Chapter 6: Process Design and Facility Layout

Introduction and Process Types

- **Process design:** Determining the form and function of how goods or services are produced, i.e. the sequence of operations
- **Make or buy**: (first step) Decide whether to make a part or product in-house or to buy it as a segment of production process from another company

Job Shop

- a process is used when a low quantity of high variety customized goods or services will be needed.
- Process is intermittent, work shifts from one small job to the next, each somewhat different.
- High flexibility of equipment and skilled workers are important
- ex. process used by a custom spring maker (manufacturing), process used in the surgery department of a hospital that is able to perform a variety of procedures (service)

Batch Process

- used when a moderate quantity and variety of goods or services is desired. The equipment need not be as flexible as in a job shop, but process is still intermittent.
- The skills level of workers doesn't need to be as high as in a job shop because there is less variety in the jobs
- ex. process used by small bakeries that make bread, cakes, or cookies in batches

Repetitive

- **Repetitive process:** A type of process used when higher quantities of more standardized goods or services are needed
- Skills of workers is low and only slight flexibility of equipment is needed
    - **Production line:** A sequence of machines/workstations that perform operations on a part/ product.
    - **Assembly line:** A production line where parts are added to product sequentially

Continuous Process

- Used when a high volume of highly standardized output is required
- Workers are low skilled/no equipment flexibility
- ex. process if gasoline, steel, paper, sugar etc. or utilities and the internet(services)

Technology

- Application of scientific discoveries to the development and improvement of goods and services and/or the processes that produce or provide them
- *Process technology* included methods, procedures and equipment used to produce goods and provide services, such as robotics and automation of factory floor
- *Information technology (IT)* is the science and use of computers and other electronics equipment to store, process and send information

Automation

- using machinery/equipment with sensing and control devices that enable it to operate automatically
- ***Numerically controlled (N/C) machines*** - Machines that perform operations by following mathematical processing instructions, best used in cases where part geometry is complex, with possibility of frequent changed in the design (higher skill levels needed with high initial cost
- ***Robot* -** Machine costing of a mechanical arm, a power supply, and a controller.
- ***Flexible Manufacturing system (FMS)*** - A group of machining centres controlled by a computer, with automatic material handling, robots or other automated equipment. They can produce a variety of similar products.

- ***Computer-Integrated Manufacturing (CIM)*** - a system for linking a broad range of manufacturing and other activities through an intreating computer system

Process Design

- involves determining the form and function of how production of goods or services is to occur. It involves identifying the operations and their sequence, resources, and controls directly needed in the production of goods or rendering of services

Methodology for Production Process Design

1. **Define the production Process (build business case - stage):**
    - Determine how completed the input materials should be. These are make-or-buy decisions
    - Set production process objectives:
        - Capacity, flexibility
        - Type of process (job shop, batch, repetitive, continuous)
        - Cost (fixed, variable), process quality capability
        - Technology/extent of automation, production start date
    - Determine the nature of process in general
2. **Production process development (Development - stage)**

(from inputs to outputs - the sequence)

- **2.1 Conceptualize the design**
    - Usually a *process flaw diagram* is used to show the operations and the movement of material between the operations
        - Incremental
        - Hierarchical (Top-down)
    - Evaluate each alternative process concept
- **2.2 Make an embodiment of the design**
    - Choose one process concept and complete the design
    - Build a prototype process and test it. (Pilot plant)
        - Determine the resources (machines, equipment, labour) needed
        - Estimate the costs, quality, etc, and compare with objectives
    - Refine the process and re-evaluate it
- **2.3 Create a detailed design**
    - Finalize the process specifications
        - Determine the specific machines, equipment (capacities), and labour
        - Design the plant layout
        - Design the work centres

3. **Buy the machines and equipment, recruit workers, and start trial runs (Testing and validation - stage)**

Process Flow Diagram

- shows the operations and movement of material between the oprations

Service Process Design

- similar to manufacturing process design except that instead of material, the flow of the customer or something belonging to the customer should be followed
- The service positioning can easily be changed by varying the choices and the degree of customization and involvement of customers at any step of the service

Service Blueprinting

- the process flow diagramming for services is called service blue-printing. It is beneficial to the service provider to distinguish operations seen by the customer and those hidden from customers. These are separated by the line of visibility on the service blueprint.

Customer Perception in Service Process Design

- Suggestions:
  - do not raise expectations too high in the beginning
  - end the service positively because customers remember the end more

Types of Layout

- Layout is the location of departments, work centres, or equipment in the facility/factory/plant.
- **Product (line) Layout**
  - Arrangement of production resources linearly according to the progressive steps by which a product is made
  - Work is divided into a series of standardized tasks, permitting specialization of both labour and equipment.
  - Only one or a few very similar items involved
- **Process (Functional) Layout**
  - Arrangement of production resources according to similarity of function
  - Has a variety of production requirements. and requires frequent adjustments to equipment, causing discontinuous work flow *(intermittent processing)*
  - ex. hospitals, grocery stores, auto repair shop
- **Cellular Layout**
  - Labour in which different machines are arranged in a cell that can process items that have similar processing requirements
  - a cell is a small version of a product layout.
  - U-shaped line permits increased communication among workers on the line = teamwork
  - Grouping of similar items is known as **group technology** and involves identifying items with similarities in either design or manufacturing characteristics, and grouping them into part families
- **Other Types:**
  - *Warehouse Layout*
  - *Retail Layout*
  - *Office Layout*
  - *Restaurant Layour*
  - *Hospital Layour*

Assembly Line Balancing

- **Line Balancing:** Assigning taste to workstations in such a way that the work stations have approximately equal time requirements

Cycle time

- The maximum time allowed at each workstation to complete its set of tasks on a unit

Precedence network

- a diagram that shows the tasks and their precedence requirements (order in which tasks may be performed)

How is a line balanced?

- Managers employe *heuristic (intuitive) rules,* which provide good sets of assignments. Such as:
  1. Assign the task with the longest time.
  2. Assign the task with the most followers
  3. Assign the task with the largest positional weight (= sum of tasks time plus the time of all the following tasks)

Measures of effectiveness of the set of assignments are:

As a general rule, the cycle time is determined by the desired output rate. We can calculate the cycle

$$\text{Percentage idle time} = \frac{\text{Sum of idle times per unit}}{N_{\text{actual}} \times \text{cycle time}} \times 100 \quad (6\text{-}1)$$

where N_{actual} = Actual number of workstations.

For the preceding example, the value is:

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

D = Desired output per day (i.e., demand)

For example, suppose that the desired output rate is 480 units per day, and the line will operate for eight hours per day (480 minutes). Using Formula 6-1, the necessary cycle time is

$$\frac{\text{480 minutes per day}}{\text{480 units per day}} = \text{1.0 minute per unit}$$

The number of workstations that will be needed is a function of the cycle time, the sum of task times, and our ability to combine tasks into workstations. We can determine the ***theoretical minimum*** number of workstations necessary, given a cycle time, as follows:

$$N_{\min} = \frac{\sum t}{CT} \quad (6\text{-}2)$$

where

$N_{\min}$ = Theoretical minimum number of workstations

Σt = Sum of task times

Given cycle time of 1 minute per unit, if sum of task times is 2.5 minutes, the minimum number of workstations required to achieve this goal is:

$$N_{\min} = \frac{\text{2.5 minutes per unit}}{\text{1 minute per unit per workstation}} = \text{2.5 workstations}$$

1. The **percentage idle time** of the line. This is sometimes referred to as the *balance decay.*
2. The *efficiency of the line*

   Efficiency = 100 − percentage idle time

   In the preceding example, efficiency = 100% − 16.7% = 83.3%

Variable Task Times
- reasons include: worker fatigue, boredom, material shortages, defects, mechanical problems, and product differences

Treatment of Bottlenecks
1. One or more tasks in the bottleneck workstation can be automated or made easier using equipment such as a tool balancer
2. if bottleneck occurs because of only some products, the tasks for these products can be done offline or online by a special crew of "floaters"
3. use *parallel workstations.* They increase the work flow and provide flexibility

Designing Process (Functional) Layouts
- Main issue id the relative positioning of the departments involved

Minimizing Total Transportation Cost or Distance
- Helpful to summarize the necessary data in *from-to charts,*
- Table below below displays the distance between centres of each pair of locations

		Location		
From	**To**	**A**	**B**	**C**
A		–	20	40
B		20	–	30
C		40	30	–

- Table after displays current or forecast work flow between each pau of departments

		Location		
From	To	A	B	C
A		–	20	40
B		20	–	30
C		40	30	–

Heuristic

1. Assign the pair of departments with the greatest interdepartmental work flow to locations whose centres are closest ti each other, keeping the future assignments in mind.
2. Then pick the pair with second highest work flow and assign them to two available locations whose centres are the next two closest, keeping their relationship with those already assigned and future assignments in mind
3. Continue until all departments have been assigned

Chapter 17: Project Management

Project Manager

- **Project:** Unique, large, one time operation designed to accomplish a specific objective in a limited time frame
- **Performance goals:** For a project; keeping the project within schedule, budget, and quality guidelines
- **Matrix organization:** An organizational structure that temporarily groups together specialists from different departments to work on special projects

The Project Managers Job

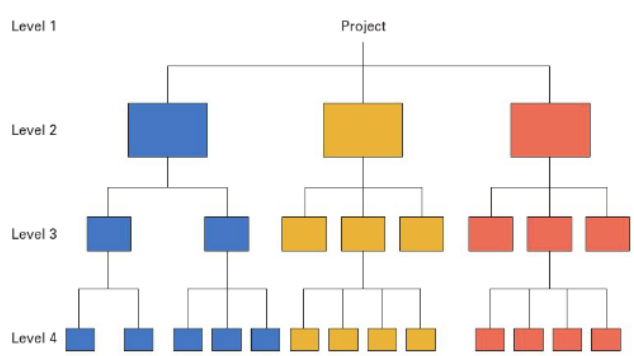
- **Project manager:** The person responsible for planning, scheduling, executing, and controlling a project from inception to completion; meeting the projects requirements; and ensuring completion on time, within budget, and to the required quality standards. Responsible for:
    1. The work
    2. the human resources
    3. Communications
    4. Quality
    5. Time
    6. Costs

Project Planning

- Analyzing the project into work packages and activities, estimating resources neededd and durations, scheduling, etc.

Work Breakdown Structure (WBS)

- A hierarchical listing of what must be done during a project
- Established a logical framework for identifying the required activities for the project

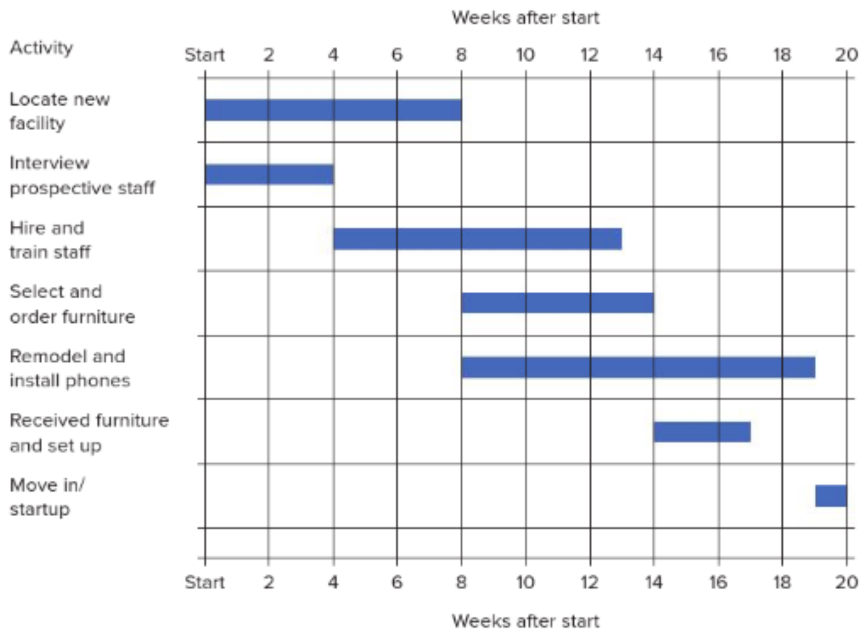


Project Scheduling

- Determining the timing of activities of the project. It starts with the identification of the activities in the WBS, including their attributes and whether an activity is a milestone activity.

Gant Chart

- visual aid for scheduling and control of the activities of a project (simple)
- indicates when activities are to occur, their planned duration, and when they are to occur
- Charts fail to reveal relationships among activities that can be crucial to effective project management.

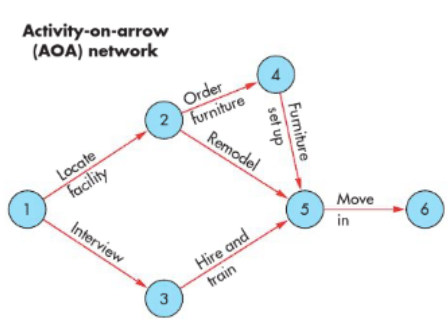


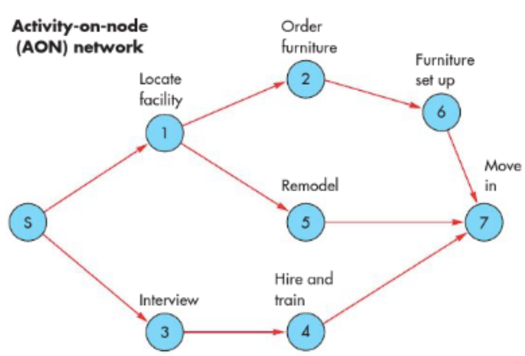
Pert/CPM Technique

- **PERT** (program evaluation and review technique) and **CPM** (critical oath method) are two of the most widely used tools for scheduling and control of large-scale projects. By using PERT and CPM, managers are bale to obtain:
    1. A graphical display of project activities and their sequential relationship.
    2. An estimate of how long the project will take
    3. An indication of which activities are most critical to timely project completion
    4. An indication of how long any activity can be delayed without delaying the project

Precedence Network

- One of the main features of PERT/CPM is its use of a **precedence network**; to depict project activities and their sequential relationships by use of arrows and nodes.
    - **Activity-on-arrow (AOA):** Network in which arrows designate activities
    - **Activity-on-nodes (AON):** Network in which nodes designate activities





- A **path**: a sequence of activities that leads from the start node to the end node.
- **Critical path:** The longest path from start to end; determined the expected project duration
- **Critical activities:** Activities on the critical (longest) path
- **Path slack time:** Allowable slippage for a path; the difference between the length of the path and the length pf the critical (longest) path.

Deterministic Activity Durations

- **Deterministic durations:** Durations that are fairly certain
- **Probabilistic durations:** Durations that allow for variation

Solution Technique

Rules for the PERT/CPM Solution Technique

Forward Pass

Start at the left side of the precedence network (i.e., the start node) and work toward the right side.

For the start activity: ES = 0.

For each activity: ES + Activity duration = EF.

If an activity has a unique immediate predecessor: ES = EF of that activity.

If an activity has multiple immediate predecessors, set its ES equal to the largest EF of its immediate predecessors.

Backward Pass

Start at the right side of the precedence network (i.e., the end node) and work toward the left side.

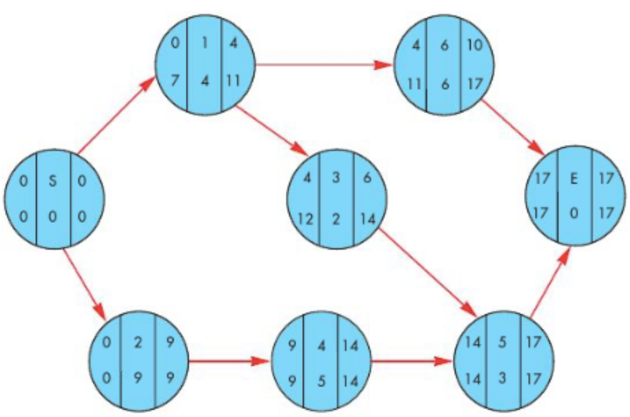
Use the EF as the LF for the end activity.

For each activity: LS = LF − Activity time.

If an activity has a unique immediate follower: LF = LS of that activity.

If an activity has multiple immediate followers, set the activity's LF equal to the smallest LS of the immediate followers.

- ES = the *earliest* time the activity can *start*
- EF = the *earliest* time the activity can *finish*
- LS = the *latest* time the activity can *start* and not delay the project
- LF = the *latest* time the activity can *finish* and not delay the project
- **Calculating Activity Slack Times (**2 ways):
    - Slack = LS - ES or LF - EF



The slack time for an activity is the difference between either LF and EF or LS and ES. Thus,

Activity	LS	ES	Slack	or	LF	EF	Slack
S	0	0	0		0	0	0
1	7	0	7		11	4	7
6	11	4	7		17	10	7
3	12	4	8		14	6	8
2	0	0	0		9	9	0
4	9	9	0		14	14	0
5	14	14	0		17	17	0
E	0	0	0		0	0	0

The activities with zero slack times indicate the critical path. In this case the critical path is S-2-4-5-E.

Probabilistic Activity Durations

- The probabilistic PERT/CPM approach, called the **3-point estimates** method, involves *three* duration estimates for each activity instead of one:
    1. **Optimistic Duration:** The length of time under the best conditions; represented by t_o

2. **Pessimistic Duration:** The length of time under the worst conditions; represented by t_p
3. **Most likely duration:** The most probable length of time; represented by t_m

- **The beta distribution** is a family of continuous positive distributions used to describe the inherent variability in activity durations.

The expected duration of an activity, t_m is an unequally weighted average of the three estimates:

$$t_e = \frac{t_o + 4t_m + t_p}{6}$$

The expected (average) duration of a path is equal to the sum of the expected duration of the activities on it:

$$\text{Path mean} = \sum (\text{expected duration of activities on the path})$$

The standard deviation of each activity's duration is estimated as one sixth of the difference between the pessimistic and optimistic estimates. We find the variance by:

$$\sigma^2_{\text{act}} = \left[\frac{(t_p - t_o)}{6}\right]^2 \quad \text{or} \quad \sigma^2_{\text{act}} = \frac{(t_p - t_o)^2}{36}$$

- The size of the variance reflects the degree of uncertainty associated with an activity's duration: the larger the variance, the greater the uncertainty.

The standard deviation of the duration of a path, done by:

$$\sigma_{\text{path}} = \sqrt{\Sigma[(\text{variances of activity durations on path})]}$$

Determining Path Probabilities

- The probability that a given path will be completed in a specific length of time can be determined using the following formula:

$$z = \frac{\text{Specified length of time} - \text{Expected path duration}}{\text{Standard deviation of path duration}}$$

- a *negative z* indicates that the specified time is *earlier* than the expected path duration
- The assumption of independence of path durations requires two conditions: (a) that the activity durations are independent of each other, and (b) that each activity is on only one path

Using Simulation

- independence assumptions are useful only if a few activities are on multiple paths, particularly much shorter than the critical path. Otherwise, using simulation to find desired probabilities is best. Using multiple passes (hundreds), and random value durations to prepare a frequency distribution.

Project Crashing

- Reducing the length of a project (crash) by using additional resources.
- Procedure for crashing is:
  1. Obtain estimates of regular and crash durations and crash cost per period for each activity, and indirect project costs per period
  2. Determine the lengths of all paths
  3. Determine the critical activities

4. Crash critical activities, starting from the cheapest, as long as crashing cost per period does not exceed the benefits of crashing.

Project Execution and Control

- **Project execution:** involves the actual performance of the activities that were planned in project planning.
- **Project control:** involves assessing a projects progress against plans and taking corrective actions, if necessary, in older to bring the project on track (also includes controlling the changes to a project)
    - A common technique used for cost control is ***earned value analysis***. The scheduled time overrun is measured by schedule "variance" = PV - EV, and the cost overrun is measured by cost "variance" = actual cost - EV (PV=Planned value, EV=Earned value)

Chapter 8: Location Planning and Analysis

Importance of Location

- **Location of raw materials:** companies locate near or at the source of their raw materials for three primary reasons, necessity, perishability, and transportation costs.
- **Location of Markets:** Retailers and service providers are usually found near the centre of the markets they serve. Like fast food restaurants, gas stations, supermarkets. They rely on convenience to attract customers.
- **Labour Factors:** Primary labour considerations are availability of workers, the wage rates and labour productivity, attitudes toward work, and whether unions are a potential problem. Large plants usually locate in or near population centres. Some companies target regions with high unemployment in order to tap the large pool of unemployed workers
- **Foreign Locations:** Some Canadian companies are attracted to foreign to foreign locations to exploit their natural resources. Others view foreign locations as a way to expand their markets. Many developing countries offer an abundant supply of cheap labour. For example, many North American companies.

Community/Site-related Considerations

- From a company standpoint, a number of factors determine the desirability of a community as a place for its workers and managers to live. They include facilities for education, shopping, recreation, transportation, entertainment, and medical services.
- Many communities actively try to attract new businesses because they are viewed as potential sources of future tax revenues and new job opportunities. Communities offer tax abatements, low cost loans, and grants for worker training.

Service and Retail Locations

- Customer access is sometimes a prime consideration.
- Manufacturers tend to be cost focused, and concerned with labour, energy, and material costs and availability, as well as distribution costs.
- Service and retailers tend to be profit or revenue focused, concerned with demographics (age, income, education etc)

Why should Foreign Companies Locate in Canada

- Canadian workers are educated, basic health care is free, and the country is politically stable. Canada is generally safe and secure, energy costs are low, and governments provide R&D tax incentives. Canada is one the of cheapest industrialized countries in which to operate a plant

Evaluating Location Alternatives

Location Break-even Analysis

- identifies the least (fixed and variable) cost location choice based on quantity to be produced
- Procedure steps:
    1. Determine the fixed and variable costs associated with each location alternative
    2. Plot the total-cost lines for all location alternatives on the same graph
    3. Determine which location will have the lowest total cost for the expected level of output

    (this method assumes that fixed and variable costs are constant for the range of probable output, and only one product is involved)

The total cost for each location is represented mathematically as:

$$\text{Total cost} = FC + v \times Q$$

where

FC = Fixed cost

v = Variable cost per unit

Q = Quantity of output

- Similar analysis can be performed using profit instead of total cost. (if the selling price and demand is the same across the sites, then the answer will be the same as when using total cost)

For a profit analysis, calculate the total profit for each location:

$$\text{Total profit} = Q(R - v) - FC$$

where

R = Revenue per unit

Transportation Method

- Transportation costs sometimes play an important role in location decisions. These stem from the movement of raw materials and finished goods.
- When there is only one facility, the company can include the transportation cost in the locational break-even analysis by incorporating the transportation cost per unit into the variable cost per unit.
- When there is more than one facility, the company should use the *transportation method* of linear programming.

Factor Rating

- involves scoring the factors (both quantitative and qualitative) and determining the weighted score for each location, and choosing the location with the highest weighted score
- the procedure:
    1. Determining which factor are relevant (location of market, labour supply, parking spaces, revenue potential etc)
    2. Assign a weight to each factor that indicates its relative importance compared will all other factors. Typically, weights sum to 1.00
    3. Decide on a common scale for all factor scores (ex. 0 to 100)
    4. Score all factors for each location
    5. Multiple the factor weight by the score for each factor, and sum the results for each location
    6. Choose the location that has the highest composite score
- example:

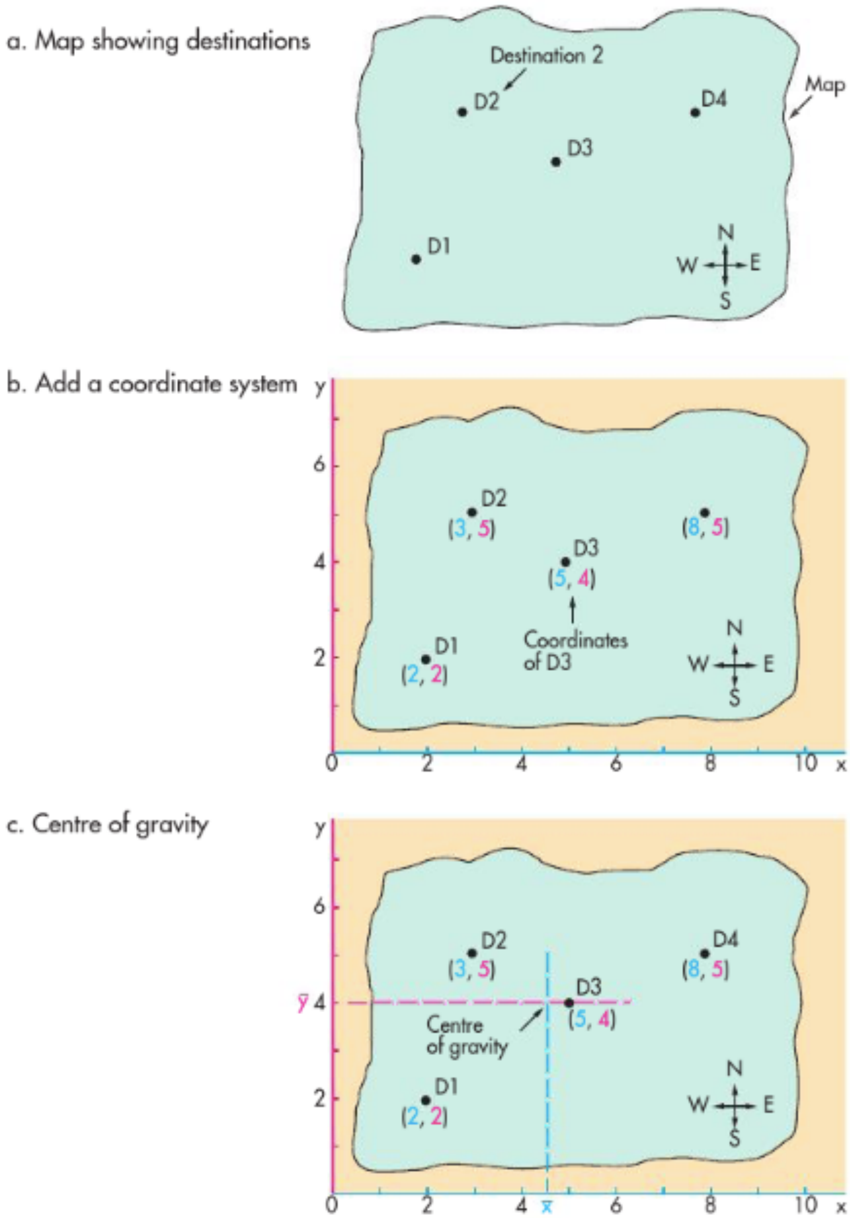
A retailer intends to open another store in the same city. The table below contains information on two potential sites. Which is the better alternative?

		Scores (Out of 100)		Weighted Scores	
Factor	Weight	Alt. 1	Alt. 2	Alternative 1	Alternative 2
Lease cost	.10	100	60	.10(100) = 10.0	.10(60) = 6.0
Renovation cost	.05	80	80	.05(80) = 4.0	.05(80) = 4.0
Traffic volume	.40	70	90	.40(70) = 28.0	.40(90) = 36.0
Operating cost	.10	86	92	.10(86) = 8.6	.10(92) = 9.2
Distance from existing store	.20	40	70	.20(40) = 8.0	.20(70) = 14.0
Size	.15	80	90	.15(80) = 12.0	.15(90) = 13.5
	1.00			70.6	82.7

Alternative 2 is better because it has higher composite score.

Centre of Gravity Method

- determines the location of a distribution centre/warehouse that will minimize total distribution cost. It treats distribution cost as a linear function of the distance and the quantity shipped
- Method uses a map that shows the location of destinations (demand points)



- If the qualities to be transported to every destination are equal, you can obtain the coordinates of the centre of gravity (i.e. the location of the distribution centre/warehouse) by finding the average of the x coordinates and the average of the x and y coordinates

These averages can be easily determined using the following formulas:

$$\bar{x} = \frac{\sum x_i}{n}$$
$$\bar{y} = \frac{\sum y_i}{n} \qquad (8\text{-}3)$$

where

x_i = x coordinate of destination i

y_i = y coordinate of destination i

n = number of destinations

When the number of units to be transported is not the same for all destinations, which is usually the case, a *weighted average* must be used to determine the centre of gravity, with the weights being the *quantities* to be transported.

The appropriate formulas in this case are:

$$\bar{x} = \frac{\sum x_i Q_i}{\sum Q_i}$$
$$\bar{y} = \frac{\sum y_i Q_i}{\sum Q_i} \qquad (8\text{-}4)$$

where

Q_i = Quantity to be transported to destination i

Location Analysis Software

- **Geographic information system (GIS)**: a computer based tool for collecting, storing, retrieving, and displaying location dependent demographic data on maps.

Chapter 7s: Learning Curves

The Concept of Learning Curves

- Learning curves display the phenomenon that the time required to perform a task decreases with increasing repetitions
- learning curves have little relevance for planning or scheduling of routine short activities, but they do have relevance for complex long repetitive activities
- Major changes that are made once production is underway, such as product redesign or new equipment, can actually cause a temporary increase in time per unit until workers adjust to the change

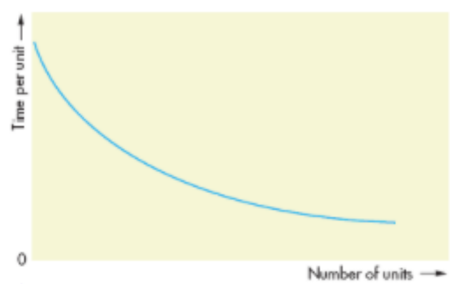


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Figure 7S-1

The learning effect: time per unit decreases as the number of units produced increases.

An activity is known to have an 80 percent learning curve. It has taken a worker 10 hours to produce the first unit. Determine expected completion times for these units: the 2nd, 4th, 8th, and 16th (note successive doubling of units).

SOLUTION

Each time the cumulative output doubles, the time per unit for that quantity should be approximately equal to the previous time multiplied by the learning percentage (80 percent in this case). Thus:

Unit	Unit Time (hours)
1	= 10
2	0.8(10) = 8
4	0.8(8) = 6.4
8	0.8(6.4) = 5.12
16	0.8(5.12) = 4.096

Determining unit times

- two ways to obtain the unit times. One is to use a formula; the other is to use a table of values

Formula

- based on the existence of a linear relationship between the time per unit and the number of units produced when these two variables are expressed in logarithms.
- The unit time (direct labours hours required) for the *n*th unit can be calculated using the formula:

$$T_n = T_1 \times n^b \qquad T_n = \text{Time for the } n\text{th unit}$$

$$T_1 = \text{Time for the first unit}$$

$$b = \frac{\ln\left(\frac{\text{learning percentage}}{100}\right)}{\ln(2)}\text{; ln stands for the natural logarithm}$$

- example:

$$T_3 = 10(3^{\ln .8/\ln 2}) = 10(3^{-.223/.693}) = 10(3^{-.322}) = 7.02$$

Learning Factor (Table)

- The table shows two things for some selected learning percentages.
    1. the unit time factor for the unit number up to 30
    2. total (cumulative) time factor

To find the time for unit *n* (e.g., *n* = 10 → the 10th unit), use the formula

$$T_n = T_1 \times \text{unit time factor} \qquad (7S\text{-}2)$$

Thus, for an 85 percent learning curve with T_1 = 4 hours, the time for the 10th unit would be 4 × .583 = 2.33 hours. To find the time for all units up to unit *n* (e.g., *n* = 10 → the first 10 units), use the formula

$$\sum T_n = T_1 \times \text{total time factor} \qquad (7S\text{-}3)$$

Thus, for an 85 percent curve with T_1 = 4 hours, the total time for all first 10 units (including the time for unit 1) would be 4 × 7.116 = 28.464 hours.

Determining the Learning Percentage:

- If the learning percentage of the activity cannot be estimated based on similar previous activities or the industry learning slope, given a few observations of unit times, one can estimate the learning percentage of the activity by fitting the power function to the chart of the data.
- The equation for the power function is   y=ax^b   (a=time of first unit)
- Solving the b equation gives:

$$\text{Learning percentage} = 100 \times 2^b$$

Applications of Learning Curves

- useful in management activities including:

Logarithm version of Formula 7S-1:

$$\ln(T_n) = \ln(T_1) + b\ln(n)$$

Rewriting (where *e* = 2.71828):

$$n = e^{[\ln(T_n) - \ln(T_1)]/b}$$

    - About planning and scheduling
    - Negotiated selling/purchasing
    - Assessing labour training needs and performance
- Learning curves contributes a method for quantifying expected future improvements
- Can also be used to determine the minimum number of repetitions to achieve a given standard:

Cautions and Criticism
- Users of learning curves sometimes fail to include carryover effects; *previous experience with similar activities* can reduce unit times. The following model could be used instead:
    - $T_n = T_1 \times (n + n_p)^b$ where n_p is the number of units produced previously