

# VEMU INSTITUTE OF TECHNOLOGY:: P.KOTHAKOTA

Chittoor-Tirupathi National Highway, P.Kothakota, Near Pakala, Chittoor (Dt.), AP - 517112  
(Approved by AICTE, New Delhi and Affiliated to JNTUA, Anantapuramu )



**DEPARTMENT OF MECHANICAL ENGINEERING**

**DESIGN OF MACHINE MEMBERS - 20A03502**

**B.TECH : III-I SEM**

**Prepared By**

**Mr. K. V. SHARATH BABU REDDY**

**&**

**Mr. G. SUDARSANA REDDY**

## UNIT-1

- Concepts of Management-Administration and Organization – Functions of Management – Schools of Management Thought: Taylor's Scientific Management, Fayol's Principles of Management, Douglas Mc-Gregor's Theory X and Y, Mayo's Hawthorne Experiments, Herzberg's Two factor Theory of Motivation, Maslow's Hierarchy of Human needs – Systems Approach to Management. Organizational Structures- Functional- Divisional- Matrix etc., Basic concepts Related to Organization – Departmentation and Decentralization and their Merits, Demerits and Suitability

## **UNIT I**

Concepts of Management-Administration and Organization – Functions of Management – Schools of Management Thought: Taylor’s Scientific Management, Fayol’s Principles of Management, Douglas Mc-Gregor’s Theory X and Y, Mayo’s Hawthorne Experiments, Herzberg’s Two factor Theory of Motivation, Maslow’s Hierarchy of Human needs – Systems Approach to Management. Organizational Structures- Functional- Divisional- Matrix etc., Basic Concepts Related to Organization – Departmentation and Decentralization and their Merits, Demerits and Suitability

## **UNIT II**

Plant Location: Definition, Factors affecting the Plant Location, Comparison of Rural and Urban sites, Selection of Plant Location – Types of Production; Plant Layout: Definition, Objectives, Types of Plant Layout - Materials Handling: Functions-Objectives – Types, Selection Criteria of Material Handling Equipment.

## **UNIT III**

Work Study – Definition, Objectives, Method Study – Steps Involved – Various Types of Process Charts –Micro motion and Memo motion Studies. Work Measurement -Definition, Time Study, Steps involved - Equipment, Different Methods of Performance Rating - Allowances, Standard Time Calculation. Work Sampling - Definition, Steps Involved, Standard Time Calculations - Applications.

## **UNIT IV**

Inventory Models- Deterministic models- EOQ Models – With and Without Shortages Models; Inventory Models with Price Breaks -Probabilistic Models –Discrete Variable, Continuous Variable. Inventory Control Systems

## **UNIT V**

Inspection & Quality Control: Statistical Quality Control- Techniques- Variables and Attributes- Control Charts: X and R Charts; P Charts and C Charts. Acceptance Sampling Plan - Single Sampling and Double Sampling Plans- OC Curves. Introduction to TQM- Quality circles-BIS & ISO Standards-Importance .

# Unit-1

## Historical Views of Management

---

- We will examine the historical roots of management theory and practice and attempt to establish a connection between the theoretical foundations of modern management and the concepts advanced in subsequent chapters of your text.

# Alfred P. Sloan

- "My Years With General Motors"

The professional managers are: to manage the facts, not opinions; to put the strengths of people to work; to set the performance example for others, and serve as mentor; to use dissent and conflict to positive advantage, and to always accept a manager's responsibility to be a "servant" of others.

# Evolution of Management Thought



- Effective management played a key role in the construction of the pyramids, the use of communication and control of the Roman Empire, and the legal framework of commerce in 14th century VENICE.



# Evolution of Management Thought

---

- The most significant historical point of reference in the evolution of management was the advent of the Industrial Revolution.
- By the turn of the 20th century the science and practices of management were on a rapid and continuing path of development.

# Major Schools of Thought

---

- **Classical** - A focus on developing universal principles for use in various management situations.
- **Human Resource** - A focus on human needs, the work group, and the role of social factors in the workplace.
- **Quantitative or Management Science**  
A focus on the use of mathematical techniques for management problem-solving.

# Major Schools of Thought

---

- **Modern Approach**

A focus on total systems and contingency thinking, and an awareness of global developments in management.

- **Continuing Directions**

Emphasis on quality and performance excellence, global awareness, and leadership roles for a new management.

# CLASSICAL APPROACHES

- **Basic Assumption: People Are Rational**

People will rationally consider the opportunities available to them and do whatever is necessary to maximize their economic gain.

- **Scientific Management**
- **Administrative Principles**
- **Bureaucratic Organization**



# Scientific Management (Frederick Taylor)

- Develop a science for every job, including rules of motion, standardized work implements, and proper working conditions.
- Carefully select workers with the right abilities for the job.
- Carefully train these workers and provide proper incentives.
- Provide these workers with the necessary support.

# Administrative Principles (Henry Fayol)

- Rules of Mgmt. (5)

- Foresight
- Organization
- Command
- Coordination
- Control

- Principles of Mgmt.

- Division of work
- Scalar Chain
- Unity of Command
- Unity of Direction

# (Mary Follett)



- **Dynamic Administration**
  - Believed that groups were mechanisms through which diverse individuals could combine their talents for a greater good.
  - Placed a high value in the power of **Human Cooperation** and pioneered the concepts and practices of such issues as **Employee-Ownership**, **Systems Theory**, and **Social Responsibility**.

# Bureaucratic Organization

(Max Weber)



An ideal, intentionally rational, and very efficient form of organization founded on principles of logic, order, and legitimate authority.

- Clear Division of Labor
- Well Defined Hierarchy of Authority
- Formal Rules and Procedures
- Impersonality
- Careers Based on Merit

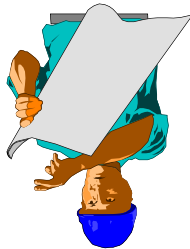
# Human Resource Approaches

- **Basic Assumption:** People are Social and Self-Actualizing.
- **The Hawthorne Studies**
  - Established the human resource as an essential concern for management, and one that has unique properties.
  - We learned that the nature of the Work Group should be important.
  - We learned about the tendency of people who are singled out for special attention to perform as anticipated merely because of expectations created by the situation.

# Human Resource Approaches

- **The Human Relations Movement**

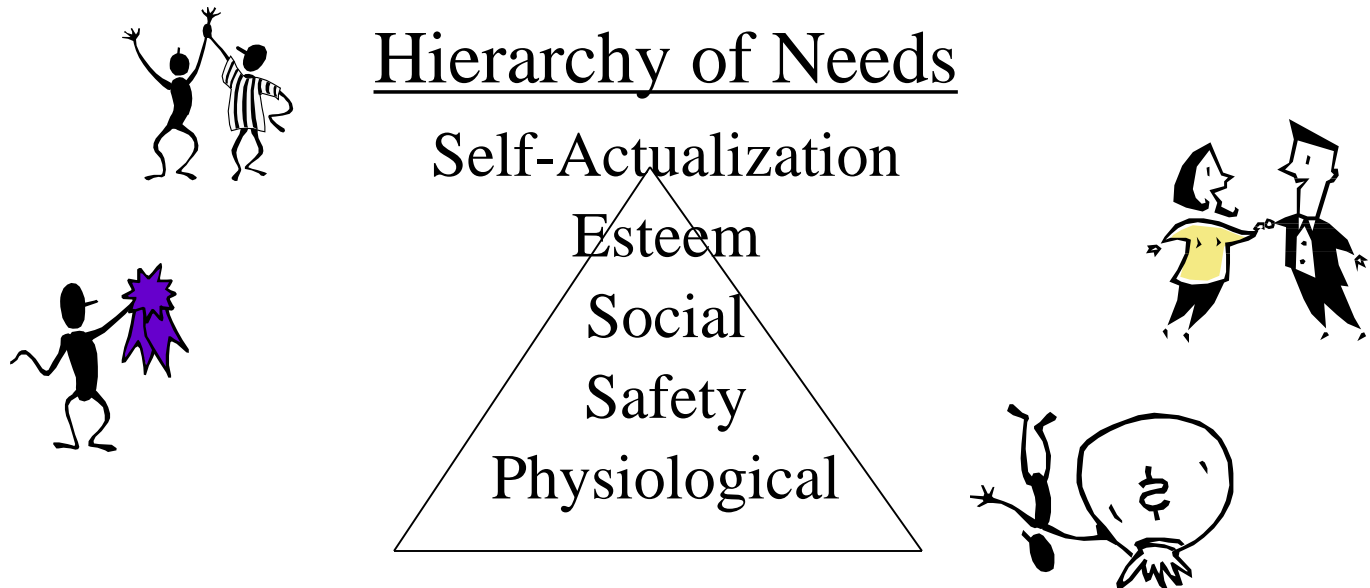
- Assertion is that managers who use good human relations in the workplace will achieve productivity.
- This movement has evolved as the field of **Organizational Behavior** - the study of individuals and groups in organizations.



# Principle Human Relation Theories

- Maslow - Theory of Human Needs

People act to satisfy "deprived" needs - needs for which a satisfaction "deficit" exists.



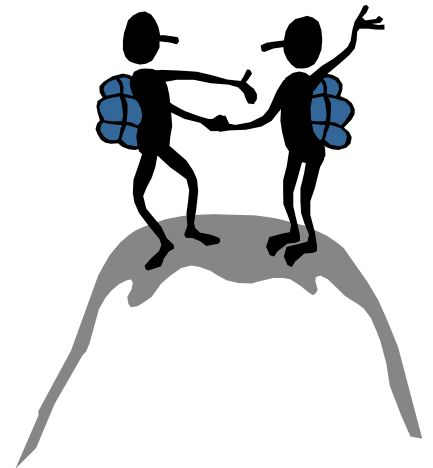
# McGregor's Theory X and Theory Y

- Theory X Managers Assume Subordinates
  - Dislike Work
  - Lack Ambition
  - Are Irresponsible
  - Resist Change
  - Prefer to be Led



# McGregor's Theory X and Theory Y

- Theory Y Managers Assume Subordinates
  - Willing to Work
  - Capable of Self-Control
  - Willing to Accept Responsibility
  - Capable of Imagination, Ingenuity, Creativity.
  - Capable of Self-Direction



# Argyris

## Theory of Personality and Organization

- Points out that some insights of the Classical Approach are inconsistent with the mature adult personality.
- Suggests that managers who treat people positively and as responsible adults will achieve productivity.
- Advises the expansion of job responsibilities, allow for more task variety, and the adjustment of supervisory styles to include more participation and better human relations.

# Quantitative Approaches

- *Assumption: Applied Mathematics Can Solve Management Problems*

## Techniques and Applications

Mathematical Forecasting

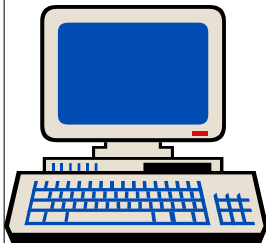
Linear Programming

Inventory Modeling

Network Models

Queuing Theory

Simulations



# Modern Approaches

- Assumption: People are Complex
  - Modern Approaches to management respect the Classical, Human Resources, and Quantitative schools.
  - But they recognize that no one approach applies universally in all situations, or the exclusion of the others.
  - This Course Is Based On The "Modern Management Approaches"

# Modern Approaches

- **Systems View**

The organization is seen as a collection of interrelated parts that function together to achieve a common purpose.

An Open System interacts with its environment and a Closed one does not.

# Contingency Thinking

- Contingency Approaches to management assert that there is no one best way to manage, and that what is best depends in any given circumstance on the nature of the situation.
- In short the best way depends upon the situation.

# Continuing Management Themes

- Quality and Performance Excellence
- Global Awareness
- Political Sensitivity
- Leadership
- Technology
- Life-long Commitment to Learning



**unit:2**  
**Plant/Facility Location**  
**and ayout**

# Learning Objectives

- Explain the concept of facility location
- Discuss factors affecting facility location decisions
- Explain the procedures and techniques for selecting facility location
- Explain the concept of facility layout
- List the types of facility layouts
- Describe service facility layouts

# 1. Concept of Facility Location

- Facility location may be defined as a place where the facility will be set up for producing goods or services. The need for location selection may arise under any of the following conditions:
  - a. When a business is newly started.
  - b. When the existing business unit has outgrown its original facilities and expansion is not possible; hence a new location has to be found.
  - c. When the volume of business or the extent of market necessitates the establishment of branches.
  - d. When the lease expires and the landlord does not renew the lease.
  - e. Other social or economic reasons.

# 2. Concept of Facility Location

- Need for Facility Location Planning

- Facility location planning is also required for providing a cost benefit to the organisation.
- The location planning should help in reducing the transportation cost for the organisation. This ultimately helps in decreasing the cost of production and generating cost advantage for the organisation.
- It is also needed to identify proximity to the sources of raw materials and transportation facilities.
- A facility should ideally be located at a place where raw materials are available.
- This is necessary for maintaining continuity in the production process.

# 3. Concept of Facility Location

## Factors Affecting Facility Location Decisions

□ While selecting a facility location, an organisation should consider various factors that may have significant impact on its performance. These factors are explained below:

- Availability of power
- Transportation
- Suitability of climate
- Government policy
- Competition between states
- Availability of labour

# 4. Concept of Facility Location

## Factors Affecting Facility Location Decisions

- Existence of complementary and competing industries
- Finance and research amenities
- Availability of water and fire-fighting facilities

# 5. Concept of Facility Location

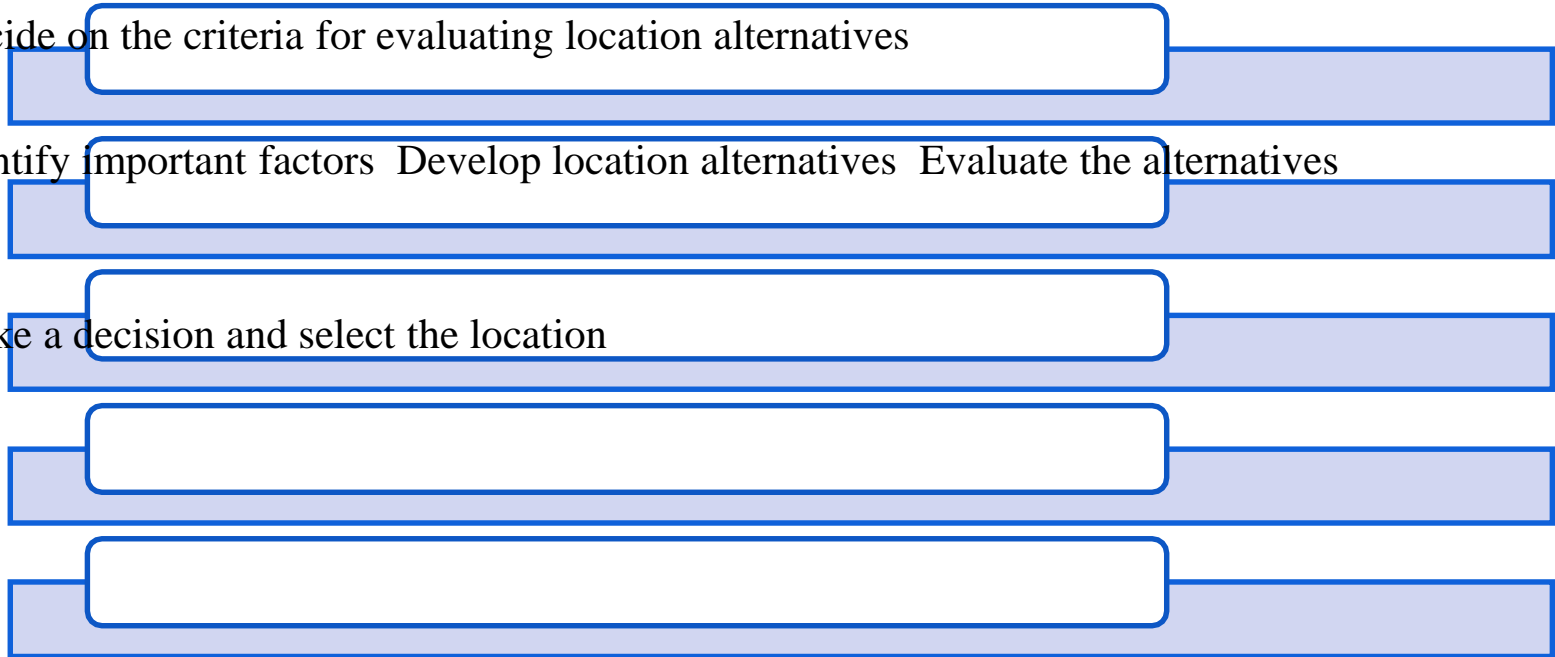
## Procedures and Techniques for Selecting Facility Location

- An organisation follows certain steps to make a correct location choice. These steps are:

Decide on the criteria for evaluating location alternatives

Identify important factors   Develop location alternatives   Evaluate the alternatives

Make a decision and select the location



# 6. Concept of Facility Location

## • Procedures and Techniques for Selecting Facility Location

- Following are some main techniques used in making location decisions:
  - **Location rating factor technique:** In this technique, first of all an organisation needs to identify the factors that influence its location decision. Next, each factor is provided a weight between '0' to '1' according to the level of importance, where '0' denotes least important and '1' denotes most important.
  - **Centre-of-gravity technique:** This technique emphasises on transportation cost in the determination of facility location. Transportation cost mainly depends on distance, weight of merchandise and the time required for transportation. Centre-of-gravity maps various supplier locations on a Cartesian plane and suggests a central facility location with respect to the locations of suppliers.

# 7. Concept of Facility Location

## Procedures and Techniques for Selecting Facility Location

➤ **Transportation technique:** In simple words, the transportation technique evaluates multiple transportation routes of shipping goods from multiple origins to multiple destinations and finds or develops the least cost route. The technique is often used in determining facility locations for evaluating transportation costs of routes by selecting different facility locations. In the transportation technique, multiple facility locations are identified and their relative transportation costs are calculated. Finally, the location that is related to the lowest cost routes is selected.

# 1. Concept of Facility Layout

- Facility layout may be defined as the arrangement of machinery, equipment, and other amenities in a facility, which should ensure a smooth movement of materials.
- According to **Moore**, *facility layout is the plan of or the act of planning an optimum arrangement of facilities, including personnel, operating equipment, storage space, material handling equipment, and all other supporting services along with the design of the best structure to contain these facilities.*

# 2. Concept of Facility Layout

## Objectives of an Effective Facility Layout

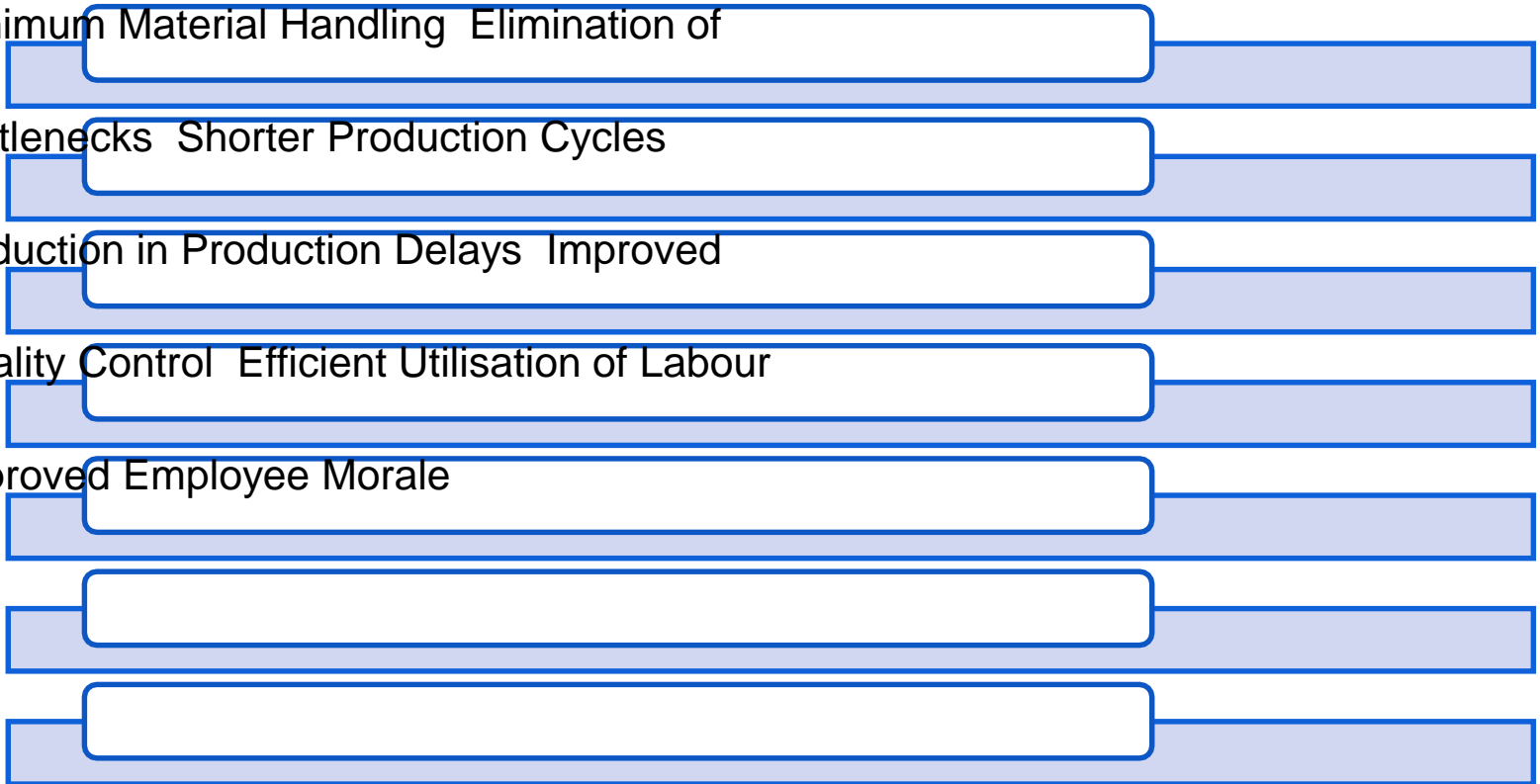
Minimum Material Handling Elimination of

Bottlenecks Shorter Production Cycles

Reduction in Production Delays Improved

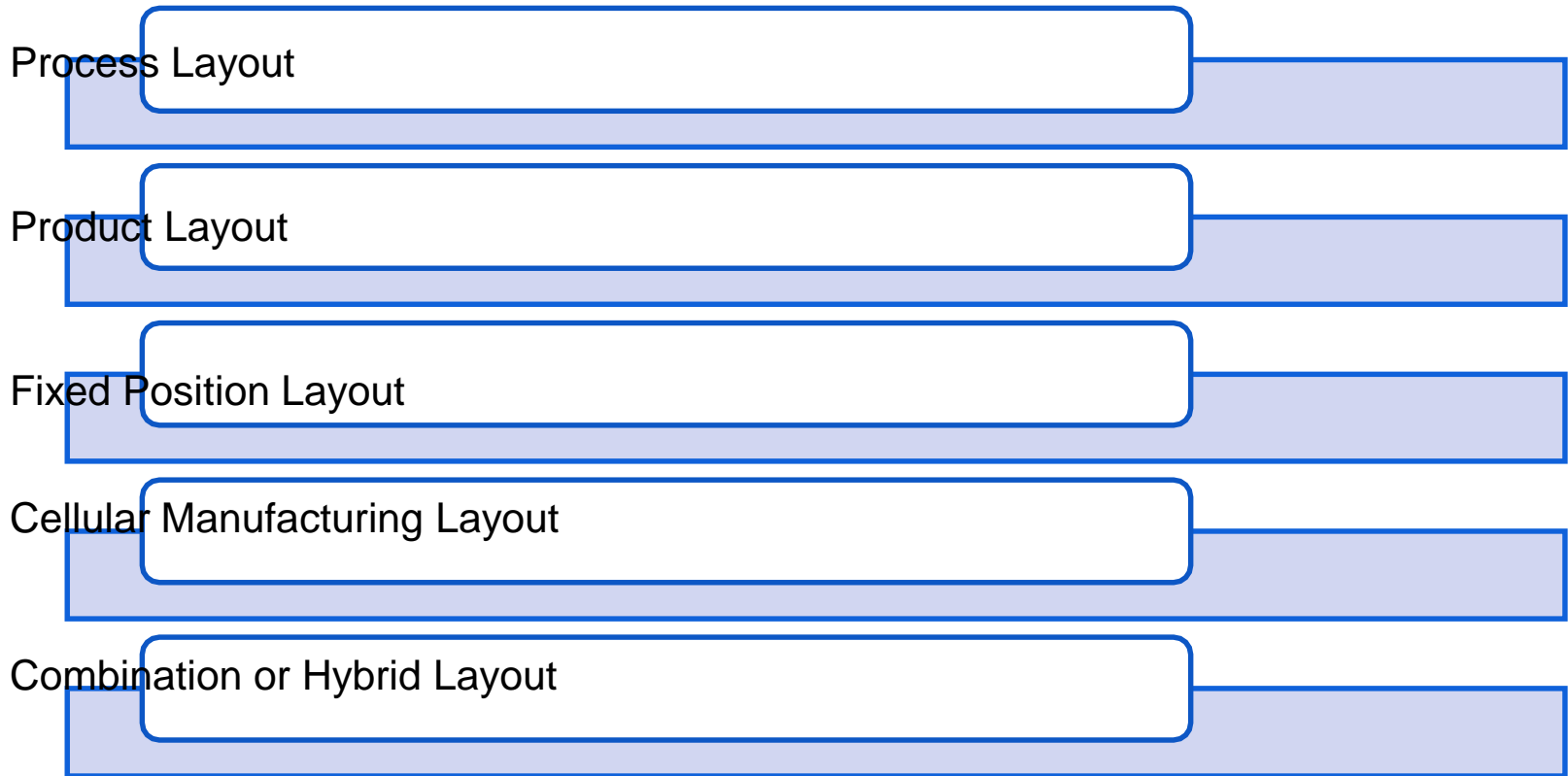
Quality Control Efficient Utilisation of Labour

Improved Employee Morale



# 3. Concept of Facility Layout

## Types of Facility Layouts



# 4. Concept of Facility Layout

## Types of Facility Layouts

□ **Process layout:** Process layout, also called functional layout or batch production layout, is characterised by the grouping together of similar machines, based upon their operational characteristics.

□ **Product layout:** In product layout, also called straight line layout, machinery is arranged in one line as per the sequence of production operations. Materials are fed into the first machine and finished products come out of the last machine.

□ **Fixed position layout:** This type of facility layout is used to assemble products that are too large, heavy or fragile to move to a location for completion. In the fixed position layout, machinery, men, as well as other pieces of material, are brought to the location where the product is to be assembled.

# 5. Concept of Facility Layout

## Types of Facility Layouts

- **Cellular manufacturing layout:** In Cellular Manufacturing (CM) layout, machines are grouped into cells, which function somewhat like a product layout in a larger shop or a process layout. Each cell in the CM layout is formed to produce a single part family, that is, a few parts with common characteristics.
- **Combination or hybrid layout:** It is difficult to use the principles of product layout, process layout, or fixed location layout in facilities that involve fabrication of parts and assembly. Fabrication tends to employ the process layout, while assembly areas often employ the product layout.

# 6. Concept of Facility Layout

- Factors Affecting a Facility Layout

- Material Handling
- Production Volume
- Type of Production
- Location
- Cost
- Safety

# 7. Concept of Facility Layout

## Prerequisites for Developing a Facility Layout

- **Developing process charts:** A process chart is the graphical representation of production activities performed by an organisation. Process charts facilitate a systematic analysis and demonstration of the entire production process. These charts are further classified into two categories, namely operation process chart and flow process chart.
- **Making process flow diagrams:** A process flow diagram represents the movement of materials on a floor layout. These diagrams help an organisation in avoiding needless material movement and rearranging facility operations.

# 8. Concept of Facility Layout

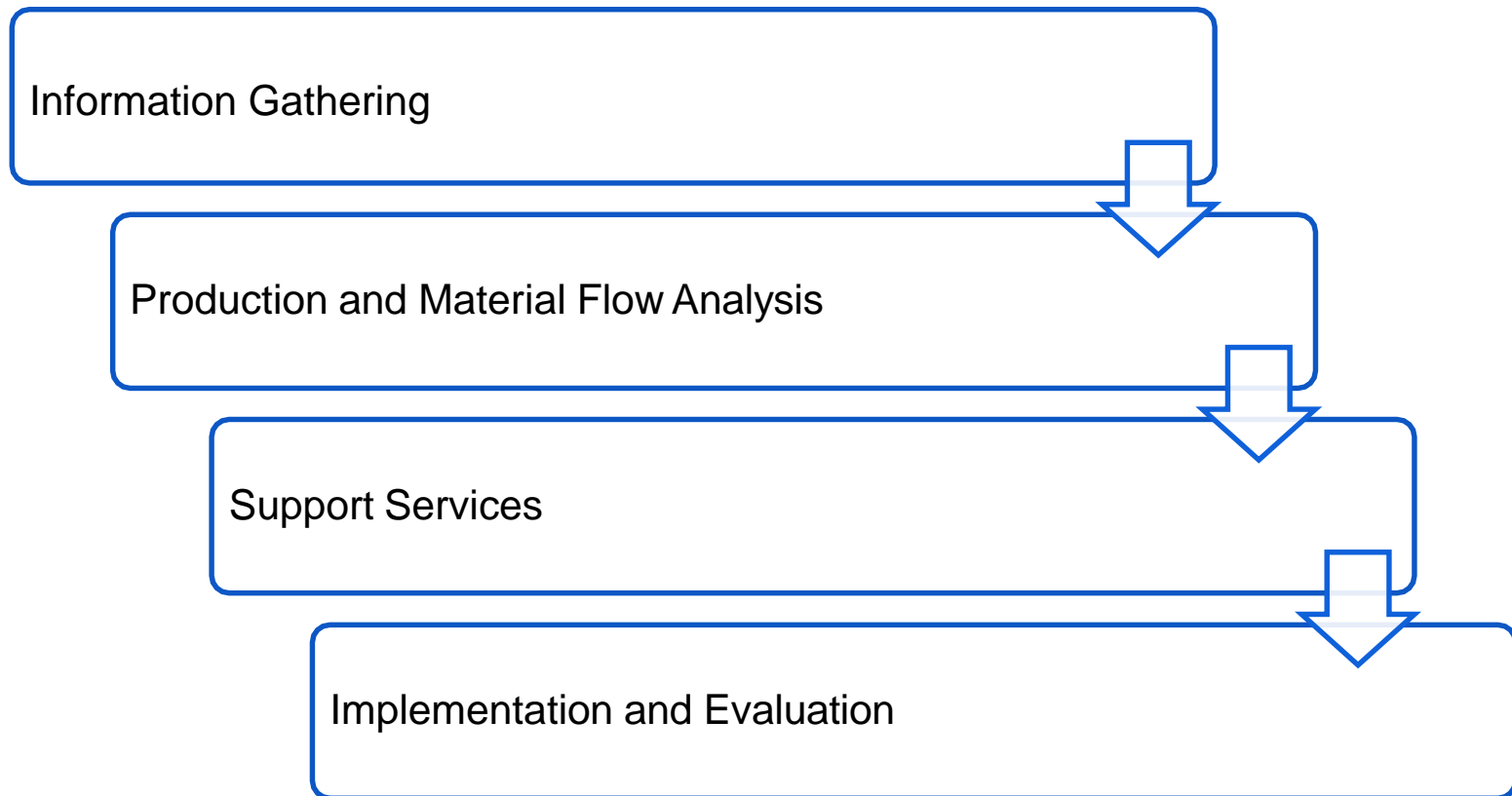
## Prerequisites for Developing a Facility Layout

□ **Developing machine data cards:** A machine data card helps in developing equipment layout (pieces of equipment layout in relation to everything including the persons using them) by providing information related to power and materials handling requirements and capacity and dimensions of different machines.

□ **Visualising the layout:** It represents the most common technique that is deployed for layout planning. It involves creating duplication of machines and equipment and arranging them in two- or three-dimensional plans for determining the effectiveness of a layout.

# 9. Concept of Facility Layout

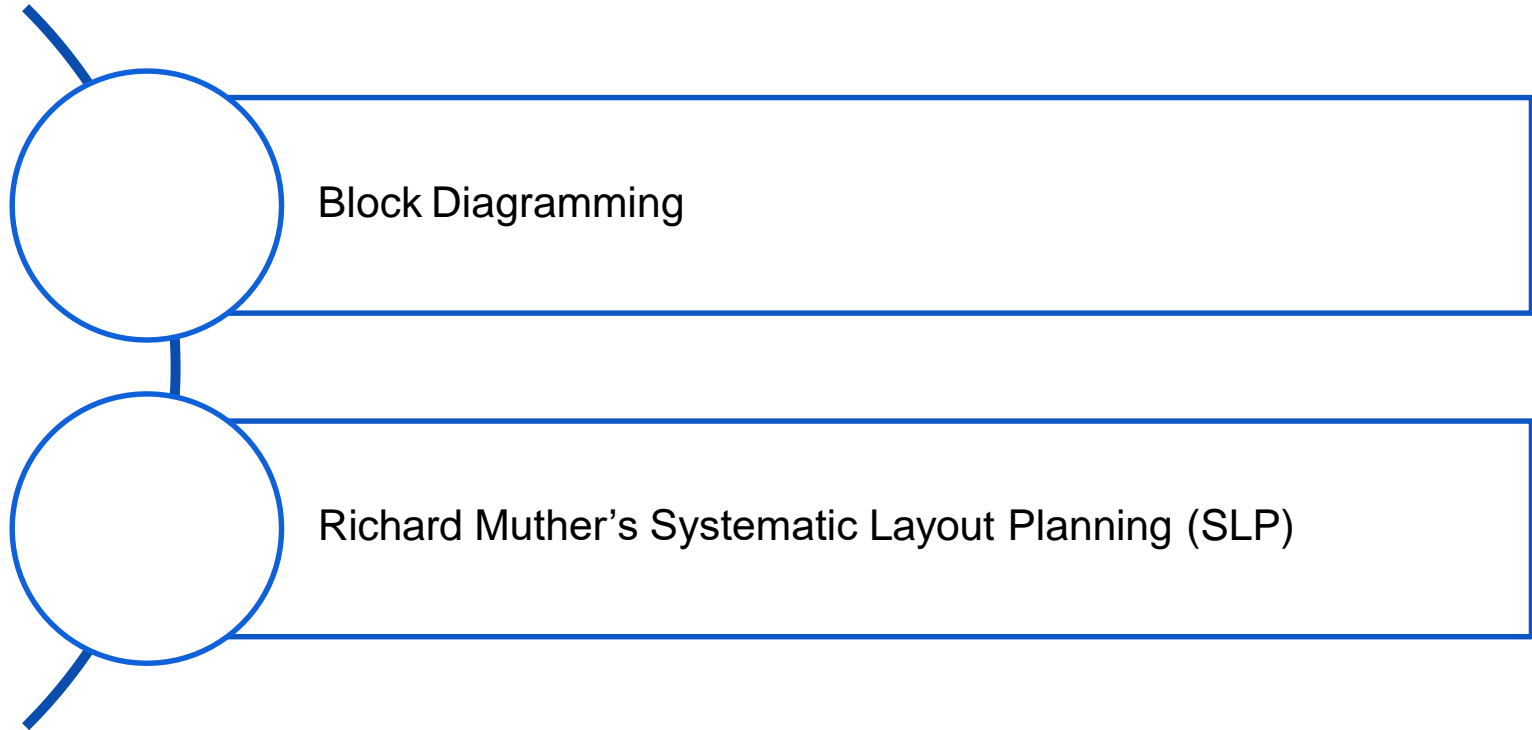
## Process of Facility Layout Designing



# 10. Concept of Facility Layout

## Techniques for Designing a Facility Layout

- The main techniques of designing a facility layout are:



# 11. Concept of Facility Layout

## Techniques for Designing a Facility Layout

□ **Block diagramming:** The block diagram can be prepared by following the steps given below:

1. Analyse the unit load summary that provides information about the average number of unit loads moved between different departments of an organisation.
2. Calculate the composite movements (back-and-forth movement) of the unit load between the departments and rank them from the highest movement to the lowest movement.
3. Place the trial layouts, which are designed using the ranking between departments, on a grid. This grid represents the relative distance between the departments.

# 12. Concept of Facility Layout

## Techniques for Designing a Facility Layout

□ **Richard Muther's systematic layout planning (SLP):** In this technique, a grid displays the ratings of the relative importance of the distance between different departments of an organisation. This grid is also called 'closeness rating chart'. In this chart, the rating for department A relative to department B is similar to the rating of department B to department A. Closeness ratings are given to departments in the form of codes, which depict the desired closeness of the departments according to the relative strength of their closeness.

# 13. Concept of Facility Layout

New Approaches to Layout Design

Computerised Relative Allocation of Facilities Technique (CRAFT)

Automated Layout Design Program (ALDEP)

Computerised Relationship Layout Planning (CORELAP)

# 14. Concept of Facility Layout

Revision of a Current Layout

- The following developments necessitate the revision of the existing layout:

Expansion

Technological Advancement

Improvement of the Layout

# 1. Service Facility Layouts

- The objectives of service facility layouts differ from those of manufacturing facility layouts.
- This is because a manufacturing facility aims to make on-time delivery of products to customers, whereas customers come to a service facility to receive services.
- Therefore, customers usually prefer a service facility that is close to them, especially when the service delivery process requires considerable customer contact. For example, if you are hungry, you would prefer to go to a restaurant near you.

# 2. Service Facility Layouts

- Service facility layouts are often categorised under three heads, which are:
  - **Product layout:** This type of layout is used only in cases where services are organised in a sequence.
  - **Process layout:** These layouts are highly common in service facilities as they successfully deal with the varied customer processing requirements.
  - **Fixed position layout:** In this type of service layout, materials, labour and equipment are brought to the customer's place. This layout is used in services like appliance repair, landscaping, home remodelling, etc.

# 3. Service Facility Layouts

## Types of Service Facility Layouts

□ **Warehouse and storage layouts:** The layouts of warehouse and storage facilities are designed by considering the frequency of order. Items that are ordered frequently are placed near the facility entrance. However, items that are not ordered frequently are placed at the rear of the facility. Apart from this, correlation between two merchandises is also important while designing a layout for a warehouse and storage facility.

# 4. Service Facility Layouts

## Types of Service Facility Layouts

□ **Retail layouts:** A retail store layout refers to a systematic arrangement of merchandise groups within a store. A well-planned retail store layout provides a description of the size and location of each department of the store, fixture locations, and traffic patterns. It also helps consumers find products of their choice in a short time. Different retail layouts are:

- Grid layout
- Free-form layout
- Loop layout
- Spine layout

# 5. Service Facility Layouts

## Types of Service Facility Layouts

□ **Office layouts:** Designing of office layouts is witnessing revolutionary changes as paperwork is now replaced with different modes of electronic communications. Today, office layouts focus more on creating an image of openness. Low-rise partitions are preferred between departments to facilitate easy communication among workers.

# Unit-3

## Time and Motion Study

# Time and Motion Study: *Defined*

- A method created to determine the ‘correct time’ it takes to complete a certain task
- A method to establish ‘the one best way to perform a task’

# Time and Motion Study: *Purposes*

- To end ‘goofing off’ and to establish what constituted a fair days work
- To make sure that the job being evaluated does not include any unnecessary motion by the worker

# Time and Motion Study: *History*

- Frederick W. Taylor and his followers developed and refined the Time Study
- Frank B. Gilbreth and his wife Lillian developed and refined the Motion Study
- Historically the two studies are discussed individually, today they generally are discussed as one

# Time and Motion Study: *In your Organization*

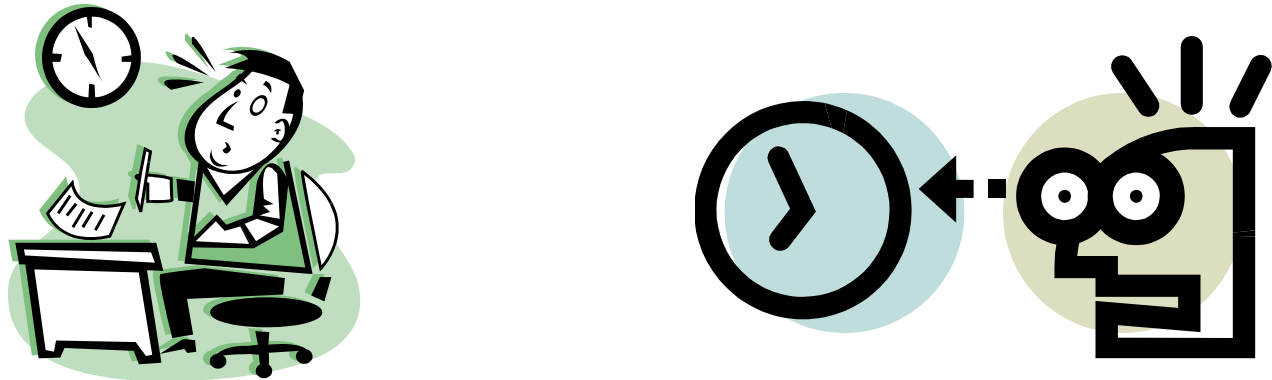
Historically: T&M Studies were used in the manufacturing industry to evolve pay scales with the thought that money was the only motivation for work



# Time and Motion Study: *In your Organization* cont'd

- Today:
  - T&M Studies can be effective for performance evaluations
  - T&M Studies can be used for planning purposes in order to predict the level of output that may be achieved
  - T&M Studies can be used to uncover problems and create solutions
  - T&M Studies can be used for time cost analysis

# Time and Motion Study: *Objective*



The objective of the Time and Motion Study is to determine a ‘normal’ or average time for a job, by using observers to record exactly how much time is being devoted to each task.

# How it Works Step-by-Step



1. Establish the standard job method.
2. Break down the job into elements
3. Study the job.
4. Rate the worker's performance

# How it Works Step-by-Step cont'd

5. Compute the average time

6. Compute the normal time

$$Nt=(t)(RF) \text{ or}$$

Normal Time=(elemental average time)  
(rating factor)

7. Compute the standard time

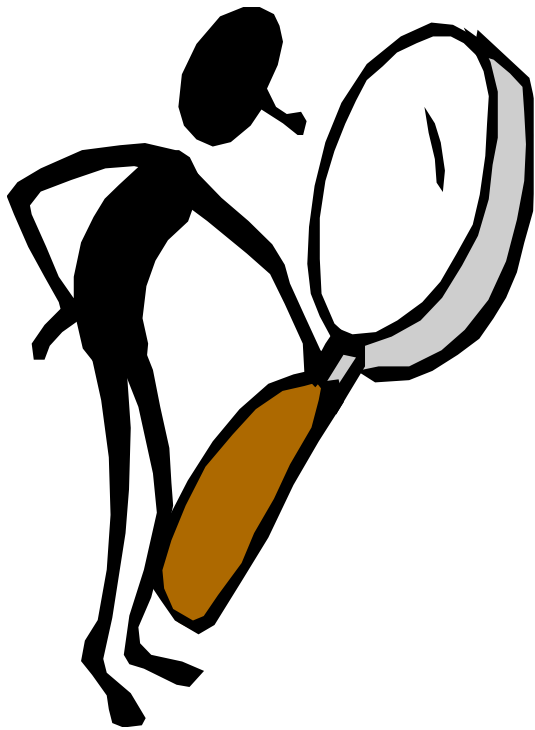
$$ST=(Nt)(1+AF) \text{ or}$$

Standard Time=(Normal cycle  
time)(1+Allowance factor)



# Time and Motion Study: *In Action*

How do medical residents  
spend their time at the  
hospital?



## *In Action* cont'd

1. Coders/observers training was the
2. Activities were broken down into separate categories, 67 in total
3. The exact number of minutes per task were determined
4. Percentages of time devoted to each task were calculated

## *In Action* cont'd

- A total of 13,383 minutes of activities were observed between the 8 residents
- Residents were involved in 1,726 coded activities
- These activities averaged 7.75 minutes each with a standard deviation of 14.5 minutes

# Time and Motion Study: *Exercise*

Elem ent	t (min)	RF
1	2.51	1.10
2	5.29	1.15
3	4.21	1.10
4	3.57	1.05

- Compute the standard time for this job using an allowance factor of 20 percent.

# Solution

Use the formula

$$(t)(RF)=Nt$$

Element 1

$$(.251)(1.10)=.2761$$

Element 2

$$(.529)(1.15)=.6084$$

And so on for  
element 3 and 4

Element	T(min)	RF	t	Nt
1	2.51	1.10	.251	.2761
2	5.29	1.15	.529	.6084
3	4.21	1.10	.421	.4631
4	3.57	1.05	.357	.3749

To get the normal cycle time  
you sum the Nt values. Here =  
1.73 min

# Solution

To compute the standard time use the 20 percent allowance factor

$$Nt(1+AF)=ST$$

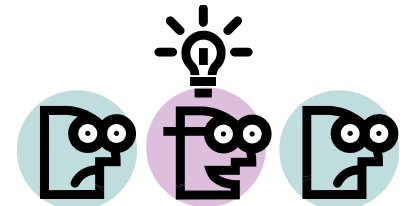
Here

$$1.73(1+.20)=2.08$$

So the standard time for each element of this job is 2.08 minutes

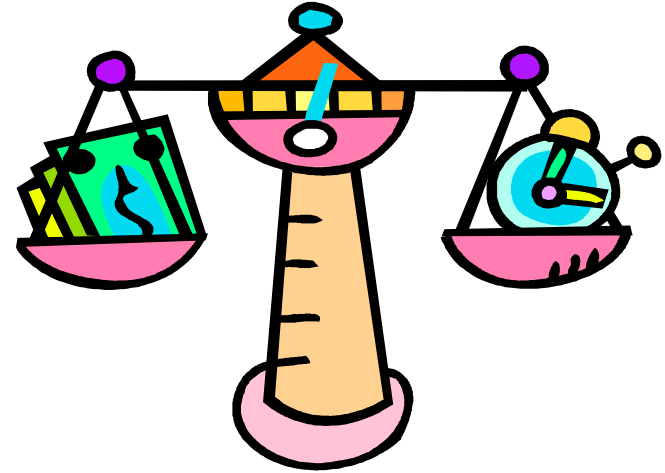
# Time and Motion Study: *Problems*

1. Observers are not always competent
2. Those conducting the study are not always proficient in the job being observed
3. The actions observed are not always reflective of the group as a whole



# Time and Motion Study: *Problems*

cont'd



Workers may not cooperate with a time and motion study:

1. They may resent the study if it is being used to determine the pay scale
2. Workers may change the rate at which they work
3. Pressure may increase mistakes made
4. Workers may alter normal work methods to disrupt the study

# Unit: 4

## Inventory Control

**Inventory:** A stock of materials kept for future sale or use

# Why Keep Inventory?

## Example 1. Ajay's Orange Juice consumption

	OPTION 1	OPTION 2
	1.8L carton / 1 each week	300ml carton/ 1 each day
Costs:	Refrigeration Capital tied up (interest cost)	Low volume surcharge Travel to shop each day
Risks:	May go bad	May want 2 on some days

# Why Keep Inventory?

## Example 2. Hospital blood bank

Setup time involved in procuring blood

- find a donor
- check for infection
- test for blood type

Patient cannot wait !

# Why Keep Inventory?

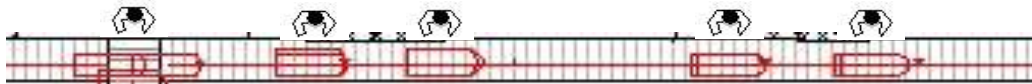
## Example 3. Computer manufacture

computer assembly line

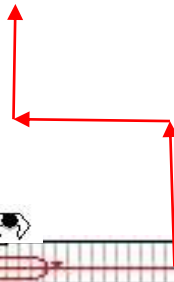


100  
computers/hr

speaker assembly line



800  
speakers/hr



Alternatives:

- (a) fewer workers on speaker line  
=> lose mass production efficiency
- (b) run speaker line for short periods  
=> inventory

# Why Keep Inventory?

## Example 4. Retail

4.1. Empty shop → less attractive to customers

4.2. Out of stock → loss of sale, loss of goodwill

Problem: cost of holding inventory

capital is held up (interest)

space is occupied (rental)

insurance

product obsolescence/decay

# Why Keep Inventory?

## Example 5. Manufacturing

CASE 1: 1 worker, variable processing time



8 hour shift:

~ 80 parts (average)

CASE 2: Assembly line, var. processing time



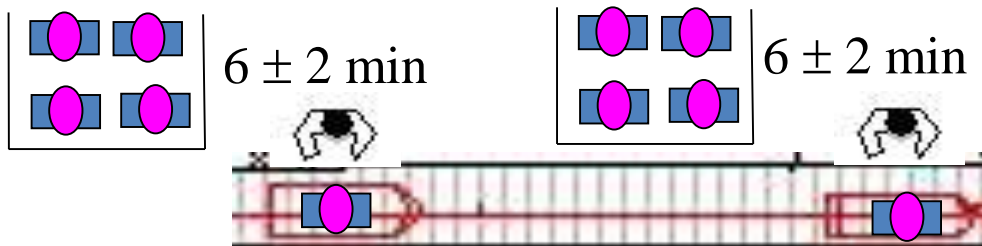
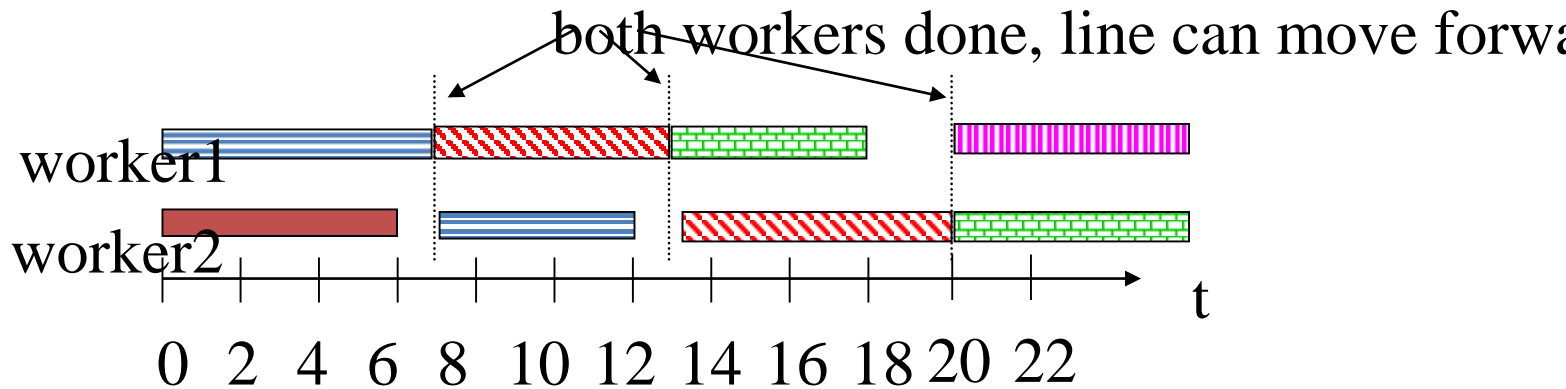
8 hour shift:

< 80 parts !

# Why Keep Inventory?

Example 5. Manufacturing, continued..

$$(T_{\text{worker 1}}, T_{\text{worker 2}}) = (7, 5) (6, 7) (5, 6)$$



8 hour shift:

~ 80 parts !

# Components of Inventory Control Models

## 1. Ordering costs

how much does it cost to order a batch of materials

## 2. Holding costs

how much does it cost to store materials

## 3. Shortage penalty (out-of-stock penalty)

what is the estimated loss on an out-of-stock event

## 4. Revenue

what is the cash made by selling an item

## 5. Salvage cost

value of item at the end of its shelf life

## 6. Discount rate

to account for the time value of capital

# Deterministic Inventory Control

## *Continuous review models*

constant, known demand rate  
how much should we order, and when ?

## *Periodic review models*

known demand, but not uniform  
how much should we order at what times ?

# Continuous review model

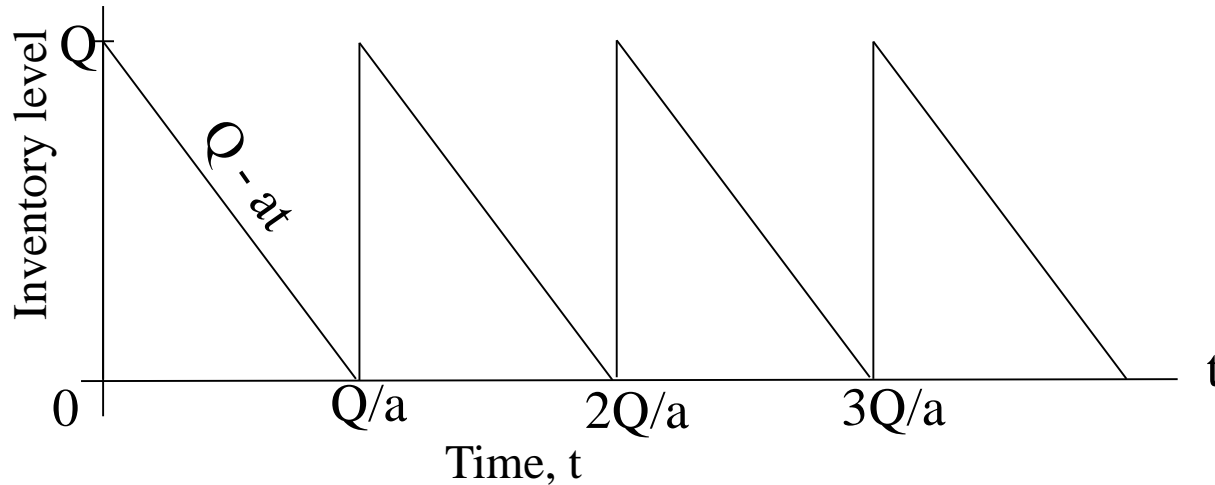
## 1. Uniform demand, no shortages

Demand (consumption) rate:	$a$	units / month
Order (lot) size:	$Q$	units / order
Setup (ordering) cost:	$K$	\$ / order
Production (purchase) cost:	$c$	\$ / item
Holding cost:	$h$	\$ / item / month

**Problem:** What is the best  $Q$  ?

Note:  $Q$  is known  $\rightarrow$  ordering interval =  $Q/a$  (why?)

# Uniform demand: Economic order quantity (EOQ)



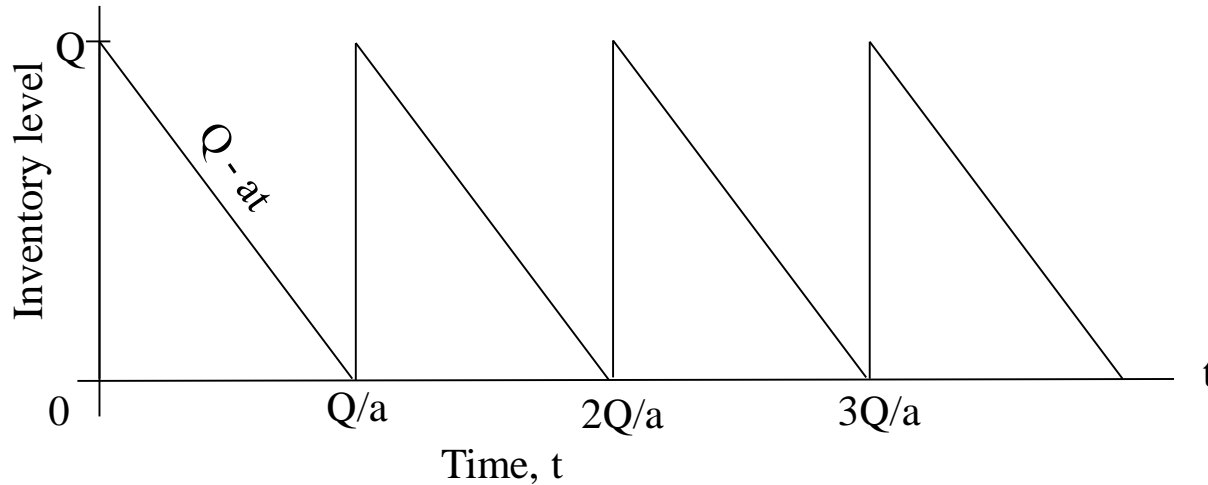
$$\text{Production cost / cycle} = K + cQ \quad (\text{if } Q > 0)$$

$$\begin{aligned} \text{Holding cost / cycle} \\ = \text{average inventory} * \text{unit holding cost} * \text{length of period} &= \frac{Q}{2} * h * \frac{Q}{a} = \frac{hQ^2}{2a} \end{aligned}$$

$$\text{Total cost per cycle} = K + cQ + \frac{hQ^2}{2a}$$

$$\text{Total cost per unit time} = \frac{K + cQ + \frac{hQ^2}{2a}}{Q/a} = \frac{aK}{Q} + ac + \frac{hQ}{2}$$

# Uniform demand: Economic order quantity (EOQ)



$$\text{Total cost per unit time} = T = \frac{aK}{Q} + ac + \frac{hQ}{2}$$

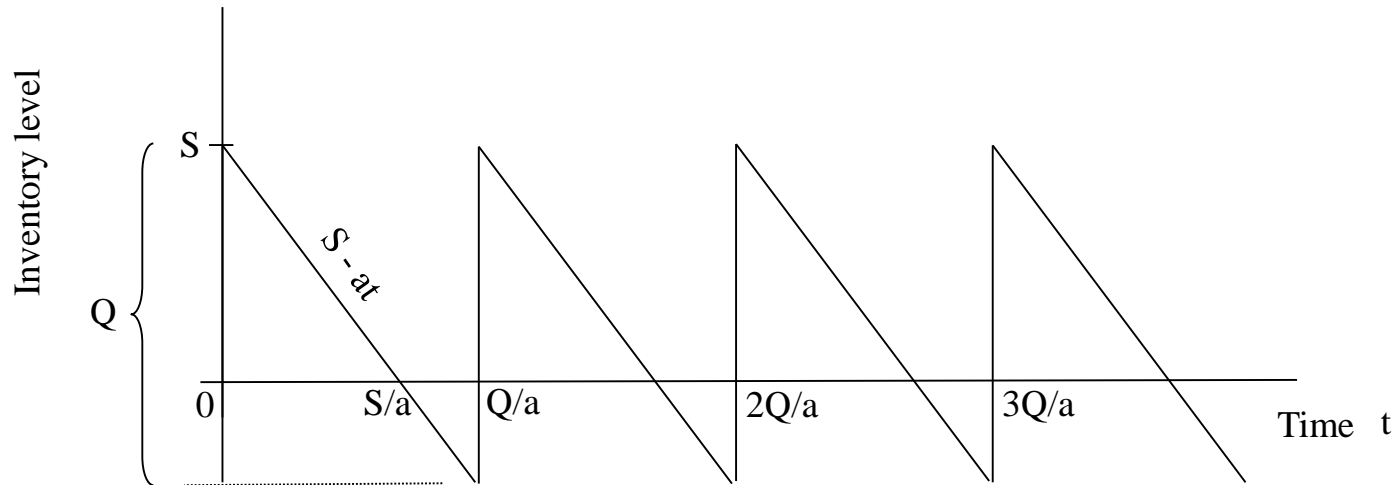
$$\text{Minimum total cost: } dT/dQ = 0 = -\frac{aK}{Q^2} + \frac{h}{2}$$

$$\text{Optimum order quantity: } Q^* = \sqrt{\frac{2aK}{h}}$$

**When to order ?** Periodically at  $t = (nQ/a - \text{lead time})$ ,  $n = 0, 1, \dots$

# Continuous review models..

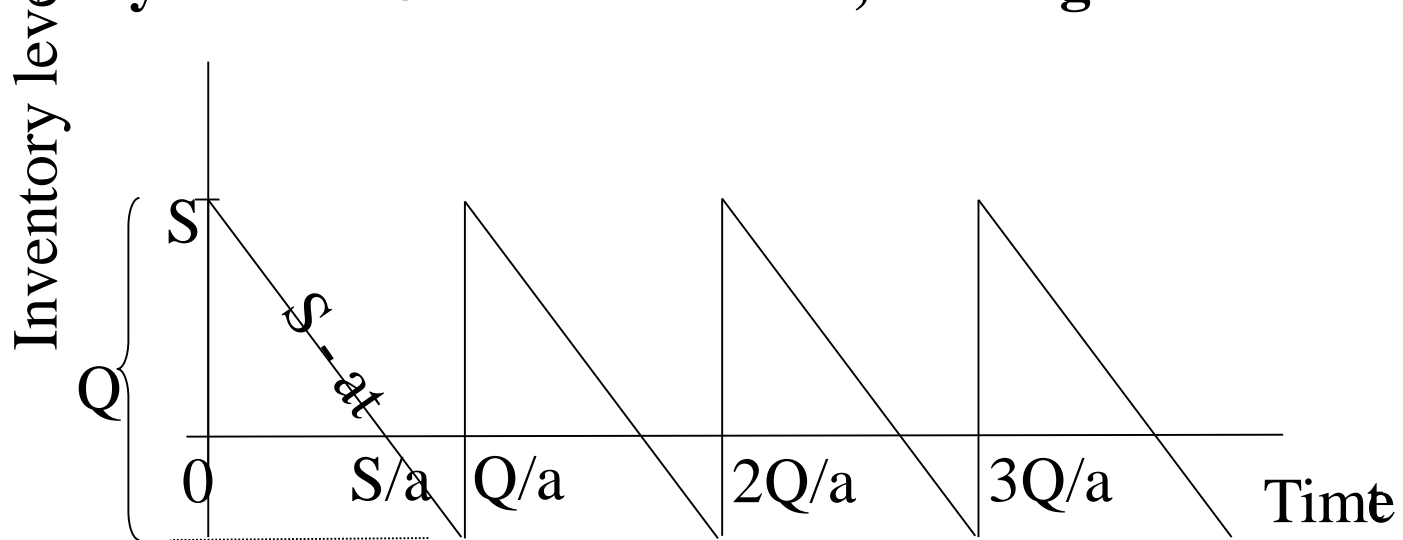
## 2. Uniform demand, shortages are allowed



**Why allow shortage ?** Average inventory held is lower

**Shortage cost:**  $p$  \$ / unit of unfulfilled demand / period

# Inventory model: Uniform demand, shortage allowed



Total cost = ordering cost + purchase cost + holding cost + shortage cost

$$\begin{array}{ccccccc}
 & \swarrow & & \swarrow & & \swarrow & \downarrow \\
 K & & cQ & & \frac{hS}{2} \frac{S}{a} = \frac{hS^2}{2a} & & \frac{p(Q-S)}{2} \frac{(Q-S)}{a} = \frac{p(Q-S)^2}{2a} \\
 & & & & & & \\
 \underbrace{\hspace{15em}} & & & & & & \\
 & & & & & & 
 \end{array}$$

\$ / period

# Inventory model: Uniform demand, shortage allowed

$$\text{Total cost/unit time} = \frac{(\text{ordering} + \text{purchase} + \text{holding} + \text{shortage}) \text{ cost per period}}{\text{length of period}}$$

$$T = \frac{K + cQ + \frac{hS^2}{2a} + \frac{p(Q-S)^2}{2a}}{Q/a}$$

$T$  is a function of  $S, Q$

$$T(S, Q) = \frac{aK}{Q} + ac + \frac{hS^2}{2Q} + \frac{p(Q-S)^2}{2Q}$$

We want to minimize  $T(S, Q)$ :  $\frac{\partial T}{\partial S} = 0$ , and  $\frac{\partial T}{\partial Q} = 0$

# Inventory model: Uniform demand, shortage allowed

$$T(S, Q) = \frac{aK}{Q} + ac + \frac{hS^2}{2Q} + \frac{p(Q-S)^2}{2Q}$$

$$\frac{\partial T}{\partial S} = \frac{hS}{Q} - \frac{p(Q-S)}{Q} = 0$$

$$(Q-S) = hS/p$$

$$Q = S(h+p)/p$$

$$\frac{\partial T}{\partial Q} = -\frac{aK}{Q^2} - \frac{hS^2}{2Q^2} + \frac{p(Q-S)}{Q} - \frac{p(Q-S)^2}{2Q^2} = 0$$

$$2aK + hS^2 + p(Q-S)^2 = 2p(Q-S)Q$$

# Inventory model: Uniform demand, shortage allowed

$$2aK + hS^2 + p(Q-S)^2 = 2p(Q-S)Q$$

$$(Q-S) = hS/p \quad \rightarrow \quad Q = S(h+p)/p$$

---

$$\rightarrow 2aK + hS^2 + \frac{h^2 S^2}{p} = \frac{2h(h+p)S^2}{p}$$

$$\rightarrow 2apK + phS^2 + h^2 S^2 = 2h(h+p)S^2$$

---

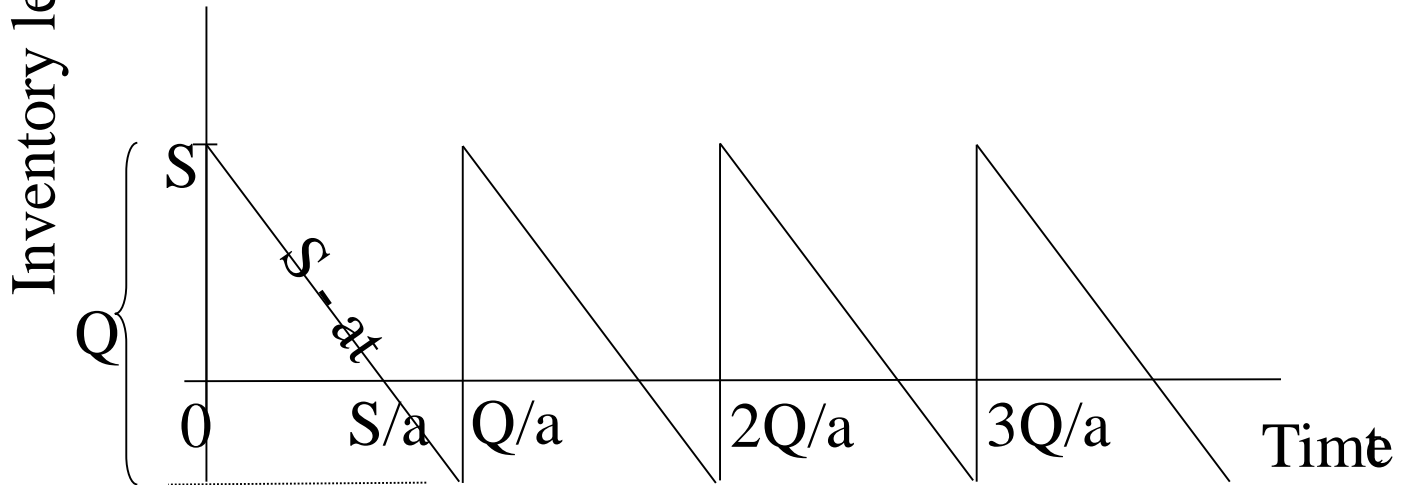
*Solving:*

$$S^* = \sqrt{\frac{2aK}{h}} \sqrt{\frac{p}{p+h}}$$

*and*

$$Q^* = \sqrt{\frac{2aK}{h}} \sqrt{\frac{p+h}{p}}$$

# Inventory model: Uniform demand, shortage allowed



Total cost is minimized if:  $S^* = \sqrt{\frac{2aK}{h}} \sqrt{\frac{p}{p+h}}$        $Q^* = \sqrt{\frac{2aK}{h}} \sqrt{\frac{p+h}{p}}$

Optimum period length:  $\frac{Q^*}{a} = \sqrt{\frac{2K}{ah}} \sqrt{\frac{p+h}{p}}$

Maximum shortage:  $Q^* - S^* = \frac{h}{p} S^* = \sqrt{\frac{2aK}{p}} \sqrt{\frac{h}{p+h}}$

## Continuous review models..

### 3. Uniform demand, no shortages, **bulk-order discount**

Typical form of discount:

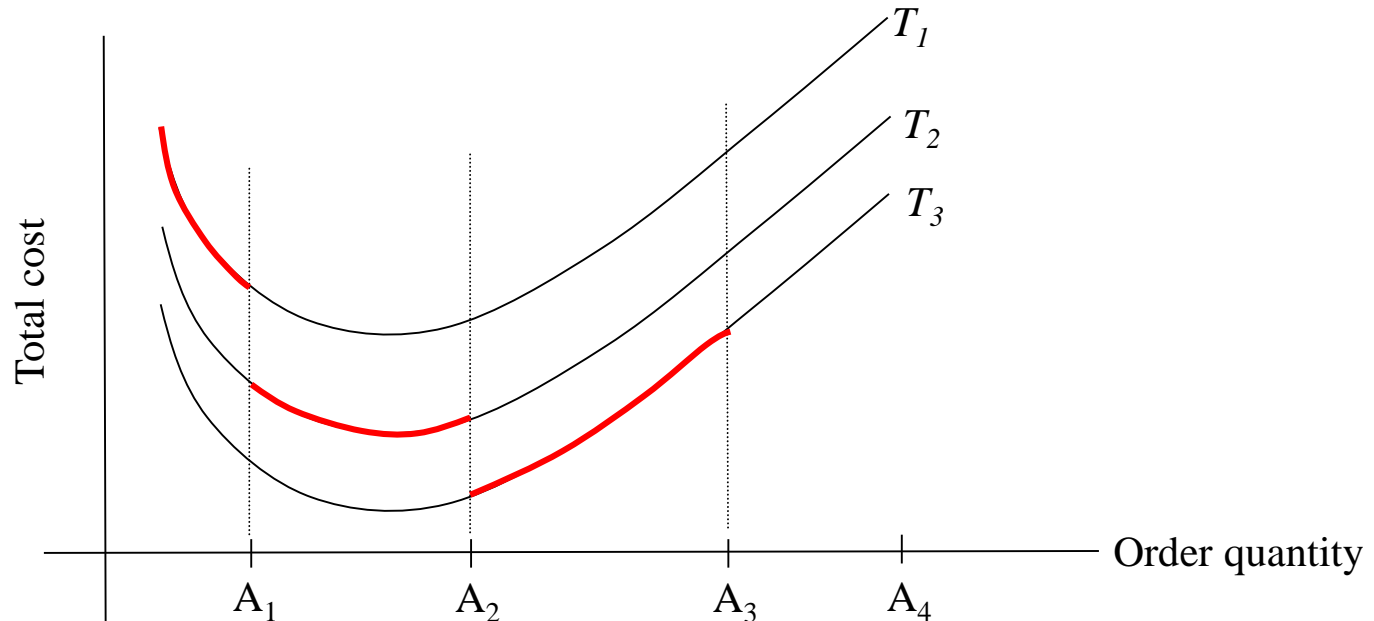
<u>Order quantity</u>	<u>cost per item</u>
$Q < 1000$	10
$1000 \leq Q < 2000$	9
$2000 \leq Q < 4000$	8
...	

# Uniform demand, no shortages, **bulk-order discount**

Order quantity                      cost per item

$Q < A_1$	$c_1$
$A_1 \leq Q < A_2$	$c_2$
$A_2 \leq Q < A_3$	$c_3$
...	

$$\text{Total cost function: } T_i = \frac{aK}{Q} + ac_i + \frac{hQ}{2}$$



# Summary: EOQ models

1. Works well if demand is steady, uniform, known
2. Yields optimal ordering “policy”

**policy** : *when to order, how much to order*

## Problems:

- (a) What if demand is not steady (known, but not constant)?
- (b) What if demand is variable, and stochastic?

# Periodic Review Models

Assumption for EOQ models: uniform demand rate

When demand rate varies with time, EOQ model is invalid

## *Periodic Review:*

Demand for each of the following  $n$  periods:  $r_1, \dots, r_n$

No out-of-stock

Setup (ordering cost):  $K$                       \$ per order

Production cost:  $c$                               \$ per item

Holding cost:  $h$                                 \$ per item per **period**

## *Decision:*

How much to order at beginning of each period

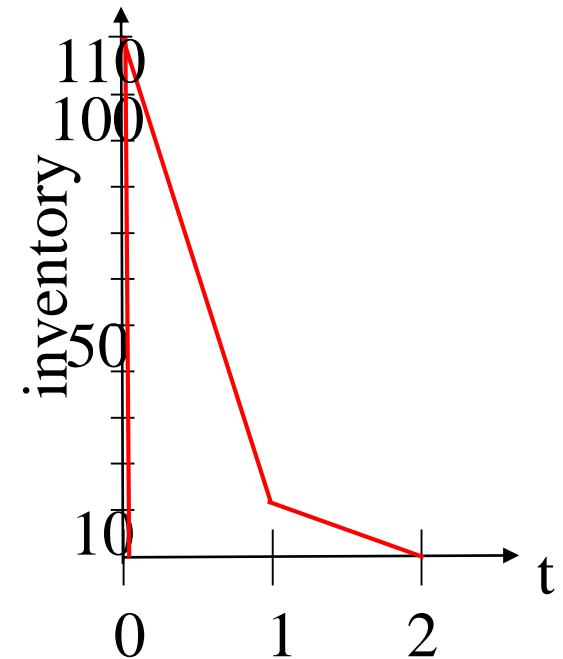
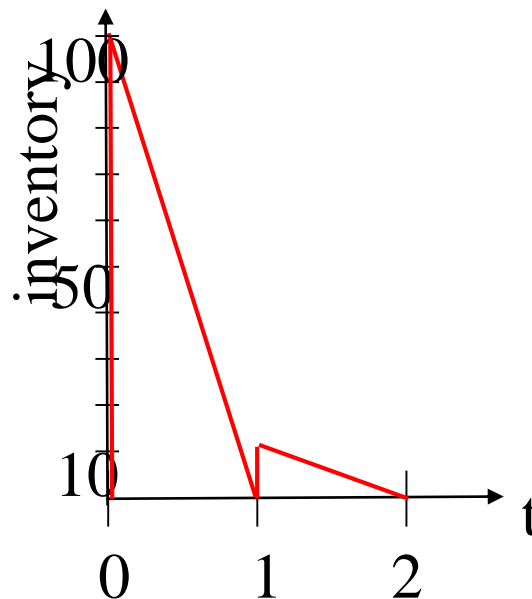
# Periodic Review Models: non-uniform demand

Why can't we use the EOQ model ?

← May be better to not buy at start of some periods

Let:  $r_1 = 100$   
 $r_2 = 10$   
 $c = 1$   
 $h = 1$   
 $K = 50$

Two possibilities

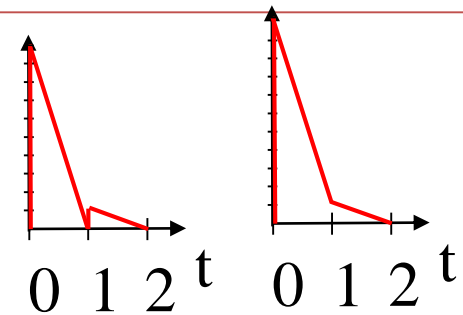


# Periodic Review Models: non-uniform demand

Why can't we use the EOQ model ?

← May be better to not buy at start of some periods

Let:  $r_1 = 100$   
 $r_2 = 10$   
 $c = 1$   
 $h = 1$   
 $K = 50$



production      holding      ordering

$$T(100 \text{ at } t=0, 10 \text{ at } t=1): (100 + 50 + 50) + (10 + 5 + 50) = 265$$

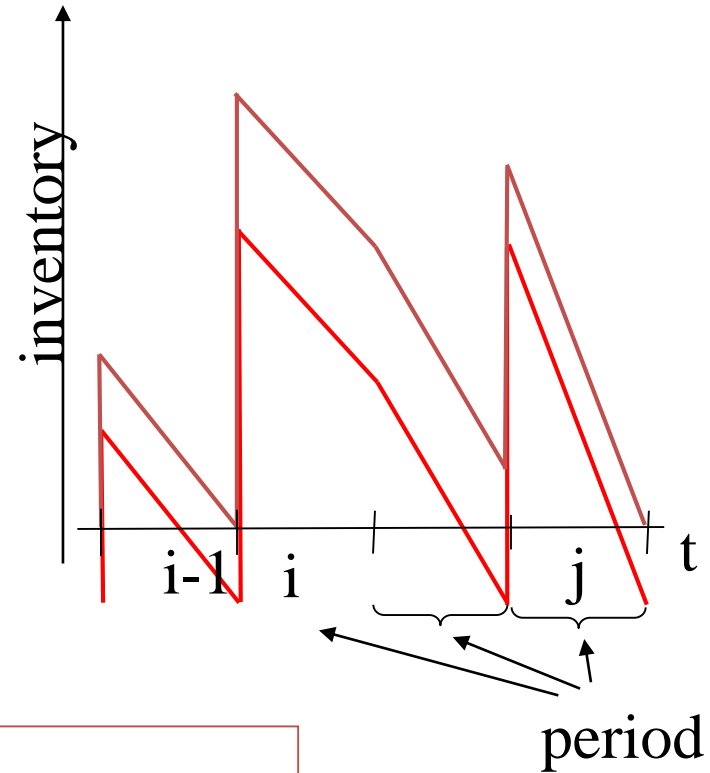
$$T(110 \text{ at } t=0): (110 + (50+10+5) + 50) = 225$$

# Periodic review: a model

## Property 1. IF

ordering cost (setup cost) is fixed,  
production cost per item is constant,  
holding cost per item per period is constant,

Optimal policy: **make a new order only when  
current inventory = 0.**



## Why?

Consider successive production points:  $i_{start}$   $j_{start}$

Order costs:  $K + K$

inventory( $t_{j,start}$ ) =  $x_j > 0$ , then these

$x_j$  units were held in inventory from period  $i$ , ...  $j-1$ .

Reducing production at  $t_{i,start}$  by any amount  $\leq x_j$  will:

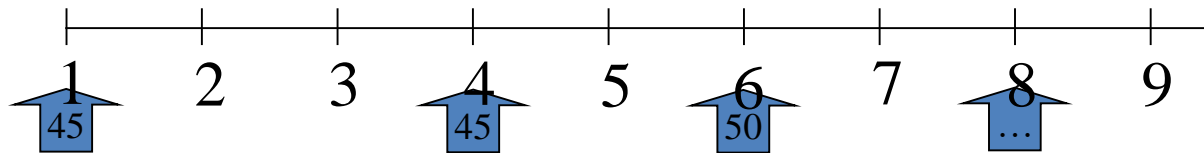
- (i) reduce holding costs
- (ii) not change production cost
- (iii) not change setup costs

# Periodic Review Models: non-uniform demand

→ If we know each *order point*, then optimum policy can be computed.

-- order just enough to meet demand up to next order point

period	1	2	3	4	5	6	7	8	9
demand, $r_i$	20	20	5	15	30	10	40	30	5



**A solution:** at the beginning of each period, decide: [produce / do not produce]

Number of possibilities to explore:  $2^{n-1}$

# Periodic review: a model

## Implications of Property 1:

1. Quantity produced (ordered) at start of period  $i \in \{ 0, r_i, r_i + r_{i+1}, \dots, r_i + \dots + r_n \}$

2. Suppose that the optimal amount produced at the start =  $Q_i^*$  covers  $k$  periods

THEN we only need to solve for the optimum solution for a smaller problem

Starting from period  $k+1$ , with demands =  $r_{k+1}, r_{k+2}, \dots, r_n$

## Periodic review: a model..

$x_i$  : inventory level at the start of period  $i$

$z_i$  = amount produced (ordered) at start of period  $i$

$C_i$  = Cost of optimum policy for periods  $i, n$  when  $x_i = 0$

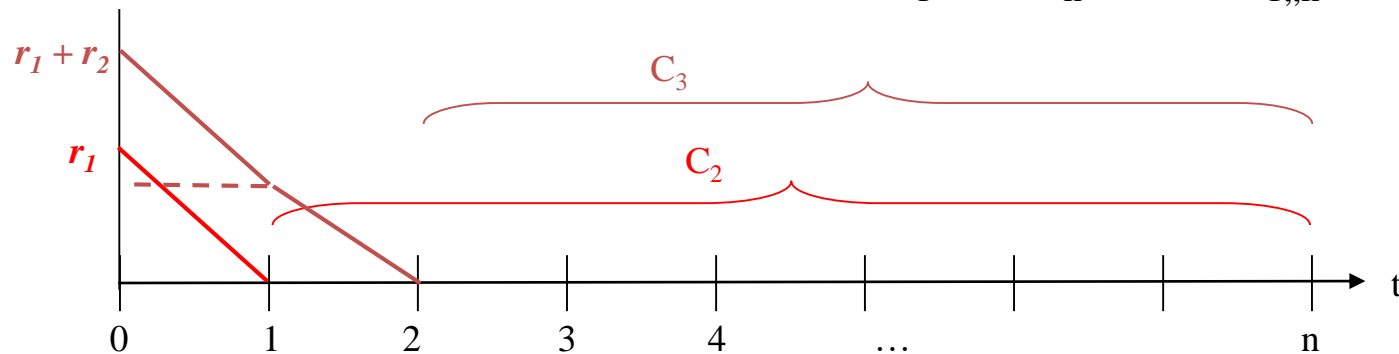
$$C_1 = \text{Min} \left\{ \begin{array}{l} \text{cost of making } r_1 \text{ at } t=0 + C_2 \\ \text{cost of making } (r_1+r_2) \text{ at } t=0 + C_3 \\ \dots \\ \text{cost of making } (r_1+r_2+ r_k) \text{ at } t=0 + C_{k+1} \\ \dots \\ \text{cost of making } (r_1+r_2+\dots+r_n) \text{ at } t=0 + C_n \end{array} \right.$$

# Periodic review: a model...

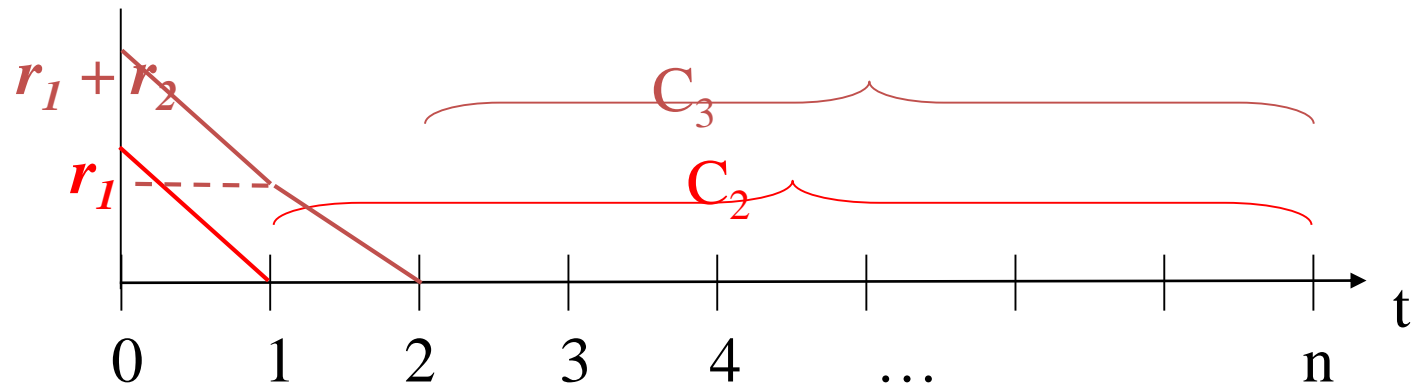
$C_i = \text{Cost of optimum policy for periods } i, n \text{ when } x_i = 0$

$$C_1 = \text{Min} \left\{ \begin{array}{l} \text{cost of making } r_1 \text{ at } t=0 + C_2 \longrightarrow K + c r_1 + h r_1 / 2 + C_2 \\ \text{cost of making } (r_1+r_2) \text{ at } t=0 + C_3 \longrightarrow K + c(r_1+r_2) + h(r_1 + 3r_2) / 2 + C_3 \\ \dots \\ \text{cost of making } (r_1+r_2+r_k) \text{ at } t=0 + C_{k+1} \\ \dots \\ \text{cost of making } (r_1+r_2+\dots+r_n) \text{ at } t=0 + C_n \end{array} \right.$$

$$K + c(r_1+\dots+r_k) + h/2 S_{1,,k} (2i - 1)r_i + C_{k+1}$$



# Periodic review: a model....



To find  $C_1$ , we need to know  $C_2, C_3, \dots, C_n$

To find  $C_2$ , we need to know  $C_3, \dots, C_n$

Strategy: Find  $C_n$ ; use it to find  $C_{n-1}, \dots$  until we find  $C_1$

$C_n$ : only option is to produce  $r_n$  at the start of period  $n$ :

$$\text{cost} = C_n = K + c r_n + h/2 r_n$$

$$C_{n-1} = \min \begin{cases} \text{produce } r_{n-1} + C_n & K + c r_{n-1} + h/2 r_{n-1} + C_n \\ \text{produce } r_{n-1} + r_n & K + c (r_{n-1} + r_n) + h/2 (r_{n-1} + 3r_n) \end{cases}$$

...

## Periodic review: a model.....

---

$C_n$ : only option is to produce  $r_n$  at the start of period  $n$ :

$$\text{cost} = C_n = K + c r_n + h/2 r_n$$

---

$$C_{n-1} = \min \begin{cases} \text{produce } r_{n-1} + C_n & K + c r_{n-1} + h/2 r_{n-1} + C_n \\ \text{produce } r_{n-1} + r_n & K + c (r_{n-1} + r_n) + h/2 (r_{n-1} + 3r_n) \end{cases}$$

---

$$C_{n-2} = \min \begin{cases} \text{produce } r_{n-2} + C_{n-1} \\ \text{produce } r_{n-2} + r_{n-1} + C_n \\ \text{produce } r_{n-2} + r_{n-1} + r_n \end{cases}$$

---

... and so on, until  $C_1$  is determined

# Concluding remarks

1. The optimum production (ordering) policy is easy to compute using a simple computer program

(easy, but tedious to do by hand calculations)

2. Assumptions

Demand (forecast) is known for each period

Periods are of fixed, known durations

3. What if the demand is **not deterministic (stochastic)** ?

→ such models are complex.

→ Simplest important model: The Newspaper Vendor's Problem

# Unit-5

## Inspection and Quality control

# After reading this chapter, you should be able to:

- Explain why quality is a fundamental factor in strategic planning.
- Define and analyze quality in terms of its many dimensions.
- Explain how to set quality standards
- Use various quality control methods
- Construct quality control charts
- Distinguish between producers' and consumers' quality concepts.

# After reading this chapter, you should be able to (continued)

- Develop acceptance sampling plans and operating characteristic curves (OC curves)
- Explain how both tangible and intangible quality dimensions are measured.
- Detail the things to consider when developing a rational warranty policy.
- Discuss ISO 9000 standards in an international context.
- Apply the costs of quality to determine rational product strategies.
- Describe the control monitor feedback model.
- Explain why quality competitions and prizes are given worldwide.

# What is Quality?

There are two viewpoints of quality that coexist and cooperate.

- Producers (manufacturers or service providers) view quality as a set of standards and specifications that must be met (called conformance).
- Customers view quality as attributes that please them.
  - While the consumer's perception of "good" quality is important, the perception of poor or terrible quality is a disaster.
  - Alienating existing customers with product weaknesses and failures has a host of other side effects, which are undesirable.

# How Much Quality?

- Producers strive to balance the market forces for high quality with consumers' cost preferences and the company's production capabilities.
- Figure (a) illustrates a common economic concept (sales – cost = profit). There is clearly an optimal quality level.
- Figure (b) shows how total profit varies as quality improves.
- One should strive to achieve the quality level at which the profit is maximized.

Figure (a)

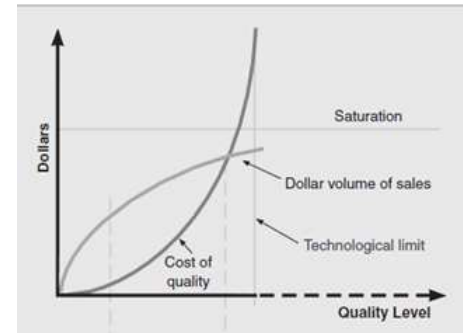


Figure (b)



# Dimensions of Quality

- The dimensions of quality are the descriptors that must be examined to determine the quality of a product.
- Define the relevant set of quality dimensions, recognizing the special needs of market niches and segments.
- The quality of wine is characterized by bouquet, color, and taste plus chemical analyses.
- Cars are evaluated within categories of cost, by their power, safety features, capacities, fuel efficiencies, and style, among other things. Appearance and style dimensions, so often important, are difficult to rate.
- When rating the quality of cities to live in, the criteria include amount of crime, cost of living, job availability, transportation, winter mildness, and the quality of schools for families with children.

# Models of Quality

Eight categories, proposed by David Garvin\* include:

- Performance
- Features
- Reliability
- Conformance
- Durability
- Serviceability
- Aesthetics
  
- Perceived quality

These quality dimensions are discussed in the next 2 slides. The automobile is used as a manufacturing example and a resort hotel is used as a service example.

\*Garvin, David A., Competing on the Eight Dimensions of Quality, Harvard Business Review, November-December 1987, page 101.

# Models of Quality (continued)

- The *performance dimension* relates to the quality of the fundamental purpose for which the product is purchased. How well does the car do what it is supposed to do? Are the rooms quiet and the beds comfortable?
- The *features dimension* refers to product capabilities not considered to be part of normal performance expectations. These might be GPS and satellite radio for the car, or a spa and access to the internet (either wired or wireless) for the resort guests.

# Models of Quality (continued)

- The *conformance* dimension alludes to the degree to which the measured production qualities correspond to the design quality standards that have been specified. Windshield wipers are not supposed to fail (say) for the first five years and the room key is expected to work for a normal stay. Conformance is definitely the producer's responsibility (auto and resort management). P/OM is charged with meeting the conformance dimensions of quality. These quality standards are specified by the management.
- The *durability* dimension deals with how well the product endures in the face of use and stress. Some cars are roadworthy after being driven more than 100,000 miles. Some room phones fail within a few weeks. Rooms get quite shabby with constant use in a few years and customers switch to other hotels when things get shabby unless (or even if) prices drop.

# Models of Quality (continued)

- The *serviceability* dimension is related to how often service is required; and how difficult, and how costly it is to service and repair the product. Serviceability for both cars and resort rooms involves the combination of preventive and remedial maintenance.
- The *aesthetics* dimension refers to the appearance of the product. For both autos and resorts, design styling counts initially, and maintenance is crucial.
- The *perceived quality* dimension relates to the customers' perceptions of the product's quality and value received for monies paid. This dimension integrates the prior seven dimensions with the customers' sense of value for them. Market research is one of the most important means for determining the customers' perceived quality. How much will you pay for a Tesla?
- For different individuals, certain dimensions are more important than others.

# Other Important Items for Quality Evaluation

A review of some items that seem to be important for quality evaluation:

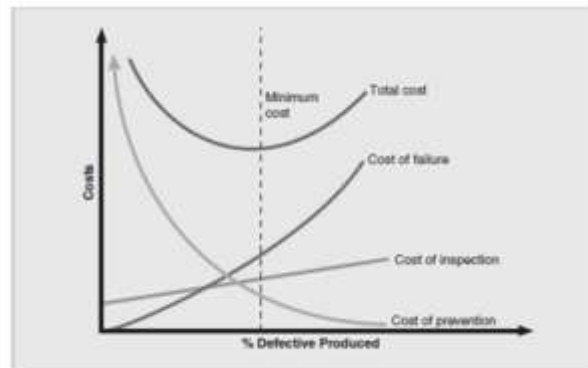
- Product and service failure,
- Warranty policies
- Repairability
- Human factors (ergonomic factors)
- Aesthetic aspects and
- Product variety

# Costs of Quality

There are three basic costs of quality that include:

- The Cost of Prevention
- The Cost of Appraisal (Inspection)
- The Cost of Failure

The following figure shows percentage Defectives Produced vs. Costs (Total, Failure, Inspection and Prevention)



# Quality Control (QC) Methodology

## Steps of Quality Control

- Detection of the problem
- Diagnosis based on the analysis of the causes of the problem
- Prescription of the corrective actions
- Observations and evaluations to see how well the treatment works

# Seven QC Methods

Seven QC methods described in this presentation include:

1. Data Check Sheets
2. Bar Charts
3. Histograms
4. Pareto Charts
5. Cause and Effect Charts
  - Scatter Diagrams
  - Fishbone Charts
6. Statistical Quality Control (SQC) Charts
7. Run Charts

# Data Check Sheets

- Data check sheets (DCSs) primary function is to organize the data.
- DCSs are ledgers to count defectives by types.
- DCSs are used for recording and keeping track of data regarding the frequency of events that are considered to be essential for some critical aspect of quality.
- 
- For almost every product or service, there are several critical dimensions for which data points are required to keep track of different qualities that are being measured (e.g., qualities of a movie, restaurant, teacher, or public utility's power reliability).

# Example: Check Sheets for Types of Power Failures

- A data check sheet, such as shown in the figure used in the next slide, could record the frequency of power failures.
- The data check sheet shows when and how often power failures occur.
- The information about when power failures have occurred can be used in various ways.
  - First, it provides a record of how frequently power failures arise.
  - Second, it shows where the failures occur.
  - Third, it can reveal how quickly power is restored.
  - Fourth, it can show how long each type of failure (A – F) has to wait before receiving attention, usually because work crews are busy on other power failures.
  - After the data check sheet is completed, problem identification follows.
  - Then causal analysis by type of failure and location can begin. Organized collection of data is essential for good process management.

# Data Check Sheet with Types of Failures A through F

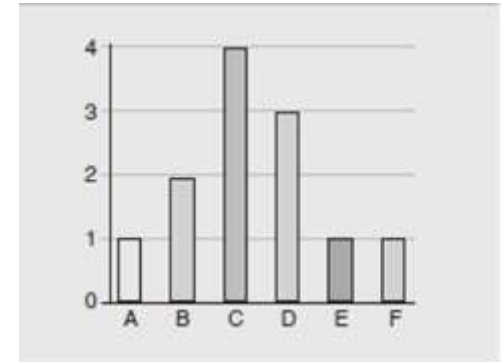
Tracking Types of Power Failures: Six types, called A through F

Note the bottom row for the number of each type.

Date	A	B	C	D	E	F	Comments	Location
12/6/12	X						Crew delay	P21
1/02/13			X				6 hr. service	P3
2/15/13				X			3 hr. service	P22
3/07/13				X			Snowstorm	P21
4/29/13			X				3 hr. service	P3
5/15/13						X	Flooding	R40
6/07/13				X			Crew delay	P5
7/29/13		X					R40/no service	P21-R40
8/21/13			X				Road delays	B2
9/30/13			X				Crew delay	R40
11/02/13					X		Partial crew	P3
12/14/13		X					Flat Tire	P5
<b>Total</b>	<b>1</b>	<b>2</b>	<b>4</b>	<b>3</b>	<b>1</b>	<b>1</b>		

# Bar Charts

- Often data is converted from check sheets to bar charts and histograms.
- Figure on the RHS shows a bar chart for the recorded number of power failures that were listed on the data check sheet.
- The six types of failures listed as A through F on the data check sheet are represented with separate bars in the figure on the next slide.
- The number of incidents is shown by the y-axis.
- Bar graphs compare the number of single-event types (e.g., types of complaints).
- A separate bar is used for each data set.
- The types should be chosen to be operationally useful, i.e., something can be done to reduce the number of incidents.



# Histograms

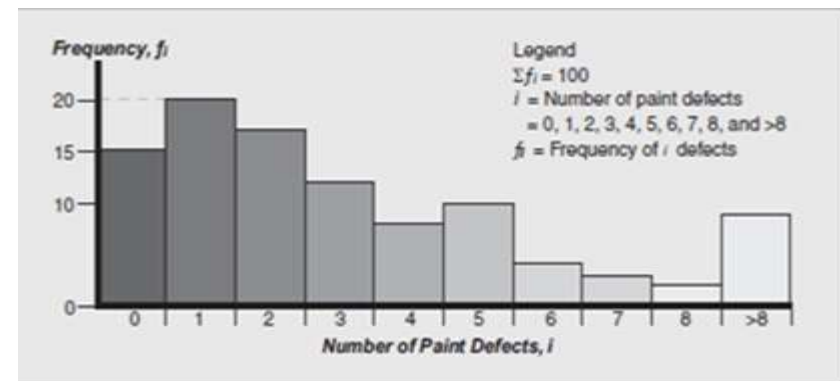
## Histograms are frequency distributions.

- For example, in the figure on RHS, the X-axis describes the number of paint defects found per hour during an inspection of autos coming off the production line.
- The Y-axis records the observed frequency for each number of paint defects.

## Some Observations:

- There are zero defects 15 out of 100 times.
- This is quite low and needs an explanation.
- One defect is found 20 percent of the time.
- More than one defect occurs 65 percent of the time.

Histogram of Paint Defects

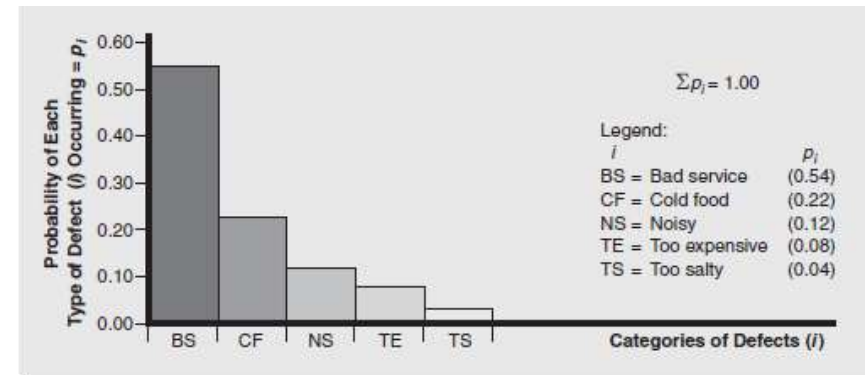


# Pareto Analysis

- Pareto analysis seeks to identify the most frequently occurring causes of product rejections.
- Often, 20 percent of the total number of problems and complaints occur 80 percent of the time. This is called the 20:80 rule. Some things occur far more frequently than others.

# Pareto Chart of Complaints in a Restaurant

- “Bad service” is the number one complaint (54%).
- “Cold food” is the second most frequent criticism (22%)..
- The third grievance is about ambiance—“Noisy” (12%).
- The fourth criticism is that the restaurant is “Too expensive” (8%).
- Excessively salty food is the fifth complaint (4%).
- The first two causes of defects account for 76 percent of the complaints which is fairly typical.



# Cause and Effect Charts

There are two types of cause and effect charts:

- Ishikawa aka the Fishbone
- Scatter diagrams

*Ishikawa (Fishbone)* charts show at a glance what factors affect quality and thereby what may be the causes of quality problems.

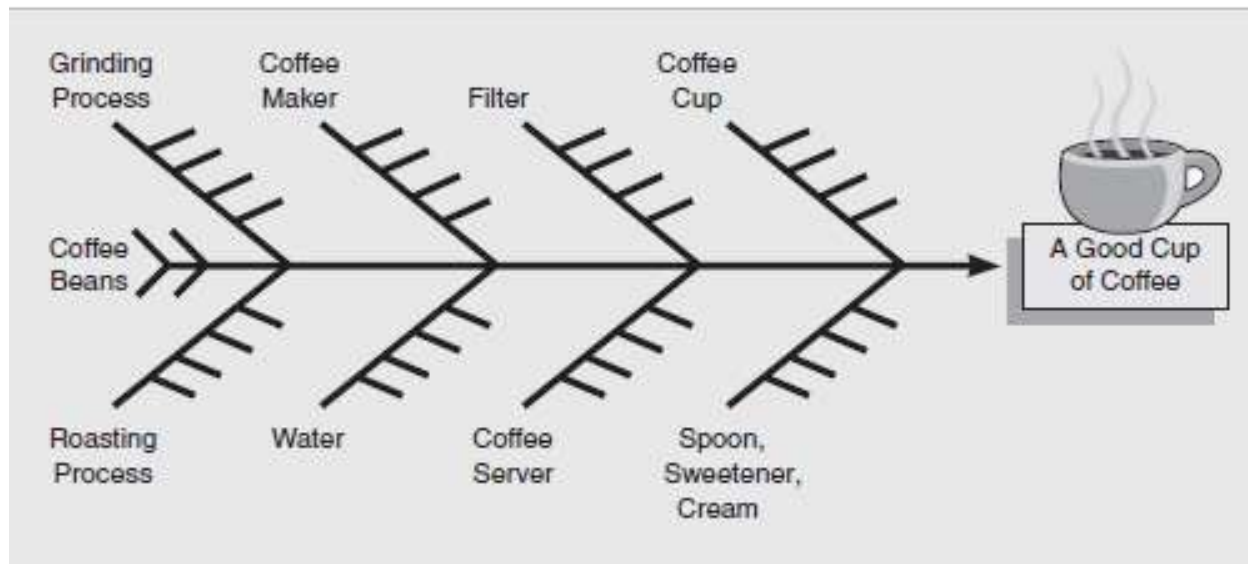
These charts are organized with the quality goal shown at the right.

*Scatter* diagrams studied in the chapter on forecasting, also help in determining causality by calculating the *coefficient of correlation*.

# Ishikawa (Fishbone) Diagram

## Making a Good Cup of Coffee

For this example, there are nine main variables, and in real situations there are different numbers of subcategory variables. The latter are shown in the figure below as fins radiating from the nine lines of the main variables, each is connected to what looks like the spine of a fish. The subcategories are listed in the table on the next slide under the nine main variables.



# Variables for the Quality of a Cup of Coffee

- ***Coffee Beans-Type Purchased***

Source of beans (locations in Sumatra, Colombia, Jamaica, Costa Rica, Hawaii, etc.)

- Grade of beans
- Size and age of beans
- How stored and packed (how long stored before grinding)

- ***Roasting Process***

- Kind of roaster
- Temperature used
- Length of roasting

- ***Grinding Process***

- Type of grinder
- Condition of grinder
- Speed and feed used
- Fineness of grind setting
- Length of grinding
- Quantity of beans ground
- Storage history before use

- ***Coffee Maker***

- Drip type or other; exact specs for coffee makers including k-cup Keurig and Verisimo
- Size and condition of machine (how many prior uses)
- Method of cleaning (vinegar, hot water, detergents)
- How often cleaned
- Number of pounds of coffee used

- ***Water***

- Amount of water used
- Type of water used (chemical composition)
- Storage history before use
- Temperature water is heated to

- ***Filter***

- Type of filter used (material: paper (and type), gold mesh, other metals)
- Size of filter
- How often used
- How often replaced

- ***Coffee Server***

- Type of container
- Size of container
- How often cleaned
- How long is coffee stored?

- ***Coffee Cup***

- Type of cup
- Size of cup
- Cleaned how (temperature of water, detergent)
- Cleaned how often

- ***Spoon in Cup-Sweetener-Milk or Cream***

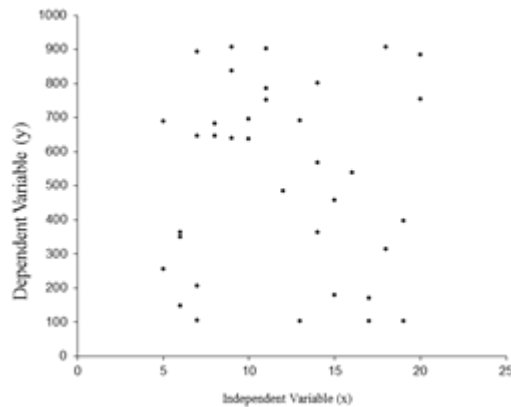
- Type of spoon (material/how often cleaned and how)
- Type of sweetener used
- Type of milk: 1 percent, 2 percent, half and half, skim, light cream, heavy cream, etc.

# Scatter Diagrams

Scatter diagrams (shown below) are useful visual aids to find whether there is a relationship between X and Y.

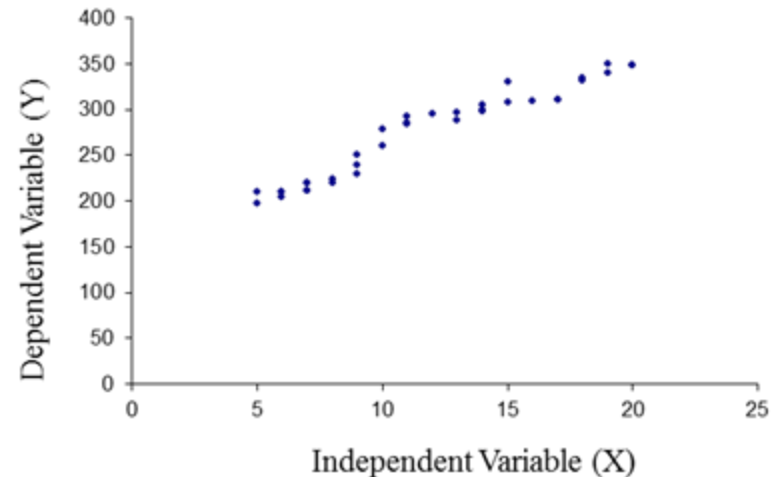
$$r = -0.04$$

Indicates an absence of any relationship..



$$r = 0.97$$

Indicates almost a perfect relationship.



# Control Charts for Statistical Process Control

- Statistical Process Control (SPC) charts are used to make sure that the product of the right quality is being produced; and service of the right quality is being provided.
- These charts detect quality problems as early warning detection systems.
- These charts monitor conditions of the process so that corrective action can be taken.
- SPC is part of the broader quality control methodology called Statistical Quality Control (SQC).
- SQC consists of SPC and Acceptance Sampling.
- The SPC charts are also called statistical quality control (SQC) charts or simply quality control (QC) charts.

These terms are used interchangeably in this presentation.

# Inspection by Variables and Attribute

Control charts are constructed by inspecting the process output.

Inspection can be done by *variables* or *attributes* as discussed below.

## *Variables*

The measurements are continuous, as with a ruler for measuring inches or with a scale for measuring pounds. The variables can have dimensions of weight, temperature, area, strength, electrical resistance, loyalty, satisfaction, defects, typing errors, complaints, accidents, readership, and TV viewer ratings.

## *Attributes*

The output units are classified as accepted or rejected, usually, by some form of inspection device that only distinguishes between a “go” or a “no go” situation.

# Process Variation – Chance Causes

The causes of process variation can be classified in two categories

- Chance causes
- Assignable causes

## *Chance Causes*

- Chance causes result from inherent (intrinsic and innate) properties of a stable system.
- These causes cannot be removed, which is why they are called inherent systems causes.
- They are also called chance causes because they are predictable and stable in statistical terms.
- A process that experiences only chance causes, no matter what its level of variability, is called a stable process.
- The variability that it experiences is called random variation.

# Process Variation – Assignable Causes

## *Assignable Causes*

- The second kind of variability has traceable and removable causes, which are called assignable or special causes.
- Unlike chance causes, these causes are not background noise.
- They produce a distinct trademark, which can be identified and traced to its origins.
- They are called assignable because these causes can be designated as to type and source, and removed.
- An alternative name that might be preferred to assignable causes is identifiable systems causes.

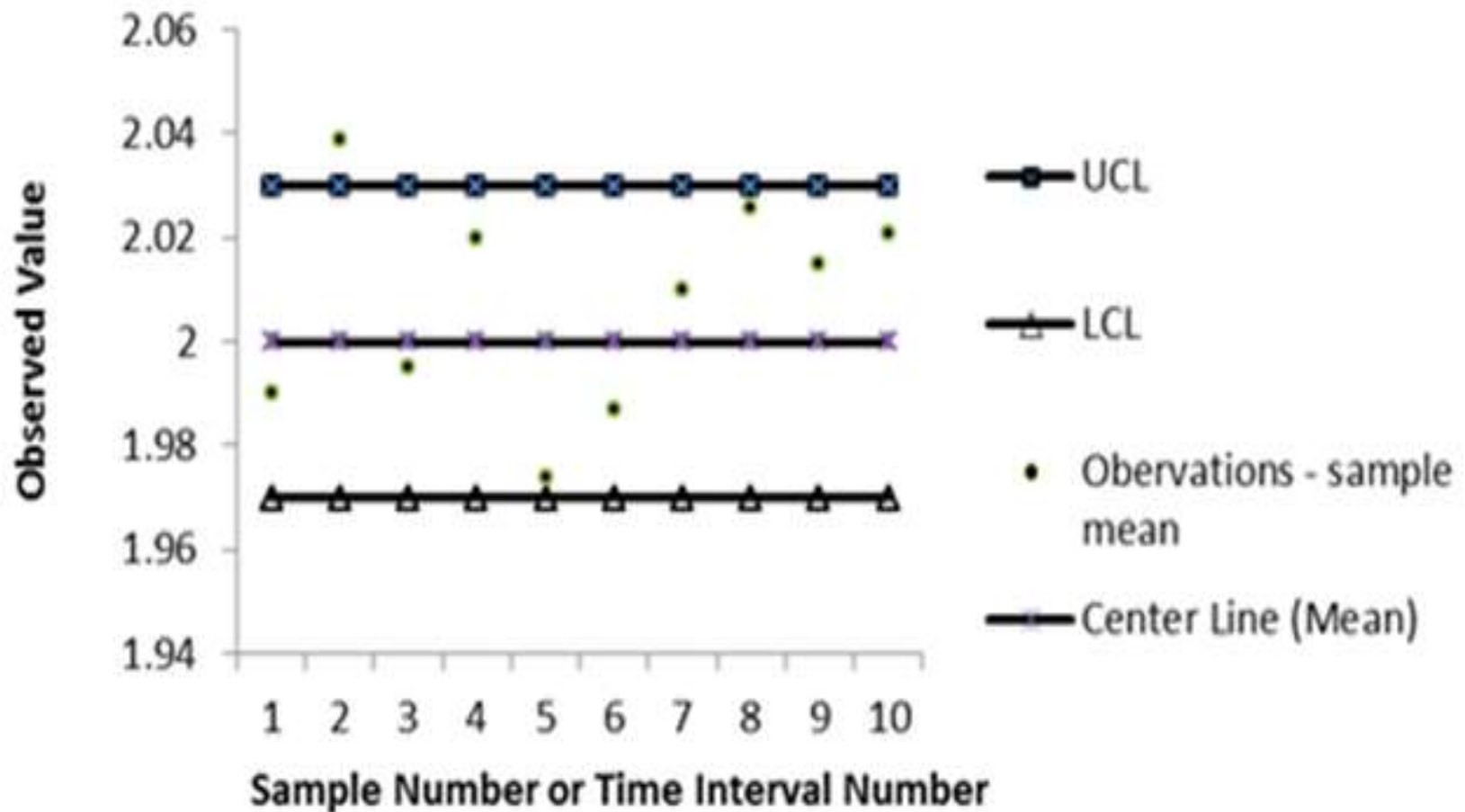
# Quality Control Charts

- Quality control (QC) charts are the means for plotting the quality of the process output measured through inspection whether by variables or attributes.
- QC charts can spot identifiable causes of system variation.
- Once identified, knowledge of the process leads to the cause, which is then removed so that the process can return to its basic, inherent causes of variability.
  
- To construct a control chart we must find the mean ( $\mu$ ) and the standard deviation ( $\sigma$ ) of the process output.
- For example, in producing steel rods, the diameter of the rods is the variable of interest and defines the quality of the output.
- To construct the control chart, we calculate the mean (average) diameter and the standard deviation of the process output.

# Quality Control Charts (continued)

- In a control chart, the Y-axis represents the observed process output measured at successive intervals (or for successive samples) and the X-axis represents the time interval (or successive sample numbers).
- The center line represents the mean of the process output and a line above the center line called the upper control limit (UCL) and a line below the center line called the lower control limit (LCL).
- The measured values of the quality variable are plotted as individual points.

# Statistical Process Control Chart



# Quality Control Charts (continued)

- In the previous control chart 10 observations are plotted.
- Point 2 lies outside the control limits – above the UCL limit.
- This is an indication that the process was out of control when that measurement was taken. It indicates a need for causal analysis.
- All other points are within the control limits and their variation is primarily due to the inherent process variability.
- It may also be noted that if the spread between UCL and LCL is made smaller some other points may go outside the control limits. Point 5 is a prime candidate to go outside the control limits because it is very close to the LCL. Point 8 is another prime candidate on the upper limit.
- The last four points are all above the center line which warrants some investigation. The process may be heading out of control.

# Analysis of Statistical Runs

- Run charts can help spot the likelihood of an impending problem.
- Thus, run analysis is another early warning detection system.
- A run of numbers on a control chart is successive values that all fall either above or below the mean line.

Consider the control chart discussed earlier.

- The first six points are well distributed around the center line. However, the last four points are all above the mean line.
- The process is currently within control limits but does not look normal and may go out of control if this trend continues.
- A monotonic run (continuously increasing or decreasing) signals even greater urgency to consider the likelihood that an assignable cause has changed the process's behavior.

# Control Chart Example

- Suppose a manufacturing process can produce steel rods with an average diameter of 2.00 inches ( $\mu = 2.00$ ). The standard deviation ( $\sigma$ ) representing process variation is 0.01.
- It is assumed that the process output follows a normal distribution.
- Based on the well-known properties of the normal distribution we can say that 99.72% of the output will lie between  $\pm 3$  standard deviations; and 95.44% of the output will lie between  $\pm 2$  standard deviations.
- The percentages 99.72% and 95.44% are known as confidence intervals.
- The values 3 and 2 are standard normal variables and are represented by the symbol  $z$ .

# Control Chart Example (continued)

The values of  $z$  for various confidence intervals are available in statistical tables. The UCL and LCL are established as follows.

- $UCL = \mu + z \sigma$  and  $LCL = \mu - z \sigma$ .
- For 99.72% confidence interval ( $z = 3$ ), the limits are:
- $UCL = 2.00 + 3 * 0.01 = 2.03$
- $LCL = 2.00 - 3 * 0.01 = 1.97$
- For 95.44% confidence interval ( $z = 2$ ), the limits will be:
- $UCL = 2.00 + 2 * 0.01 = 2.02$
- $LCL = 2.00 - 2 * 0.01 = 1.98$

# Control Chart Example (continued)

- We will discuss four control chart examples – two charts for variables and two charts for attributes in the following sections. Control charts are used to stabilize a process and are then used to monitor for process (stability) once it has been stabilized.

# Stable Process

- For quality to be consistent, it must come from a process that is stable, i.e., one with fixed parameters.
- This means that the process average and its standard deviation are not shifting.
- In the case of measurement by attributes a stable system will give a consistent proportion of defective items.
- A process that is operating without any assignable causes of variation is stable by definition, although its variability can be large. Stability does not refer to the degree of variability of a process.
- Instability reflects the invasion of assignable causes of variation, which create quality problems (e.g., something wears or breaks).
- Process capability studies are used to establish the limits within which a process can operate.

# Selecting a Manufacturing Process

After the design of a product is complete, an appropriate manufacturing process is to be selected.

*Example*

- Suppose the desired diameter in manufacturing steel rods is 2”.
- The product design specifies the tolerances on the diameter as  $\pm .05$ ”.
- This means that the required output should be between 2”  $\pm .05$ ”.
- In other words any rod whose diameter is between 1.95” and 2.05” meets the required quality level.
- 1.95” is called the lower specification limit (LSL) and 2.05” is called the upper specification limit (USL).
- Two processes A and B are available to produce the required steel rods.
- The average diameters ( $\mu$ ) of the rods produced by both processes are 2”.
- The standard deviation ( $\sigma$ ) are .01 and .025 respectively for processes A and B.

# Selecting a Manufacturing Process

(continued)

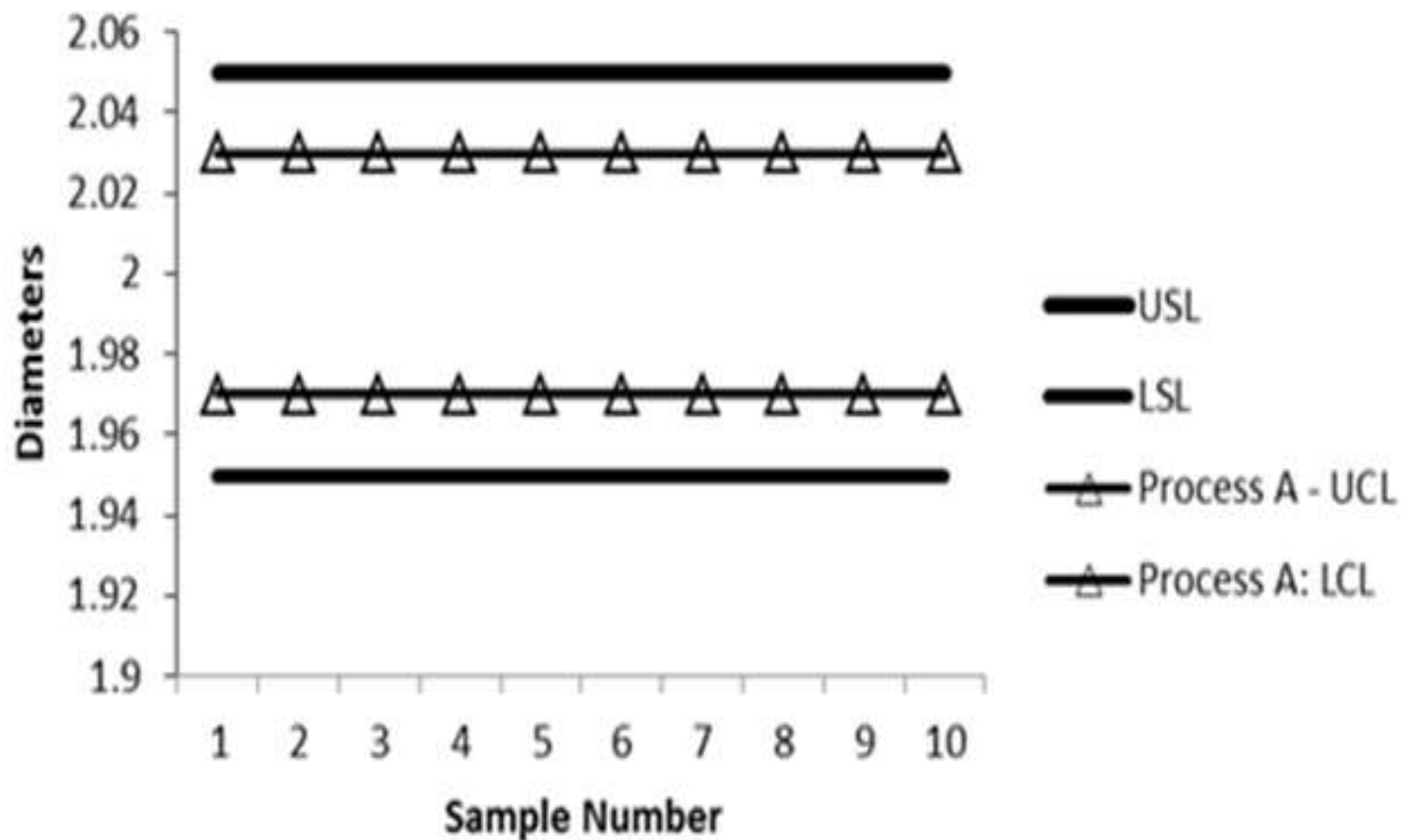
For a 99.72% confidence level, the UCL and LCL for process A will be:

$$\text{UCL (Process A)} = 2.00 + 3 * 0.01 = 2.03$$

$$\text{LCL (Process A)} = 2.00 - 3 * 0.01 = 1.97,$$

The USL, LSL and UCL and LCL for process A are shown in the figure below.

# Process A



# Selecting a Manufacturing Process

(continued)

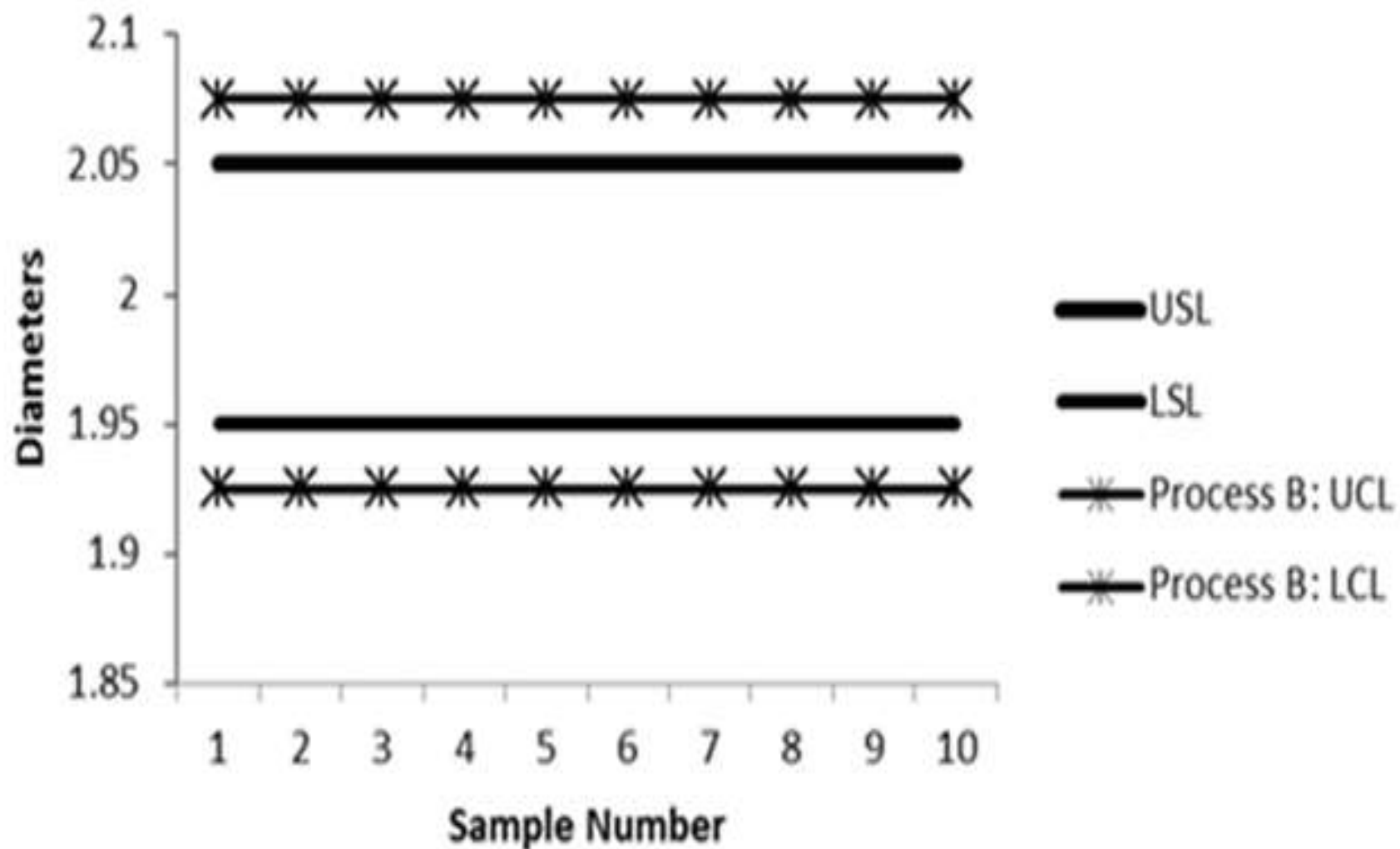
The UCL and LCL for 99.72% confidence interval for process B will be:

$$\text{UCL (Process B)} = 2.00 + 3 * 0.025 = 2.075$$

$$\text{LCL (Process B)} = 2.00 - 3 * 0.025 = 1.925$$

The USL, LSL and UCL and LCL for process B are shown in the figure below.

# Process B



# Selecting a Manufacturing Process

(continued)

- The UCL (2.03) and LCL (1.97) of process A lie within the USL (2.05) and the LSL (1.95). This means that at least 99.72 % of the output will be of acceptable quality.
- On the other hand the UCL (2.075) and LCL (1.925) of process B lie outside the USL (2.05) and LSL (1.95). Therefore, some items produced by process B will fall outside the USL and LSL. By definition, these items will be considered defective.
- Process A is more accurate and precise as compared to process B and hence process A is likely to be more expensive.
- Process B is less expensive but produces more defective units.
- An appropriate process is selected after doing a careful analysis of the costs of the processes and the cost of rejected units which might have to be scrapped if they cannot be reworked.

# Control Charts for Variables: x-bar Charts

- The x-bar chart uses measurement by variables.
- A sample of size  $n$  of the product is taken at pre-defined intervals.
- Each unit in the sample is measured along the appropriate scale for the quality being analyzed. The mean of each sample is calculated.
- After that the grand mean (average) which is the mean of all the sample means is calculated.
- The grand mean represents the center line of the control chart.
- The following formulas are used to find the upper and lower control limits.

$$UCL(\bar{x}) = \text{Grand average} + A2 * \bar{R}$$

$$LCL(\bar{x}) = \text{Grand average} - A2 * \bar{R}$$

where,  $\bar{R}$  (R-bar) is the mean of the ranges of the samples.

A2 is a factor which is dependent on the sample size  $n$ .

We illustrate the construction of x-bar charts with an example entitled The Belgian Chocolate Truffle Factory (BCTF).

# Factors for Determining Three-Sigma Control Limits

Confidence interval is assumed to be three standard deviations in the following table.

Number of Observations in Subgroup (n)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A <sub>2</sub>	n.a.	1.88	1.02	0.73	0.58	0.48	0.42	0.37	0.34	0.31	0.29	0.27	0.25	0.24	0.22	0.21	0.2	0.19	0.19	0.18
D <sub>3</sub>	n.a.	0	0	0	0	0	0.08	0.14	0.18	0.22	0.26	0.28	0.31	0.33	0.35	0.36	0.38	0.39	0.4	0.41
D <sub>4</sub>	n.a.	3.27	2.57	2.28	2.11	2	1.92	1.86	1.82	1.78	1.74	1.72	1.69	1.67	1.65	1.64	1.62	1.61	1.6	1.59

# Example: The Belgian Chocolate Truffle Factory (BCTF)

- ❖ The standard weight per piece set by BCTF is 30 grams.
- ❖ A perfect pound box contains 16 chocolates, each weighing 28.35 grams.
- ❖ Company policy, based on principles of ethical practice, is to err on the side of giving more, rather than less, by targeting 1.65 extra grams per piece.
  - However, extra chocolate is expensive.
  - Worse yet, if weight and size are inconsistent, the larger pieces create dissatisfaction with the truffles that meet the standard.
  - Also, consistency of size is used by customers to judge the quality of the product.
  - Even though the company claims customization as an advantage, complaints are received that the candies are uneven in size and weight.

This is an ideal opportunity to use an x-bar chart to find out if the chocolate-making process is stable or erratic.

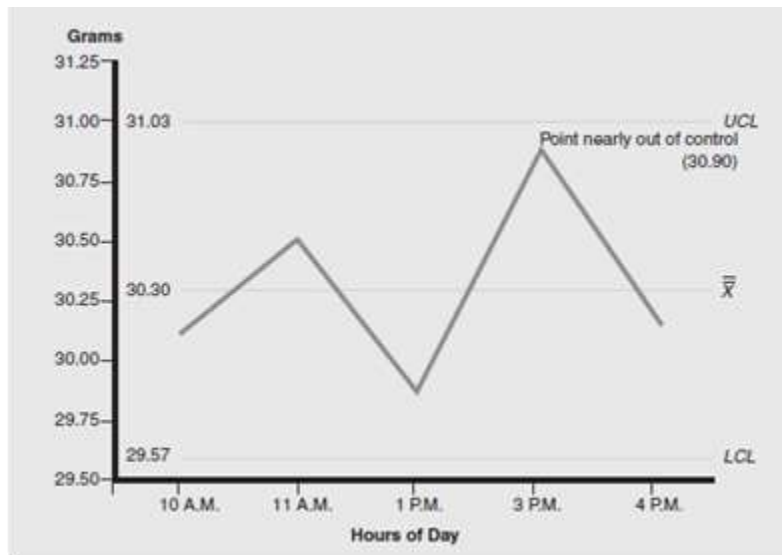


# Control Chart for Belgian Chocolate Truffle Factory (BCTF)

$$UCL (\bar{X}) = 30.30 + 0.73 * 1.00 = 31.03$$

$$LCL (\bar{X}) = 30.30 - 0.73 * 1.00 = 29.57$$

where 0.73 is the value of A2 for a sample size of 4.



# CONTROL CHARTS FOR VARIABLES: R-CHARTS

- ❖ The R-chart monitors the stability of the range—that is the spread of the distribution around the mean of the process.
- ❖ In other words, R-charts control for shifts in the process standard deviation.

The formulas for the control limits for three standard deviations for the R-chart are:

$$UCL (R\text{-bar}) = D4 * R\text{-bar}$$

$$LCL (R\text{-bar}) = D3 * R\text{-bar}$$

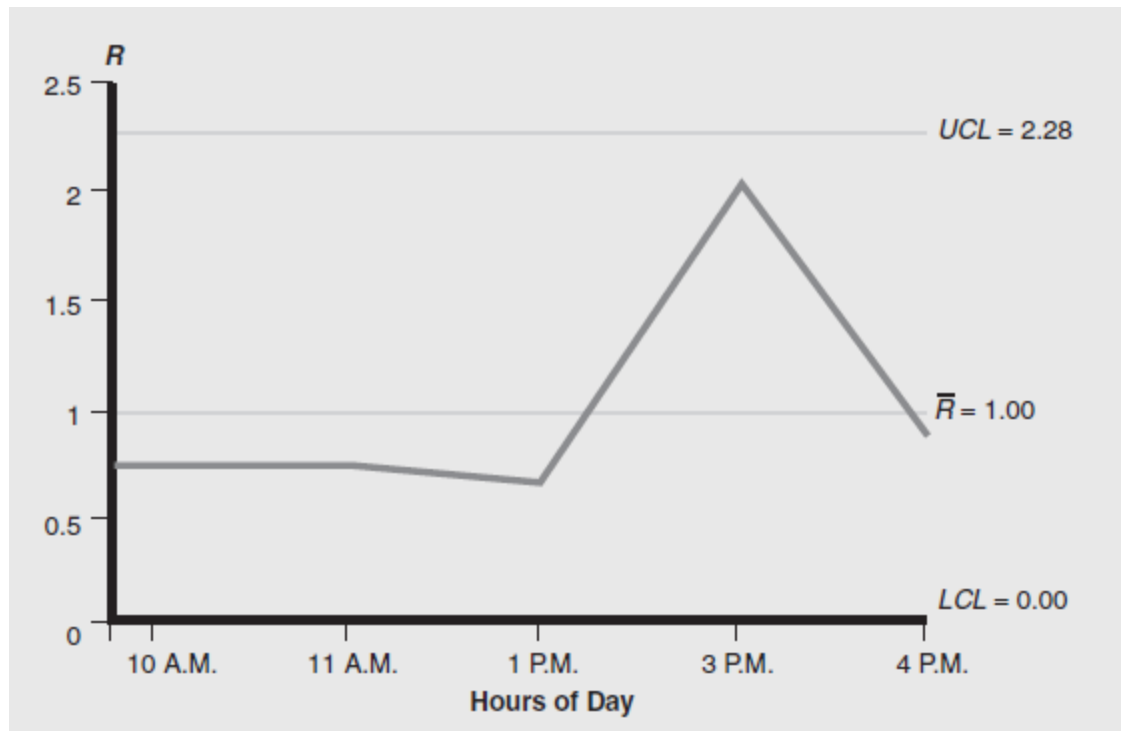
where, D4 and D3 are given in the table discussed earlier (slide 43).

# The Three Sigma Limits R Chart for Belgian Chocolate Truffle factory (BCTF)

The mean value of the range is 1.0. The values of D4 and D3 are 2.28 and 0.00 respectively.

$$UCL(\bar{R}) = 2.28 * 1.00 = 2.28$$

$$LCL(\bar{R}) = 0.0 * 1.00 = 0.00$$



# CONTROL CHARTS FOR ATTRIBUTES: $p$ -CHARTS

- ❖ The  $p$ -chart shows the proportion (or percent) defective in successive samples.
- ❖ The attribute used is good (accepted) or bad (rejected).

The value of  $p$  is defined as:

$$p = \frac{\text{number rejected}}{\text{number inspected}}$$

The standard deviation  $\sigma$  is given by the following formula.

# Rejects (R) Due to Excessive Weight for BCTF

A defective occurs when the weight of a chocolate  $< 29.60$  grams or the weight of a chocolate  $> 30.40$  grams.

Rejects are marked with an R in the following table.

Subgroup	I	II	III	IV	V	Sum	Grand Mean
Time	10 A.M.	11 A.M.	1 P.M.	3 P.M.	4 P.M.		
Day 1	30.5R	30.30	30.15	30.6R	30.15		
Day 2	29.75	31.00R	29.5R	32.00R	30.25		

# The $p$ -chart for Belgian Chocolate Truffle Factory (BCTF)

$$\bar{p} = 0.40$$

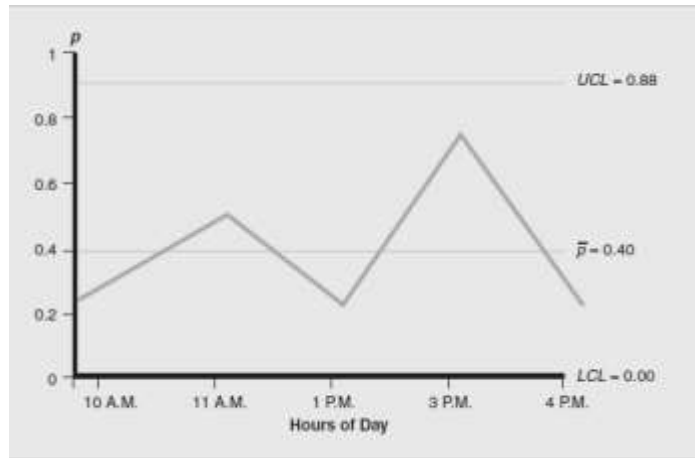
$$\sigma = \text{square root } ((.4*.6)/4) = 0.245.$$

For a confidence interval of 95%,  $z = 1.96$ ,

$$UCL = 0.4 + 1.96*0.245 = 0.88$$

$$LCL = 0.4 - 1.96*0.245 = -0.08 = \text{zero}$$

The LCL cannot be less than zero, so it is set to zero when the calculated value of LCL is negative.



There are no points outside the control limits, although the 3:00 P.M. value of 0.75 is close to the upper limit's value of 0.88.

# CONTROL CHARTS FOR ATTRIBUTES: $c$ -CHARTS

In many situations the number of defects in an item, rather than percentage of defectives, is of interest.

For example, the finish of an automobile or the glass for the windshield is typical of products that can have multiple defects. It is common to count the number of imperfections for paint finish and for glass bubbles and marks.

The  $c$ -chart is constructed in such cases. It shows the number of defects in successive samples.

The expected number of defects per part is  $\bar{c}$ . The standard deviation of the distribution of  $c$  is the square root of  $\bar{c}$ . The upper- and lower-control limits are calculated by the following formulas (similar to  $p$ -charts).

- $UCL(\bar{c}) = \bar{c} + z^*\sigma$
- $LCL(\bar{c}) = \bar{c} - z^*\sigma$
- where,  $\sigma = \text{square root of } \bar{c}$  and  $z$  values are calculated just like the calculation for  $p$ -charts.

# Data for $c$ -charts

The total number of defects in 10 samples is 38.

Therefore,  $\bar{c} = 3.8$  ( $38/10$ ) and  $\sigma = 1.95$ .

For a two-sigma limit ( $z = 2$ ),

$$UCL(\bar{c}) = 3.8 + 2 * 1.95 = 7.70$$

$$LCL(\bar{c}) = 3.8 - 2 * 1.95 = - 0.098 = \text{zero}$$

A negative LCL is interpreted as zero.

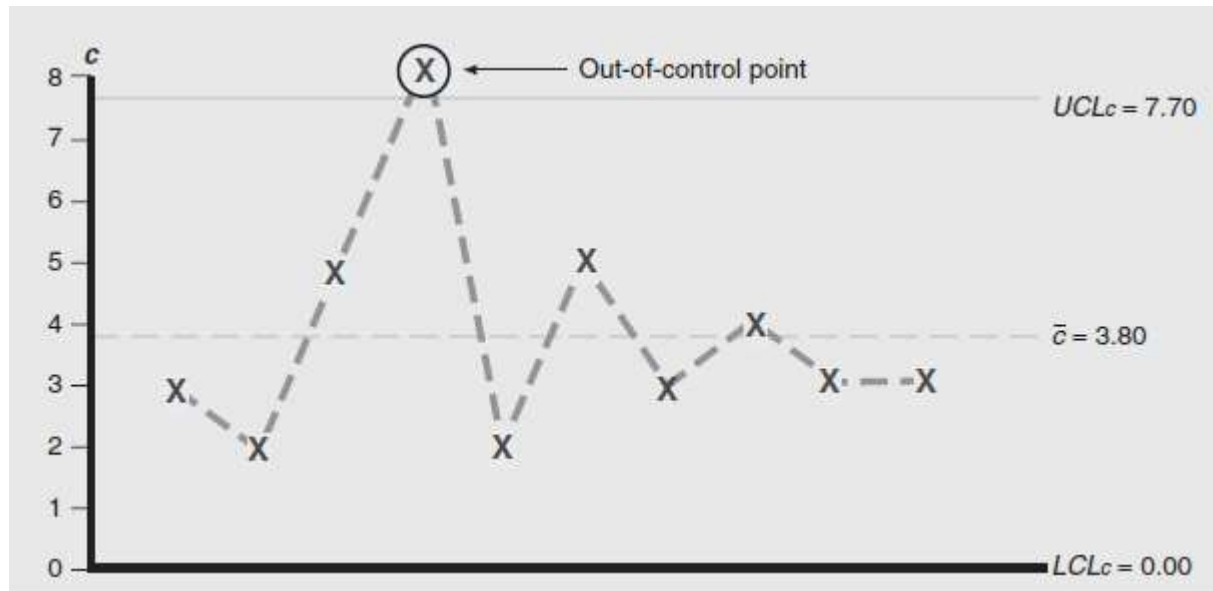
Sample Number	Number of Defects
1	3
2	2
3	5
4	8
5	2
6	5
7	3
8	4
9	3
10	3
Total	38

# c-Chart for Number of Defects per Part

The UCL is breached by the fourth sample as shown below.

This violation seems to indicate that all is not well with this process.

This must be checked since out-of-control points have a statistical probability of occurring and sending false alarms.



# Acceptance Sampling

- ❑ In acceptance sampling, there is a supplier (manufacturer and/or seller) and a buyer (customer). Suppliers' goods are checked for adherence to quality standards.
- ❑ After the inspection the buyer decides whether the submitted lot is of the right quality or not.
- ❑ The decision may lead to two types of errors: Type I and Type II errors.
  - Type I errors occur when an innocent person is found guilty by a jury of peers or when a medical test falsely proclaims illness in a healthy patient.
  - Type II errors occur when a guilty person is found innocent by a jury of peers or when a medical test erroneously declares an ill person to be healthy.

# Type I and II Errors

- In the operations management context Type I errors occur when work is rejected on false premises.
- Type II errors occur when work is accepted that should be rejected (according to mutually agreed upon standards).
- Type I errors are called errors of commission because an action (return or detail) follows the test result.
- When a supplier's shipment has been rejected by a test sample, that supplier may call for a 100 percent inspection. Defectives can be removed from the shipment by a procedure called detailing.
- Type II errors are called errors of omission. The shipment is accepted and the buyer may or may not discover that the percent defectives were above the contract specification.

*How does one discover that he or she did not marry the person best suited to be a lifelong companion?*

# Sampling vs. 100% Inspection

- The inspection process may involve a 100% inspection or the decision may be based on inspecting a sample of items taken from the lot—this is called acceptance sampling.
- The sample is assumed to represent the quality of the shipment submitted for inspection (called a lot).
- It is also assumed that the process that made the product is under control in the SQC sense.
- Sampling plans are often part of the buyer–supplier contract.

# Sampling vs. 100% Inspection (continued)

- There are times when 100% inspection is the best procedure.
- The use of 100% inspection makes sense for products where failure is life-threatening, for example, parachutes.
- Aircraft take-off rules are a series of checks that constitute 100% inspection of certain features of the plane.
- An economic reason to shun 100% inspection is that it is often expensive.
- A common criticism of 100% inspection is that it is not fail-safe because it is human to err, and the inspectors are human (increasingly robots inspect).
- If destructive testing is required (as with firecrackers), sampling is the only alternative.
- The inspection results are available sooner in case of sampling as compared to 100% inspection.

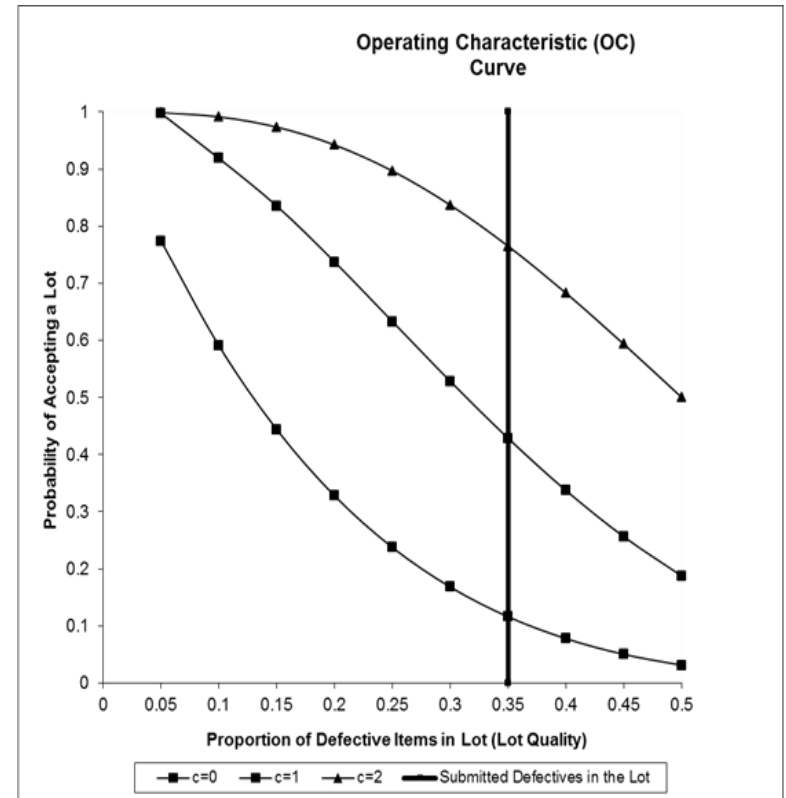
# Single Sampling Plan

- A single sampling plan is defined by the following three numbers:
  - $N$  = Lot Size (shipment size). This is the total number of items received in a lot.
  - $n$  = The sample size. The items to be inspected should be a representative sample drawn at random from the lot size  $N$ .
  - $c$  = The acceptance number which is the maximum number of defective items allowed in the sample. When defectives exceed  $c$ , reject the lot, which is shown below in the formula.
- The sampling process consists of inspecting  $n$  items picked up randomly from the lot of  $N$  items.
- Suppose  $d$  items are found to be defective. The criteria to accept/reject the lot are given below.
- Accept the lot if  $d \leq c$  and Reject the lot if  $d > c$ .

*Example:* Five items ( $n = 5$ ) are drawn from a lot size of 200 ( $N = 200$ ). Suppose  $c = 2$ . Then if  $d = 3$ , reject the entire lot because  $d > c$ . If two or fewer items are found to be defective then accept the lot.

# Operating Characteristic Curve (OC)

- In the figure on RHS, it is assumed that  $N$  and  $n$  are constant for all three OC curves; however, the values of  $c$  are 0, 1 and 2.
- The OC curve shows the probability of accepting a lot as the actual percent defective in the lot ( $p$ ) goes from 0 to one.
- For example, see the vertical line at  $p = 0.35$  and read the probabilities where it intersects the OC curves on the Y-axis.
- The probability of acceptances are approximately 12%, 43% and 76% for  $c = 0, 1,$  and  $2$  respectively.
- This means allowing more defectives in sample (larger  $c$ ) increases the probability of acceptance and vice versa (for smaller  $c$ ).



# Multiple-Sampling Plans

- Multiple-sampling plans are utilized when the cost of inspection required by the single-sampling plan is too great.
- Double-sampling is used when it can lower inspection costs.
- Single-sampling plans require that the decision to accept or reject the lot must be made on the basis of the first sample drawn.
- With double-sampling, a second sample is drawn if needed.
- The double-sampling plan uses two samples of sizes, say  $n_1$  and  $n_2$ .
- Two acceptance numbers  $c_1$  and  $c_2$  such that  $c_2 > c_1$  are needed.

*The decision rules are:*

Suppose the observed number of defectives in the first sample is  $d_1$ .

- Accept the lot if  $d_1 \leq c_1$ .
- Reject the lot if  $d_1 > c_2$ .
- If  $c_1 < d_1 \leq c_2$ , then draw an additional sample.

# Multiple-Sampling Plans (continued)

- The total sample size after taking the second sample is  $n_1 + n_2$ .
- The total number of defectives in the two samples  $d_1 + d_2$ .

*The decision rules are:*

- Accept the lot if  $(d_1 + d_2) \leq c_2$ .
  - Reject the lot if  $(d_1 + d_2) > c_2$ .
- 
- Double sampling saves money by hedging. The first sample, which is small, is tested by a strict criterion of acceptability. Only if it fails are the additional samples taken. Double-sampling costs have to be balanced against the costs of the single large sample.
  - Multiple sampling plans follow the same procedures as double sampling where more than two samples can be taken.
  - OC curves can be drawn for double and multiple sampling plans also.

# International Quality Standards

- Standards establish common parts and international consensus on terminology, which makes technology transfer easier.
- Each country has its own quality standards.
- For example, The American National Standards Institute (ANSI) and the American Society for Quality Control (ASQC) have jointly published a series of quality specifications—called the Q90 series.
- However, it is important to establish global quality standards because of increasing world trade and global supply chains.
- The International Organization for Standardization (ISO) was set up to meet the need for international quality standards.
- ISO officially began operation on February 23, 1947.
- The most well-known ISO standards are the ISO 9000 (quality series) and the ISO 14000 (environmental series).

# Industrial Recognition of Quality

Two of the most important quality awards include:

- The Deming Prize
- The Malcolm Baldrige National Quality Award

## *The Deming Award*

Since 1951, the Japanese Union of Scientists and Engineers (JUSE) has awarded the Deming Prize to companies (from any country) that have achieved outstanding quality performance.

The companies include both manufacturing and service industries.

## *The Malcolm Baldrige National Quality Award*

The Malcolm Baldrige National Quality Award was established in 1987 as a program to promote competitiveness based on high standards of quality management among U.S. companies.

Thank you