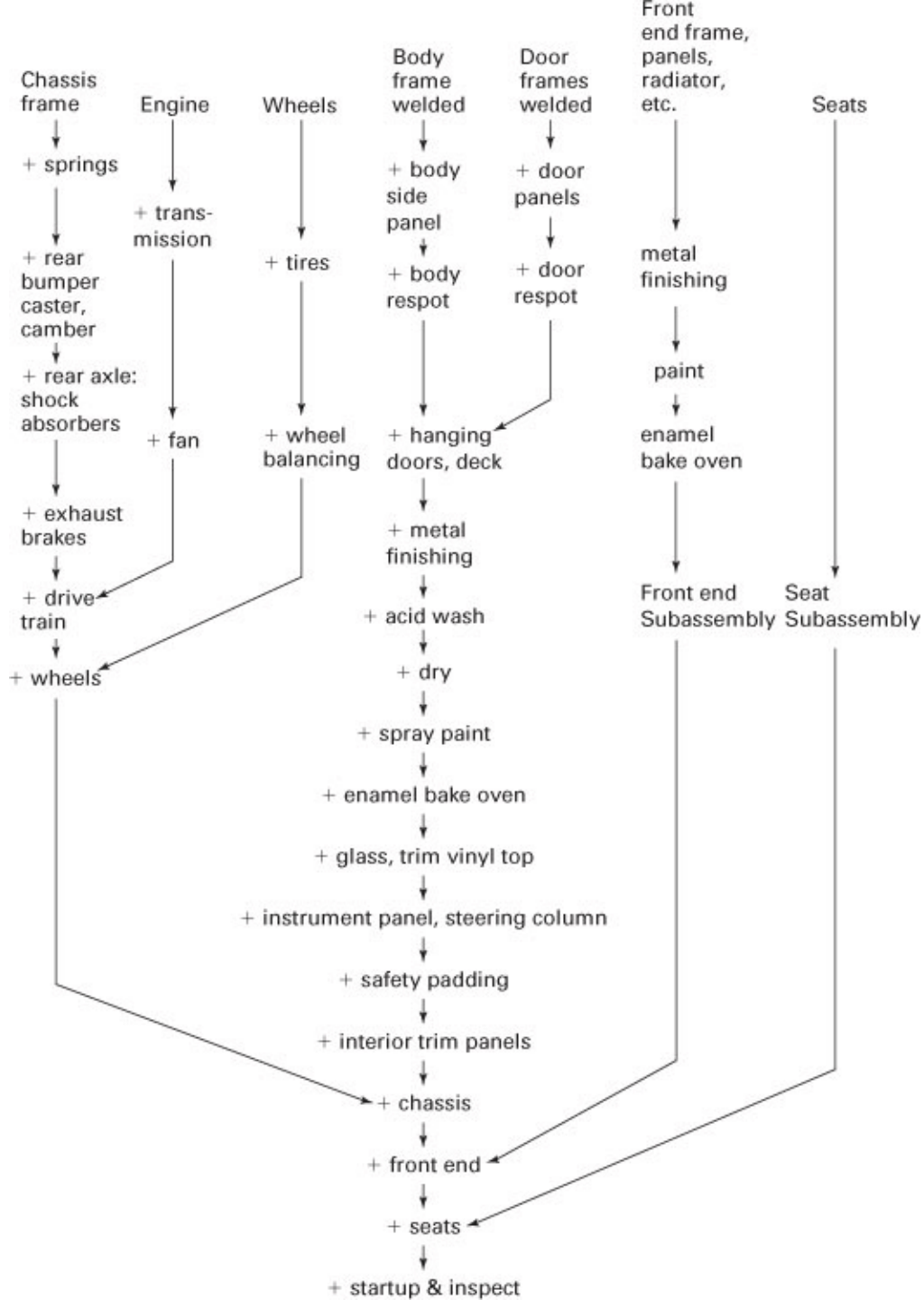
Office Layouts

Office layouts are undergoing transformations as the flow of paperwork is replaced with the increasing use of electronic communications. That means there is less need to place office workers in a layout that optimizes the physical transfer of information or paperwork. Another trend is to create an image of openness; office walls are giving way to low-rise partitions.

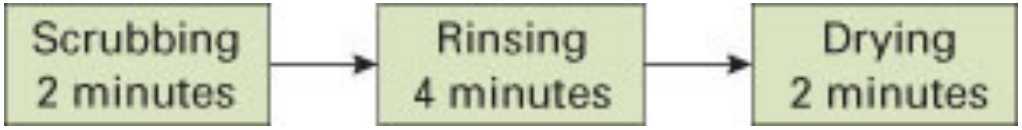
Designing Product Layouts: Line Balancing

The goal of a product layout is to arrange workers or machines in the sequence that operations need to be performed.

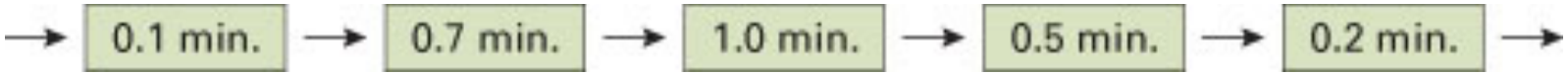
The sequence is referred to as a production line or an assembly line. These lines range from fairly short, with just a few operations, to long lines that have a large number of operations. Automobile assembly lines are examples of long lines. At the assembly line for Ford Mustangs, a Mustang travels about **nine miles** from start to finish!


Chassis frame
Engine
Wheels
Body frame welded
Door frames welded
Front end frame, panels, radiator, etc.
Seats
+ springs
+ trans-mission
+ tires
+ body side panel
+ door panels
metal finishing
+ rear bumper caster, camber
+ body respot
+ door respot
paint
+ rear axle: shock absorbers
+ fan
+ wheel balancing
+ hanging doors, deck
enamel bake oven
+ exhaust brakes
+ metal finishing
+ drive train
Front end Subassembly
Seat Subassembly
+ acid wash
+ wheels
+ dry
+ spray paint
+ enamel bake oven
+ glass, trim vinyl top
+ instrument panel, steering column
+ safety padding
+ interior trim panels
+ chassis
+ front end
+ seats
+ startup & inspect

Line Balancing



Cycle Time

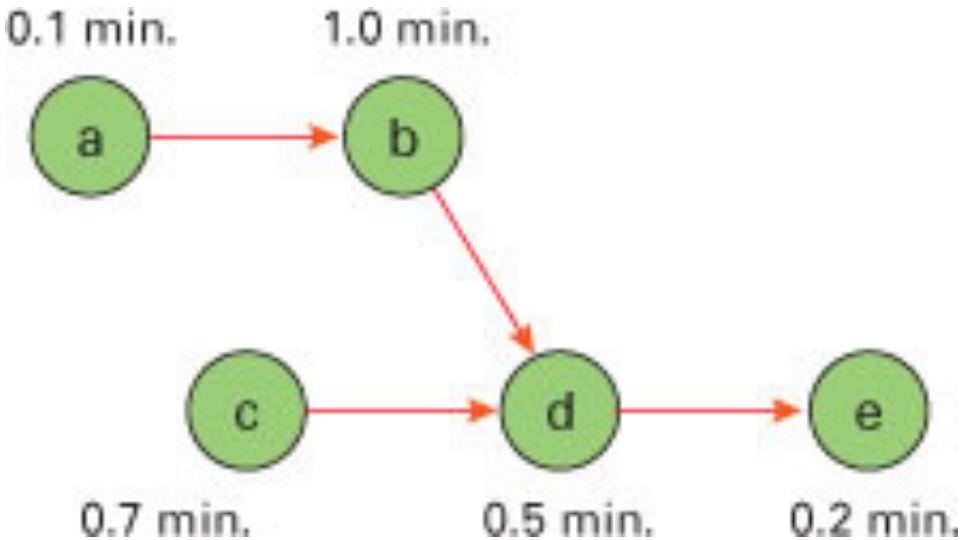


$$\text{Output rate} = \frac{\text{Operating time per day}}{\text{Cycle time}}$$

$$\text{Cycle time} = \frac{\text{Operating time per day}}{\text{Desired output rate}}$$

$$N_{\min} = \frac{\Sigma t}{\text{Cycle time}}$$

Precedence Diagram



Line Balancing Procedure

1. Determine the cycle time and the minimum number of workstations.
2. Make assignments to workstations in order, beginning with Station 1. Tasks are assigned to workstations moving from left to right through the precedence diagram.
3. Before each assignment, use the following criteria to determine which tasks are *eligible* to be assigned to a workstation:
   a. All preceding tasks in the sequence have been assigned.
   b. The task time does not exceed the time remaining at the workstation.

If no tasks are eligible, move on to the next workstation.

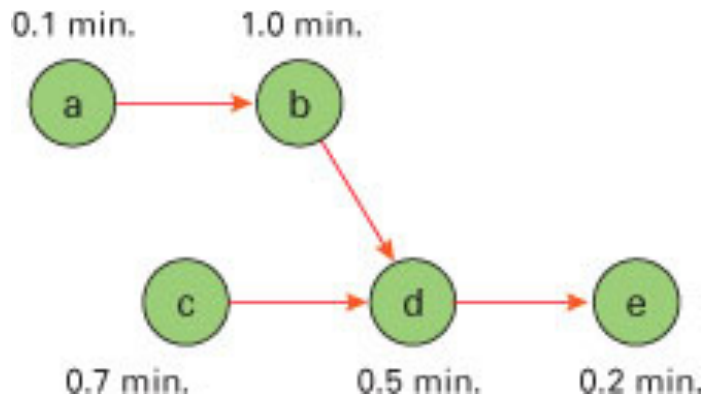
4. After each task assignment, determine the time remaining at the current workstation by subtracting the sum of times for tasks already assigned to it from the cycle time.
5. Break ties that occur using one of these rules:
   a. Assign the task with the longest task time.
   b. Assign the task with the greatest number of followers.

If there is still a tie, choose one task arbitrarily.

6. Continue until all tasks have been assigned to workstations.
7. Compute appropriate measures (e.g., percent idle time, efficiency) for the set of assignments.

Example

Arrange the tasks shown in figure into three workstations. Use a cycle time of 1.0 minute. Assign tasks in order of the most number of followers.



Workstation Time	Time Remaining	Eligible	Assign Task	Revised Time Remaining	Station Idle
1	1.0	a, c	a	0.9	
	0.9	c	c	0.2	
	0.2	none	—		0.2
2	1.0	b	b	0.0	0.0
3	1.0	d	d	0.5	
	0.5	e	e	0.3	
	0.3	—	—		0.3
					0.5

$$\text{Percentage of idle time} = \frac{\text{Idle time per cycle}}{N_{\text{actual}} \times \text{Cycle time}} \times 100$$

$$\text{Percentage of idle time} = \frac{.5}{3 \times 1.0} \times 100 = 16.7\%$$

$$\text{Efficiency} = 100\% - \text{Percent idle time}$$

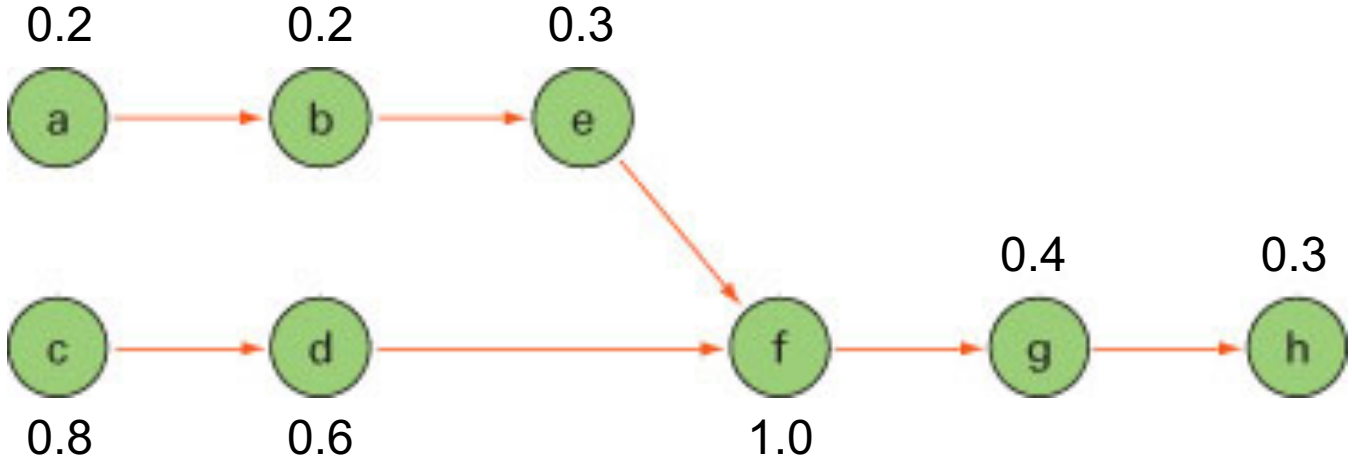
$$\text{Efficiency} = 100\% - 16.7\% = 83.3\%$$

Example

Using the information contained in the table shown, do each of the following:

- Draw a precedence diagram.
- Assuming an eight-hour workday, compute the cycle time needed to obtain an output of 400 units per day.
- Determine the minimum number of workstations required.
- Assign tasks to workstations using this rule: Assign tasks according to greatest number of following tasks. In case of a tie, use the tiebreaker of assigning the task with the longest processing time first.
- Compute the resulting percent idle time and efficiency of the system.

Task	Immediate Follower	Task Time (in minutes)
a	b	0.2
b	e	0.2
c	d	0.8
d	f	0.6
e	f	0.3
f	g	1.0
g	h	0.4
h	end	0.3
		$\Sigma t = 3.8$



$$\text{Cycle time} = \frac{\text{Operating time}}{\text{Desired output rate}} = \frac{480 \text{ minutes per day}}{400 \text{ units per day}} = 1.2 \text{ minutes per cycle}$$

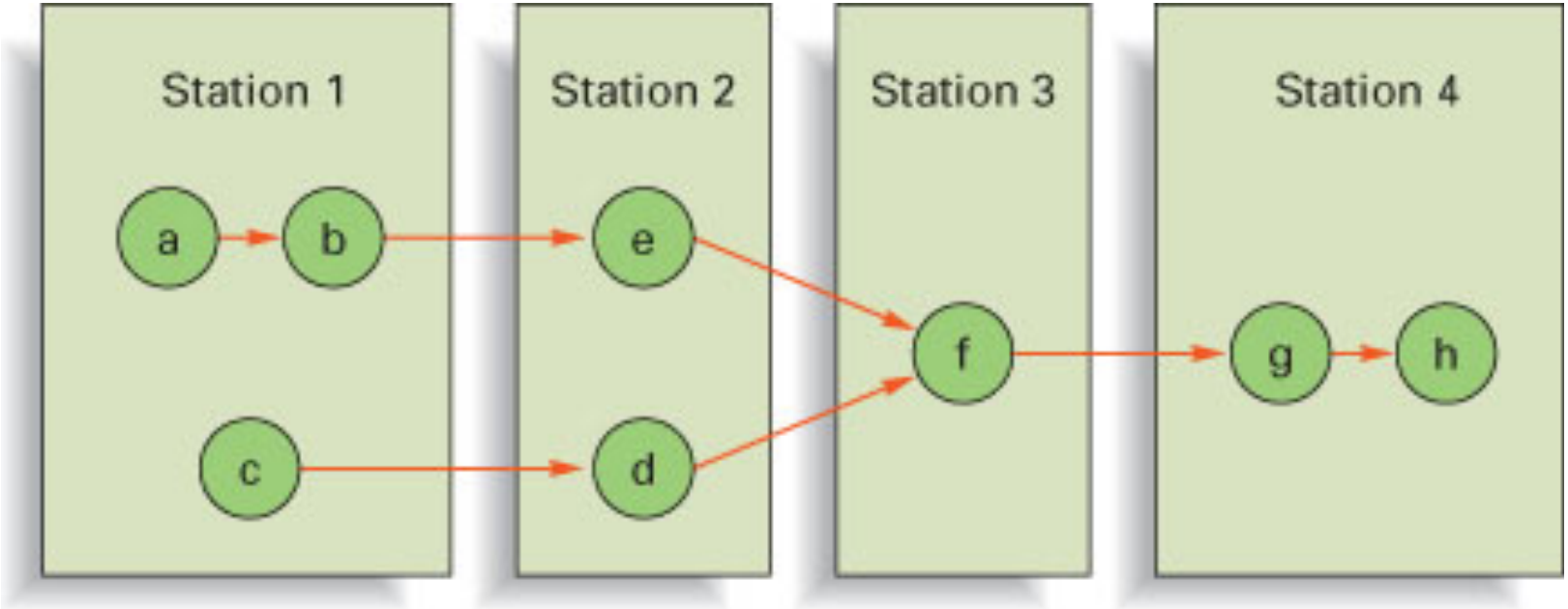
$$N_{min} = \frac{\Sigma t}{\text{Cycle time}} = \frac{3.8 \text{ minutes per unit}}{1.2 \text{ minutes per cycle per station}} = 3.17 \text{ stations (round to 4)}$$

Station	Time Remaining	Eligible	Will Fit	Assign (task time)	Revised Time Remaining	Idle
1	1.2	a, c*	a, c*	a (0.2)	1.0	
	1.0	c, b**	c, b**	c (0.8)	0.2	
	0.2	b, d	b	b (0.2)	0.0	
	0	e, d	None	—		0.0
2	1.2	e, d	e, d	d (0.6)	0.6	
	0.6	e	e	e (0.3)	0.3	
	0.3***	f	None	—		0.3
3	1.2	f	f	f (1.0)	0.2	
	0.2	g	None	—		~~0.2~~
4	1.2	g	g	g (0.4)	0.8	
	0.8	h	h	h (0.3)	0.5	
	0.5	—	—	—		0.5
						1.0 min.

*Neither *a* nor *c* has any predecessors, so both are eligible. Task *a* was assigned since it has more followers.

**Once *a* is assigned, *b* and *c* are now eligible. Both will fit in the time remaining of 1.0 minute. The tie cannot be broken by the "most followers" rule, so the longer task is assigned.

***Although *f* is eligible, this task will not fit, so station 2 is left with 0.3 minute of idle time per 1.2-minute cycle.

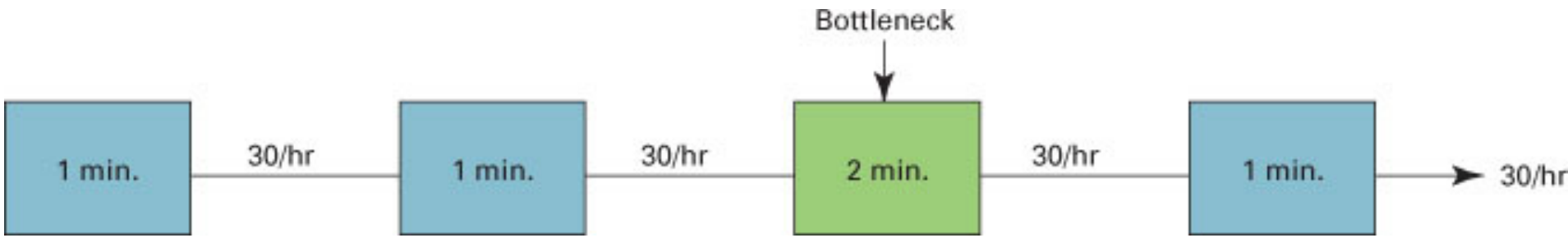


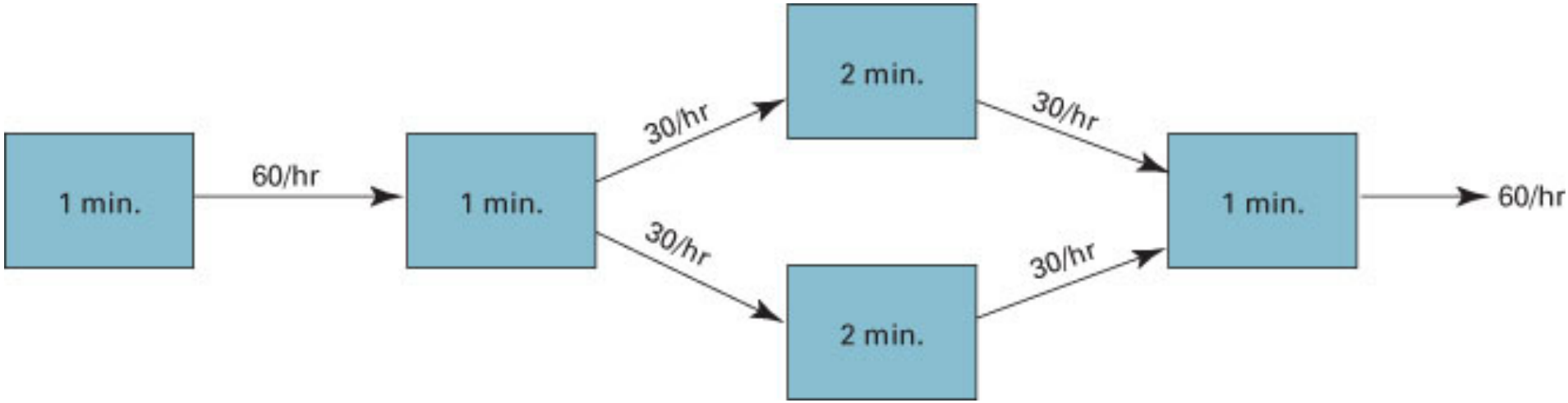
$$\text{Percent idle time} = \frac{1.0 \text{ min.}}{4 \times 1.2 \text{ min.}} \times 100 = 20.83\%.$$

$$\text{Efficiency} = 100\% - 20.83\% = 79.17\%.$$

Other Approaches

$$\frac{60 \text{ minutes per hour}}{2 \text{ minutes per unit}} = 30 \text{ units per hour}$$





Designing Process Layouts

The main issue in designing process layouts concerns the relative positioning of the departments involved. Departments must be assigned to locations. The problem is to develop a reasonably good layout; some combinations will be more desirable than others.

Locations

A	B	C
D	E	F

Work centers to be assigned

1
2
3
4
5
6

Layouts can also be influenced by external factors such as the location of entrances, loading docks, elevators, windows, and areas of reinforced flooring. Also important are noise levels, safety, and the size and locations of restrooms.

A major obstacle to finding the most efficient layout of departments is the large number of possible assignments. For example, there are more than 87 billion different ways that 14 departments can be assigned to 14 locations if the locations form a single line. Different location configurations (e.g., 14 departments in a two-by-seven grid) often reduce the number of possibilities, as do special requirements (e.g., the stamping department may have to be assigned to a location with reinforced flooring). Still, the remaining number of layout possibilities is quite large. Unfortunately, no algorithms exist to identify the best layout arrangement under all circumstances. Often planners must rely on heuristic rules to guide trial-and-error efforts for a satisfactory solution to each problem.

Measures of Effectiveness

One advantage of process layouts is their ability to satisfy a variety of processing requirements. Customers or materials in these systems require different operations and different sequences of operations, which causes them to follow different paths through the system. Material-oriented systems necessitate the use of variable-path material-handling equipment to move materials from work center to work center. In customer-oriented systems, people must travel or be transported from work center to work center. In both cases, transportation costs or time can be significant. Because of this factor, one of the major objectives in process layout is to minimize transportation cost, distance, or time. This is usually accomplished by locating departments with relatively high interdepartmental work flow as close together as possible.

Other concerns in choosing among alternative layouts include initial costs in setting up the layout, expected operating costs, the amount of effective capacity created, and the ease of modifying the system.

In situations that call for improvement of an existing layout, costs of relocating any work center must be weighed against the potential benefits of the move.

Information Requirements

The design of process layouts requires the following information:

A list of departments or work centers to be arranged, their approximate dimensions, and the dimensions of the building or buildings that will house the departments.

A projection of future work flows between the various work centers.

The distance between locations and the cost per unit of distance to move loads between locations.

The amount of money to be invested in the layout.

A list of any special considerations (e.g., operations that must be close to each other or operations that must be separated).

The location of key utilities, access and exit points, loading docks, and so on, in existing buildings.

The ideal situation is to first develop a layout and then design the physical structure around it, thus permitting maximum flexibility in design. This procedure is commonly followed when new facilities are constructed. Nonetheless, many layouts must be developed in existing structures where floor space, the dimensions of the building, location of entrances and elevators, and other similar factors must be carefully weighed in designing the layout. Note that multilevel structures pose special problems for layout planners.

Minimizing Transportation Costs or Distances

The most common goals in designing process layouts are minimization of transportation costs or distances traveled. In such cases, it can be very helpful to summarize the necessary data in *from-to charts*.

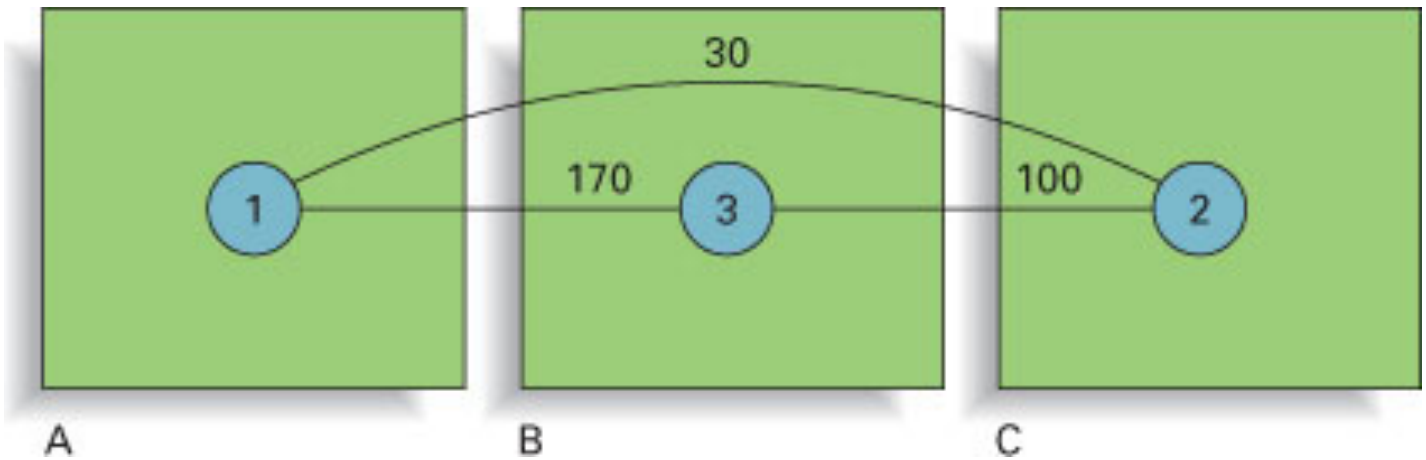
		LOCATION		
From	To	A	B	C
A			20	40
B				30
C				

	DEPARTMENT		
	1	2	3
	1	30	170
Dept.	2		100
	3		

Example

Assign the three departments shown in table to locations A, B, and C, which are separated by the distances shown in table, in such a way that transportation cost is minimized. Note that table summarizes the flows in both directions. Use this heuristic: Assign departments with the greatest interdepartmental work flow first to locations that are closest to each other.

Trip	Distance (meters)	Department Pair	Work Flow
A–B	20	1–3	170
B–C	30	2–3	100
A–C	40	1–2	30



Department	Number of Loads Between	Location	Distance To:	Loads	Distance
1	2: 30	A	C: 40	30 × 40 =	1,200
	3: 170		B: 20	170 × 20 =	3,400
2	3: 100				
3		B	C: 30	100 × 30 =	3,000
					7,600

Closeness Ratings

Although the preceding approach is widely used, it suffers from the limitation of focusing on only one objective, and many situations involve multiple criteria. Richard Muther developed a more general approach to the problem, which allows for subjective input from analysis or managers to indicate the relative importance of each combination of department pairs.

Muther suggests the following list:

Use same equipment or facilities.

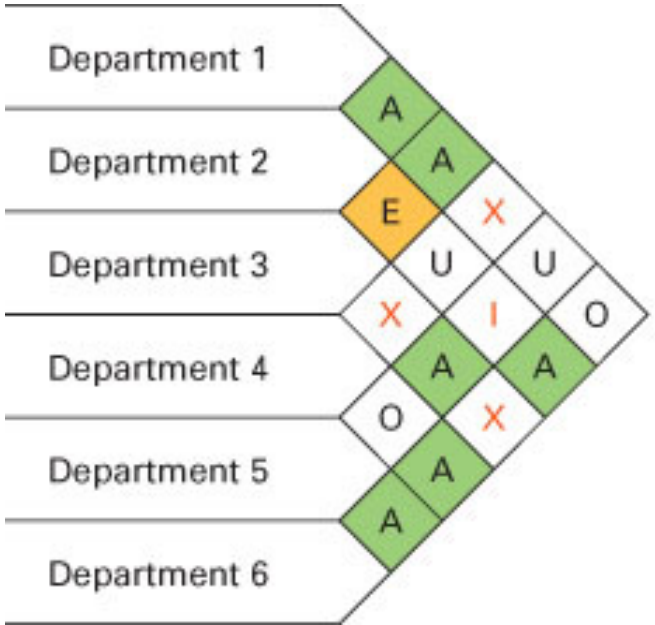
Share the same personnel or records.

Sequence of work flow.

Ease of communication.

Unsafe or unpleasant conditions.

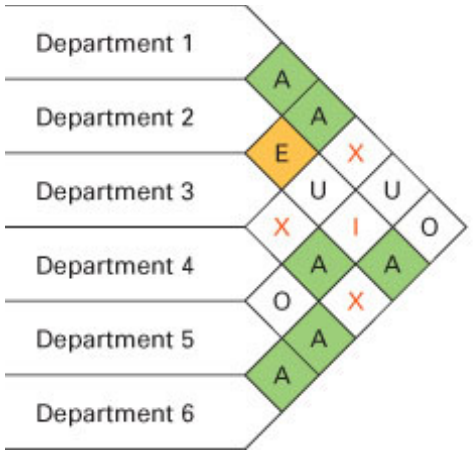
Similar work performed.



Code	Degree of closeness
A	Absolutely necessary
E	Very important
I	Important
O	Ordinary importance
U	Unimportant
X	Undesirable

Example

Assign the six departments in figure to a 2 × 3 set of locations using the heuristic rule: Assign critical departments first, because they are the most important.



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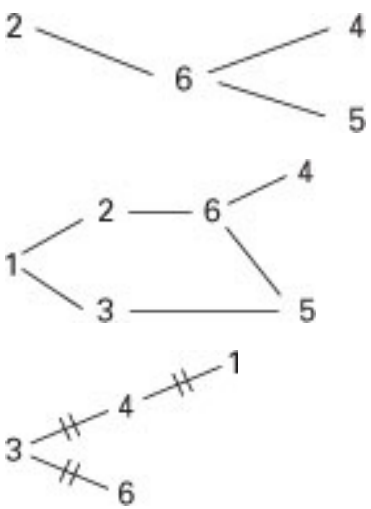

A Links	X Links
1–2	1–4
1–3	3–6
2–6	3–4
3–5	
4–6	
5–6	

1	2	6
3	5	4