eMDP on
Lean Operations Management (LOM)
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Defining Quality, Quality Strategy, Quality control and Management, History and Trends, Contribution of Quality Gurus, Philosophies and frameworks for Quality management, 7 QC tools, Control Charts

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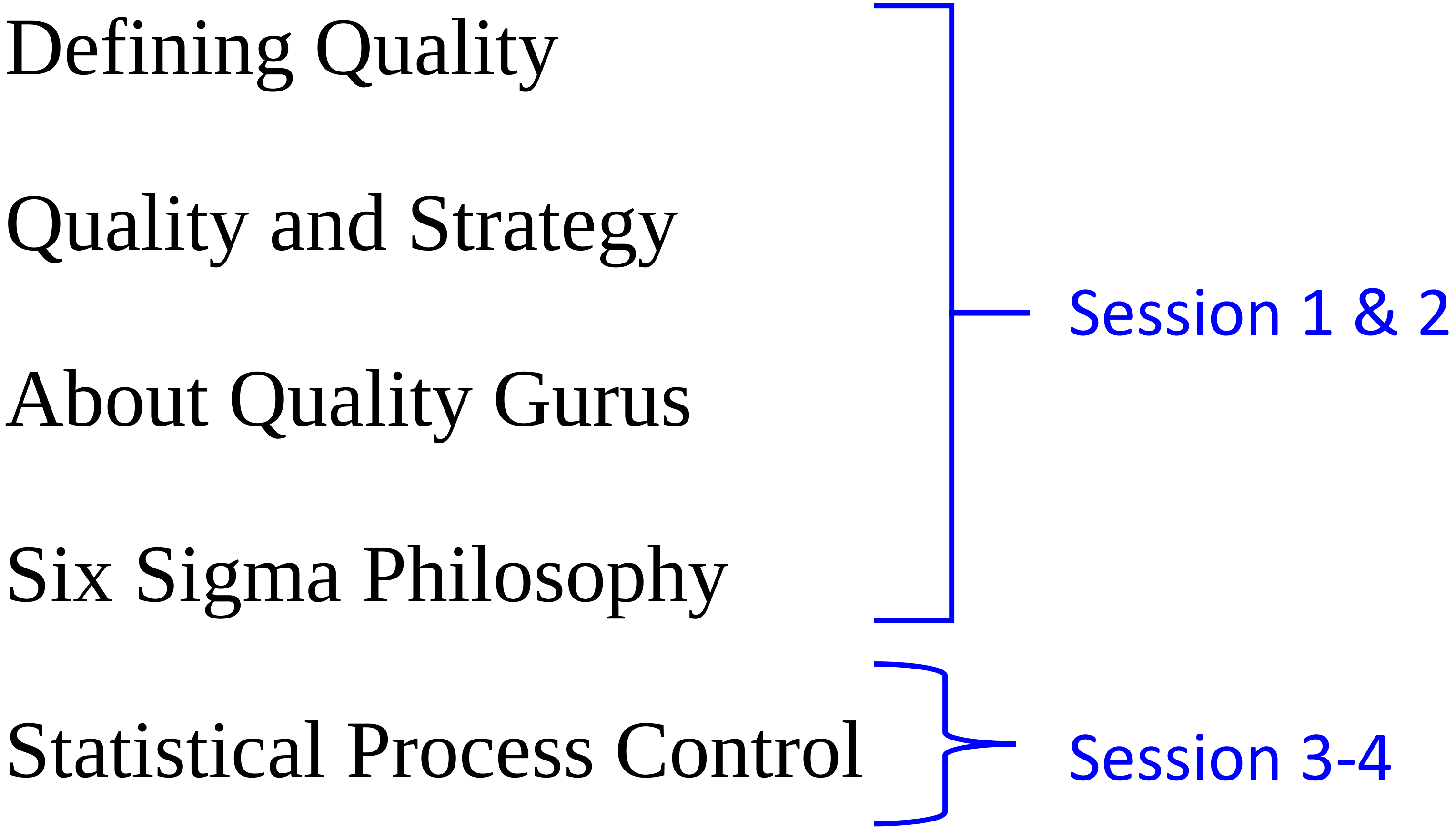


Defining Quality

Quality and Strategy

About Quality Gurus

Six Sigma Philosophy

Session 1 & 2

Statistical Process Control

Session 3-4

Defining Quality

Quality

An operations manager's objective is to build a total quality management system that *identifies* and *satisfies* customer needs

The totality of features and characteristics of a product or service that bears on its ability to satisfy stated or implied needs

American Society for Quality

Different Views

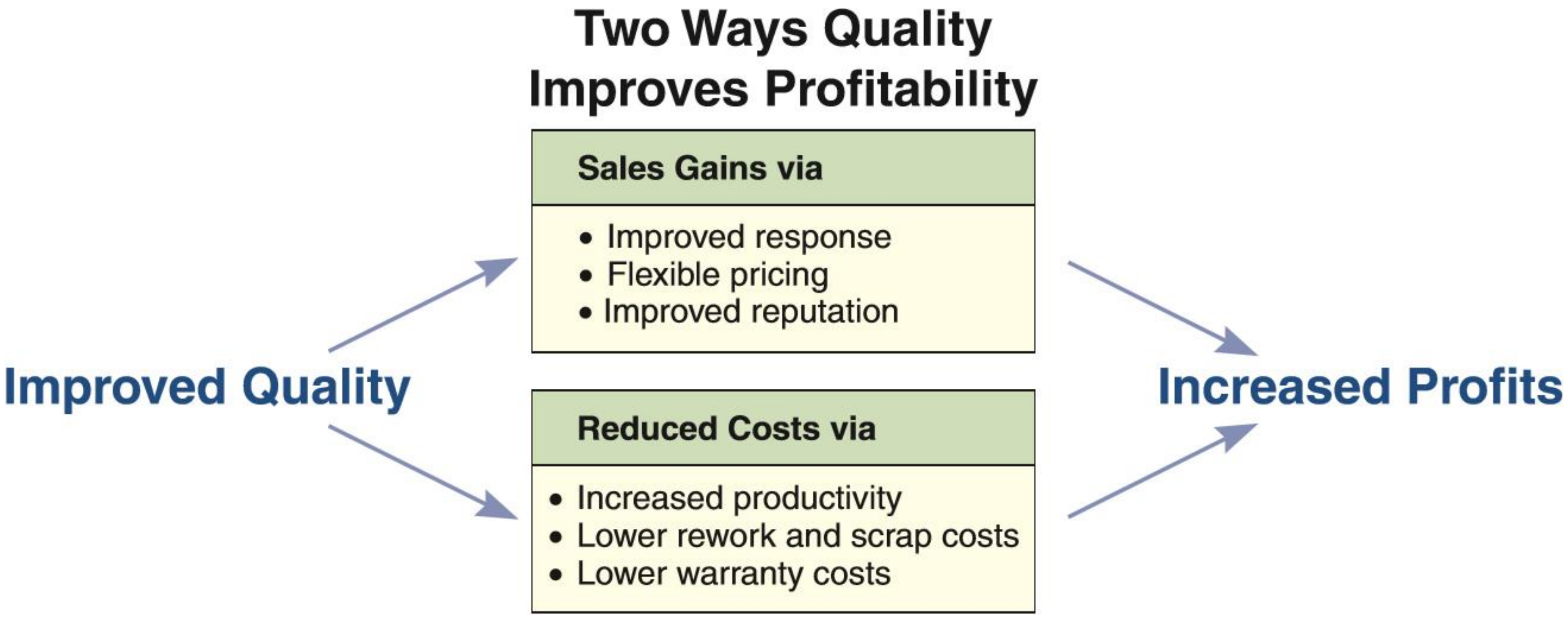
- **User based:** better performance, more features
- **Manufacturing based:** conformance to standards, making it right the first time
- **Product based:** specific and measurable attributes of the product

Quality and Strategy

Quality and Strategy

- Managing quality supports **differentiation**, **low cost**, and **response** strategies
- Quality helps firms increase sales and reduce costs
- **Building** a quality organization is a demanding task

Two Ways Quality Improves Profitability



Two Ways Quality Improves Profitability

Improved Quality

Sales Gains via

- Improved response
- Flexible pricing
- Improved reputation

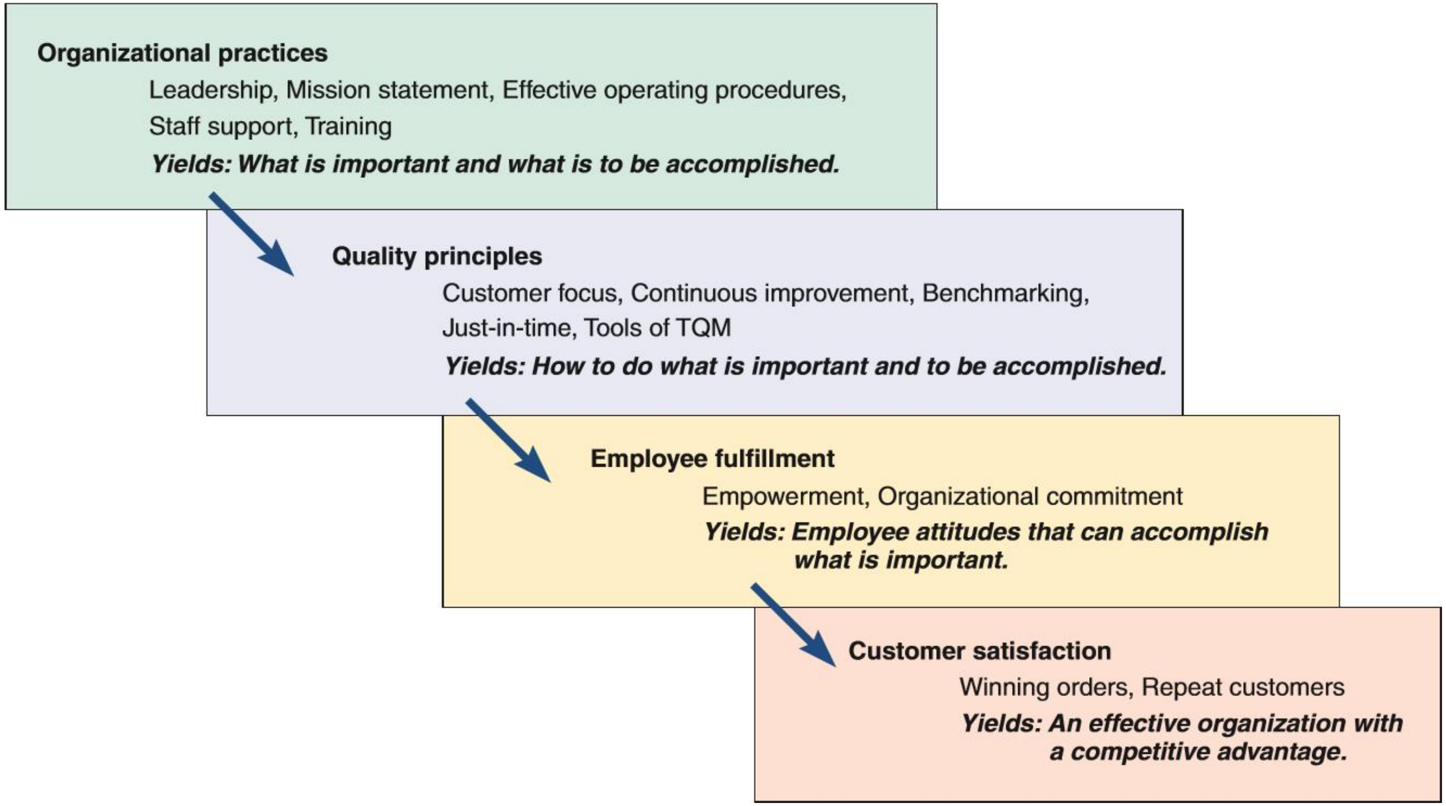
Reduced Costs via

- Increased productivity
- Lower rework and scrap costs
- Lower warranty costs

Increased Profits

The Flow of Activities

The Flow of Activities Necessary to Achieve Total Quality Management



Organizational practices

Leadership, Mission statement, Effective operating procedures, Staff support, Training

Yields: What is important and what is to be accomplished.

Quality principles

Customer focus, Continuous improvement, Benchmarking, Just-in-time, Tools of TQM

Yields: How to do what is important and to be accomplished.

Employee fulfillment

Empowerment, Organizational commitment

Yields: Employee attitudes that can accomplish what is important.

Customer satisfaction

Winning orders, Repeat customers

Yields: An effective organization with a competitive advantage.

Implications of Quality

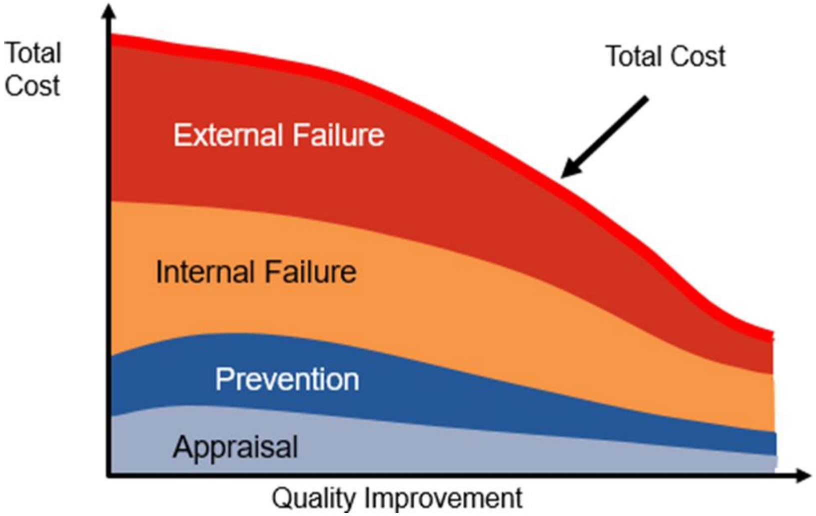
1. Company reputation
   - Perception of new products
   - Employment practices
   - Supplier relations

2. Product liability
   - Reduce risk

3. Global implications
   - Improved ability to compete

Costs of Quality

- **Prevention costs** - reducing the potential for defects
- **Appraisal costs** - evaluating products, parts, and services
- **Internal failure costs** - producing defective parts or service before delivery
- **External failure costs** - defects discovered after delivery



Takumi

A System to Protect Quality & Safety Management

A Japanese character that symbolizes a broader dimension than quality, a deeper process than education, and a more perfect method than persistence

Quality
Gurus

Understanding Quality from eminent personalities popularly known as Quality Gurus.

1. W. Edwards Deming
2. Joseph M. Juran
3. Philip B. Crosby
4. Armand Vallin Feigenbaum
5. Kaoru Ishikawa
6. David A. Garvin
7. Shigeo Shingo
8. Genichi Taguchi

Despite there are eight gurus in assessing total quality management , but there are differences in their opinions.

Three groups of gurus

Early 1950’s	Americans who took the messages of quality to Japan
	↓
Late 1950’s	Japanese who developed new concepts in response to the Americans
	↓
1970’s-1980’s	Western gurus who followed the Japanese industrial success

W. Edwards Deming

- Born:- October 14, 1900.
- Died:- December 20, 1993
- Dr. W. Edwards Deming is known as the father of the Japanese post-war industrial revival and was regarded by many as the leading quality guru in the United States.
- His expertise was used during World War II to assist the United States in its effort to improve the quality of war materials

- He got his PhD in the states in physics and math's
- Get his first employment chance in an electricity company in Chicago
- He taught physics , mathematics , statistics and quality in Japan .

* Deming is best known for his management philosophy , establishing quality , productivity and competitive position .

Deming focus on 5 ideas :

1. Statistical process controlling (SPC)
2. Deming philosophy
3. Deming 14 points
4. Deming Cycle (for continuous improvements)
5. Seven deadly diseases of quality

1. ***Statistical process controlling (SPC)***:

- It’s a process which aims at achieving good quality during manufacture through prevention rather than detection .

- It is concerned with controlling the process (machine) which make the product through inspecting the machine rather than the product itself.

- For example why the salesman can’t sell the same amount every month ?

- SPC will answer this question by discovering and analyzing these items :

I. <u>Common causes</u> : which inherent to the process as machine fails

II. <u>Special causes</u> : Not inherent to the process and should be defined such as poor performance

III. <u>Natural Variation</u>: producing certain amount of defects

IV. <u>Significantly different variation</u>: Discovering exactly where it is by management.

Note. Deming said :

*80% depends on management

*20% depends on employee

2. ***Deming Philosophy***:

The quality and the productivity increases when the process fluctuation decreases

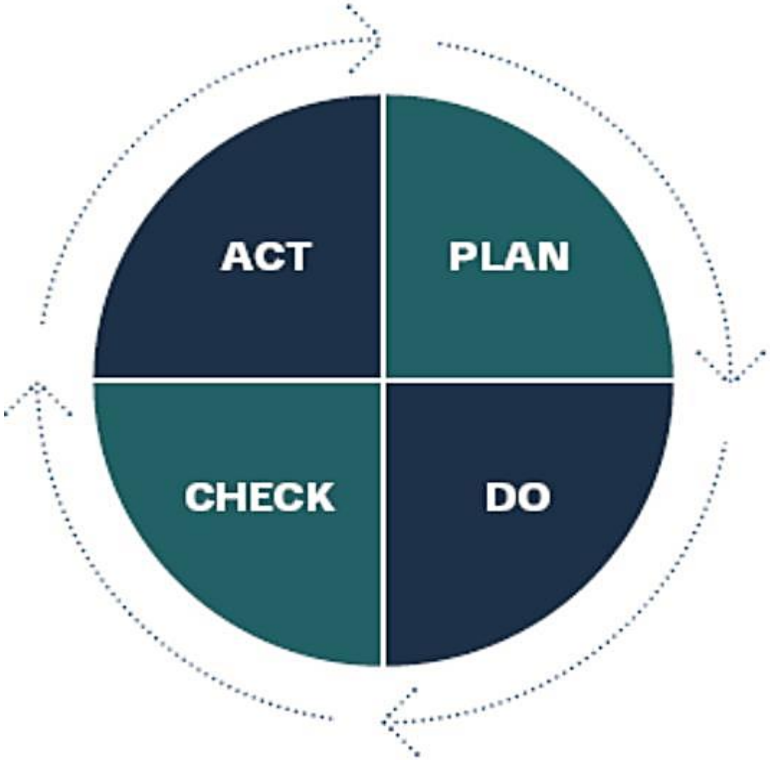
3. ***Deming 14 Points:***

- Create constancy of purpose for improving products and services.
- Adopt the new philosophy.
- Cease dependence on inspection to achieve quality.
- End the practice of awarding business on price alone; instead, minimize total cost by working with a single supplier.
- Improve constantly and forever every process for planning, production and service.
- Institute training on the job.

- Adopt and institute leadership.
- Drive out fear.
- Break down barriers between staff areas.
- Eliminate slogans, exhortations and targets for the workforce

- Eliminate numerical quotas for the workforce and numerical goals for management.
- Remove barriers that rob people of pride of workmanship, and eliminate the annual rating or merit system.
- Institute a vigorous program of education and self-improvement for everyone.
- Put everybody in the company to work accomplishing the transformation.

4. Deming's cycle



Plan *what is needed*

Do *it*

Check *that it works*

Act *to correct any problems or improve performance*

5. *Deming's Seven Deadly Diseases*

Lack of constancy of purpose to plan product and service that will have a market and keep the company in business, and provide jobs.

Emphasis on short-term profits: short-term thinking (just the opposite from constancy of purpose to stay in business), fed by fear of unfriendly takeover, and by push from bankers and owners for dividends.

Evaluation of performance, merit rating, or annual review.

Mobility of management; job hopping.

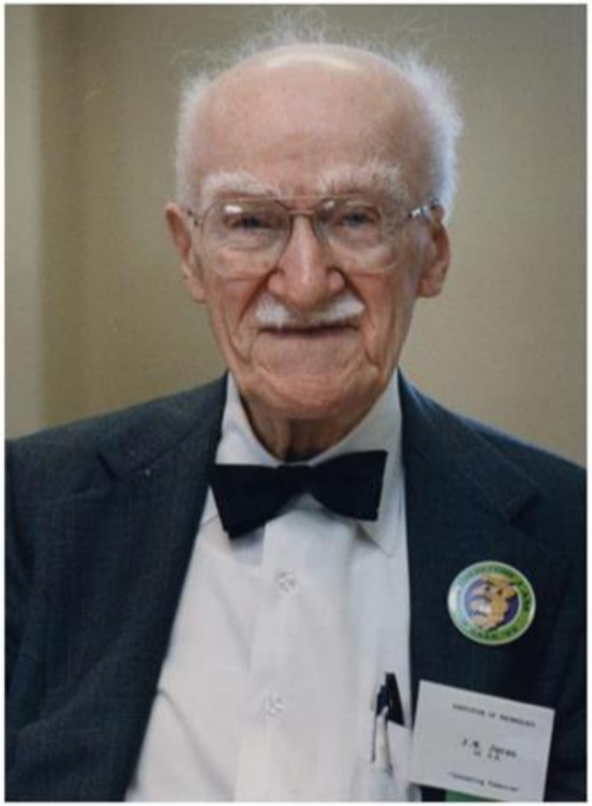
Management by use only of visible figures, with little or no consideration of figures that are unknown or unknowable.

Excessive medical costs.

Excessive costs of liability, swelled by lawyers that work on contingency fees.

Joseph M. Juran

- Born:- December 20, 1904
- Died:- February 28, 2008
- American
- Joseph Juran is an internationally acclaimed quality guru, similar to Edwards Deming, strongly influencing Japanese manufacturing practices.
- Joseph Juran's belief that "*quality does not happen by accident*" gave rise to the quality trilogy.



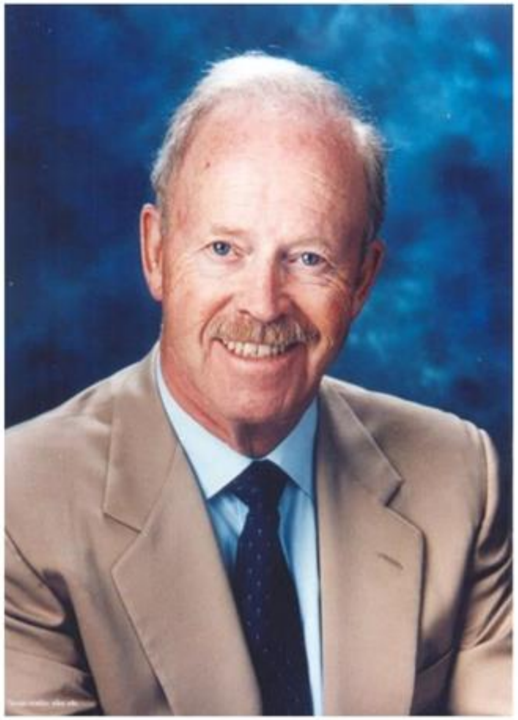
Juran Ideas are:

1. Quality definition
2. Breakthrough concept
3. Internal customer
4. Quality Trilogy
5. Pareto analysis
6. Cost of quality
7. Quality council

Philip B. Crosby

* Known as The Fun Uncle of the Quality Revolution

- Born:- June 18, 1926
- Died:- August 18, 2001
- American
- Where Philip Crosby excellence was in finding a terminology for quality that mere mortals could understand.
- He popularized the idea of the "cost of poor quality", that is, figuring out how much it really costs to do things badly.



CROSBY quality costs :

- ***Price of NON conformance*** :

  All the costs involved in not getting the product or a service right .

- ***Price of conformance*** :

  Costs for doing things right .

Crosby has 14 points like Deming , like :

- Management commitment
- Building awareness
- Educating employees
- Quality councils

And others but the main difference between Deming and Crosby is that :

**Deming focus on quality management .

**Crosby focus on action plan and implementation process .

Armand Vallin Feigenbaum

- Born:- April 6, 1922
- Died:- November 13, 2014
- He was an American quality control expert and businessman.
- Feigenbaum concept's of Total Quality Control , known today as total quality management , combines management methods and economic theory with organizational principles.

- He does not get the great attention that the others (Deming, Juran, Ishikawa, etc.) get.
- Feigenbaum believed that quality was a way of operating or a way of life, thus the term "Total Quality."
- Believes that quality has become the single most important force leading to organizational success and growth.
- Feigenbaum defined total Quality control as an effective system for integrating the quality development, quality maintenance, and quality improvement efforts of the various groups in an organization so as to enable production and service at the most economical levels which allow full customer satisfaction.

David A. Garvin

David A. Garvin is the Professor of Business Administration at the Harvard Business School.

"If quality is to be managed, it must be understood first."

The eight dimensions of quality

Performance: Main operating characteristics such as power, sound, speed etc.

Features: The extras that supplement the main characteristics

Reliability: How often it breaks down

Conformance: How close it is to the design specification or service to the customers experience.

Durability: Length of life, toughness in use, service frequency etc.

Serviceability: Ease, cost and friendliness of service.

Aesthetics: Appearance and impression.

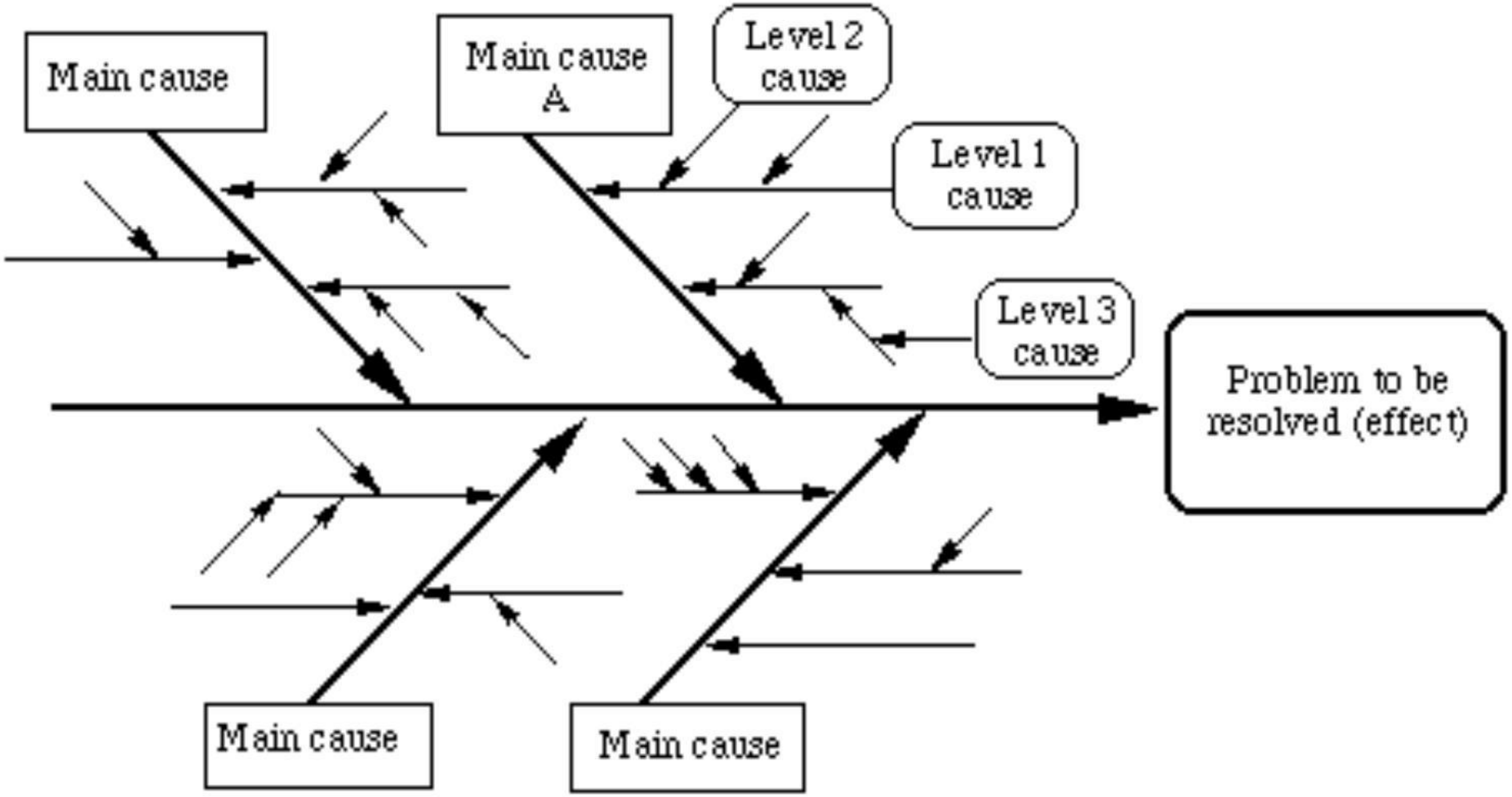
Perceived quality: The feel, finish and manner in which the customer is dealt with.

Kaoru Ishikawa

- Born:- July 13, 1915
- Died:- April 16, 1989
- Kaoru Ishikawa was a Japanese professor and influential quality management innovator best known in north America for the Ishikawa or cause and effect diagram (also known as fishbone diagram) that are used in the analysis of industrial process.

Ishikawa diagram

The Ishikawa diagram (or fishbone diagram or also cause-and-effect diagram) are diagrams, that shows the causes of a certain event. A common use of the Ishikawa diagram is in product design. Also it reveals key relationships among various variables.


Main cause
Main cause A
Level 2 cause
Level 1 cause
Level 3 cause
Problem to be resolved (effect)
Main cause
Main cause

Shigeo Shingo

- Born:- 1909
- Died:- 1990
- Shigeo Shingo, born in Saga City, Japan.
- He was a Japanese industrial engineer who distinguished himself as one of the world's leading experts on manufacturing practices and The Toyota Production System.
- Shingo is known far more in the West than in Japan.

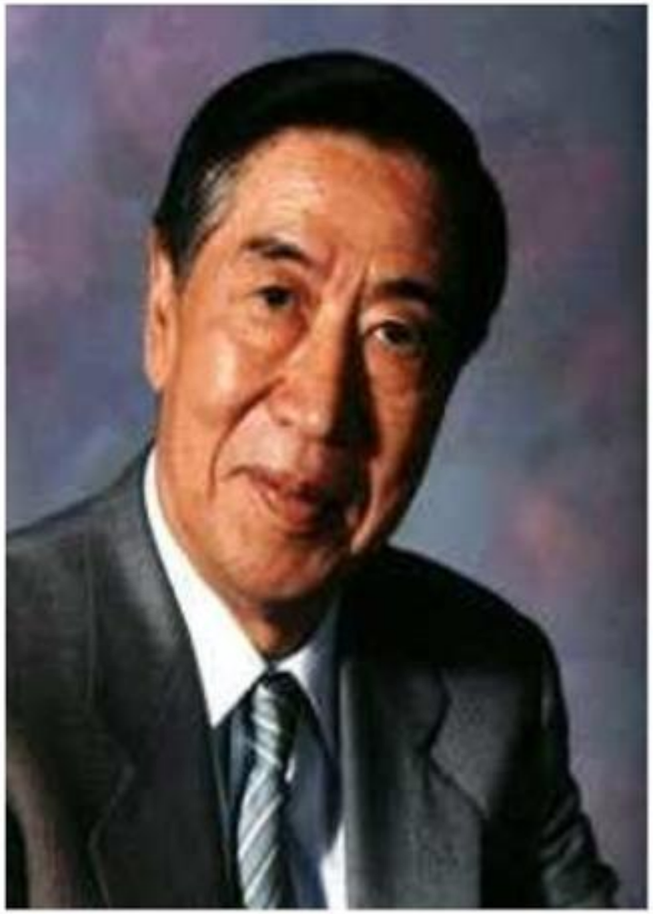
1) The single minute exchange of die (SMED) system, in which set up times are reduced from hours to minutes, and

2) The Poka-Yoke (mistake proofing) system. In Poka Yoke, defects are examined, the production system stopped and immediate feedback given so that the root causes of the problem may be identified and prevented from occurring again.

Poke-yoke

Zero quality control is the ideal production system and this requires both Poka-Yoke and source inspections.

Genichi Taguchi



- Born:- January 1, 1924
- Died:- June 2, 2012
- Genichi Taguchi was an engineer and statistician.
- Taguchi developed a methodology for applying statistics to improve the quality of manufactured goods.
- Taguchi methods have been controversial among some conventional Western statisticians, but others have accepted many of the concepts introduced by him as valid extensions to the body of knowledge.

Taguchi methodology

“Taguchi methodology” is fundamentally a prototyping method that enables the designer to identify the optimal settings to produce a robust product that can survive manufacturing time after time, piece after piece, and provide what the customer wants. Today, companies see a close link between Taguchi methods, which can be viewed along a continuum, and quality function deployment (QFD).

Taguchi contributions:

Taguchi has made a very influential contribution to industrial statistics. The key elements of his quality philosophy are:

Taguchi loss function: used to measure financial loss to society resulting from poor quality.

The philosophy of off-line quality control: designing products and processes so that they are insensitive to parameters outside the design engineer's control.

Innovations in the statistical design of experiments: notably the use of an outer array for factors that are uncontrollable in real life, but are systematically varied in the experiment

Six Sigma Quality

Six Sigma

- A philosophy and set of methods, companies use to eliminate defects in their products and processes

- Seeks to reduce variation in the processes that lead to product defects

DPMO

- Six Sigma allows managers to readily describe process performance using a common metric: Defects Per Million Opportunities (DPMO)

$$DPMO = \frac{\text{Number of defects}}{\left[\begin{array}{l}\text{Number of}\\ \text{opportunities}\\ \text{for error per}\\ \text{unit}\end{array}\right] \text{x No. of units}} \text{x } 1{,}000{,}000$$

Example DPMO calculation.

Suppose, we observe 200 letters delivered incorrectly to the wrong addresses in a small city during a single day, when a total of 200,000 letters were delivered. What is the DPMO in this situation?

So, for each one million letters delivered, this city's postal managers can expect to have 1,000 letters incorrectly sent to the wrong address.

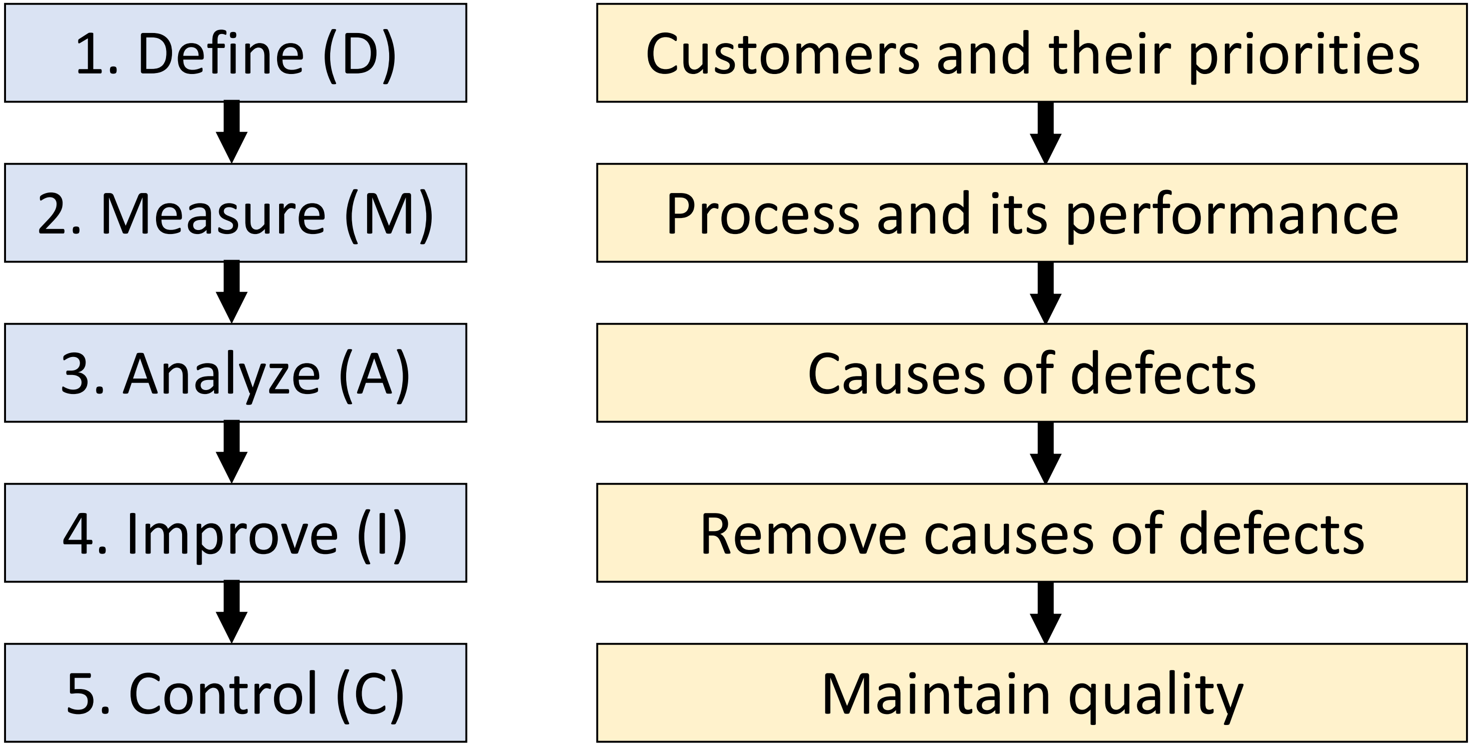
$$DPMO = \frac{200}{[\,1\,] \text{ x } 200{,}000} \text{ x } 1{,}000{,}000 = 1{,}000$$

Cost of Quality: What does DPMO mean in terms of over-time employment to correct the errors?

DMAIC

- Define, Measure, Analyze, Improve, and Control (DMAIC)
- Developed by General Electric as a means of focusing effort on quality using a methodological approach
- Overall focus of the methodology is to understand and achieve what the customer wants
- A 6-sigma program seeks to reduce the variation in the processes that lead to these defects
- DMAIC consists of five steps….

DMAIC



1. Define (D)
2. Measure (M)
3. Analyze (A)
4. Improve (I)
5. Control (C)

Customers and their priorities

Process and its performance

Causes of defects

Remove causes of defects

Maintain quality

Example

- We are the maker of this cereal. Consumer reports has just published an article that shows that they frequently have less than 16 ounces of cereal in a box.
- What should we do?

Step 1 - Define

- What is the critical-to-quality characteristic?

- The CTQ (critical-to-quality) characteristic in this case is the weight of the cereal in the box.

2 - Measure

- How would we measure to evaluate the extent of the problem?
- What are acceptable limits on this measure?

Example

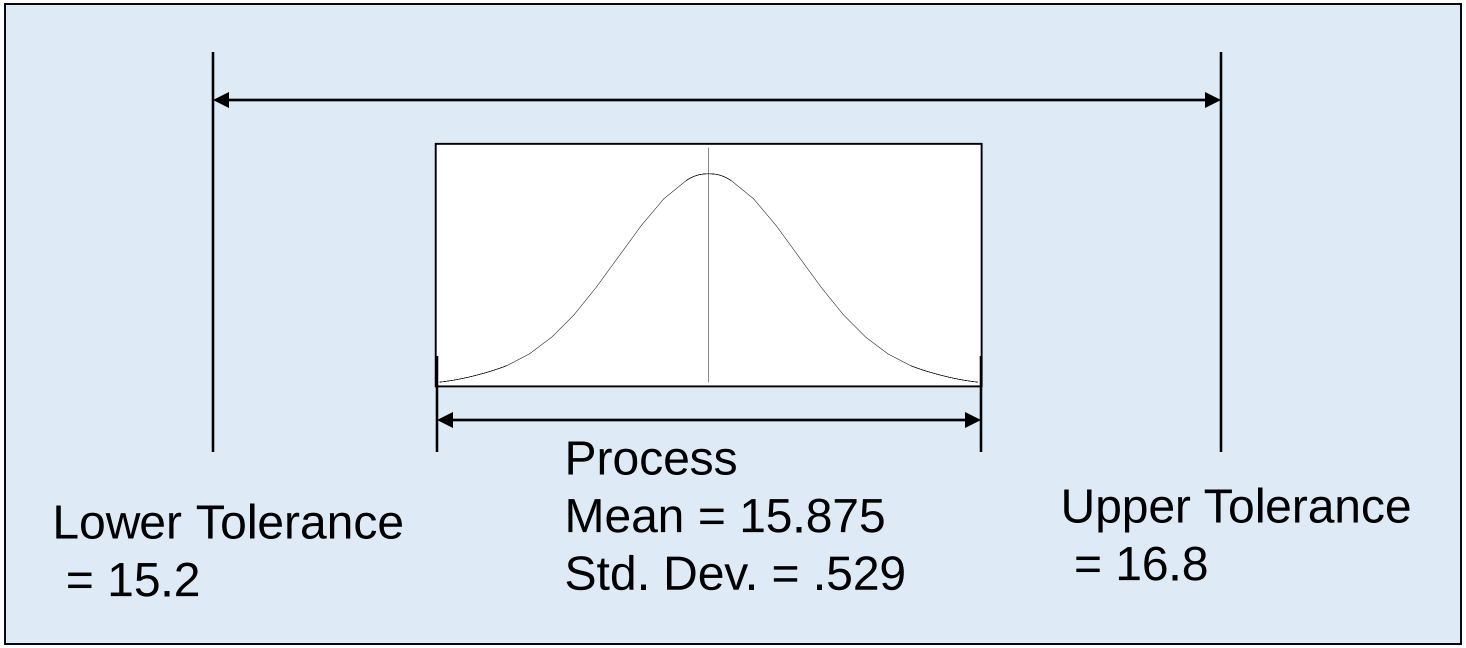
- Let's assume that the government says that we must be within ± 5 percent of the weight advertised on the box.

- Upper Tolerance Limit = 16 + .05(16) = 16.8 ounces

- Lower Tolerance Limit = 16 – .05(16) = 15.2 ounces

- We go out and buy 1,000 boxes of cereal and find that they weight an average of 15.875 ounces with a standard deviation of .529 ounces.

- What percentage of boxes are outside the tolerance limits?



Lower Tolerance
 = 15.2

Process
Mean = 15.875
Std. Dev. = .529

Upper Tolerance
 = 16.8

What percentage of boxes are defective (i.e., less than 15.2 oz)?

Z = (x – Mean)/Std. Dev. = (15.2 – 15.875)/.529 = -1.276

= NORM.S.DIST(Z) = NORM.S.DIST (-1.276) = .100979

Approximately, 10 percent of the boxes have less than 15.2
Ounces of cereal in them!

Step 3 - Analyze

How can we improve the capability of our cereal box filling process?

- Decrease Variation
- Centre Process
- Increase Specifications

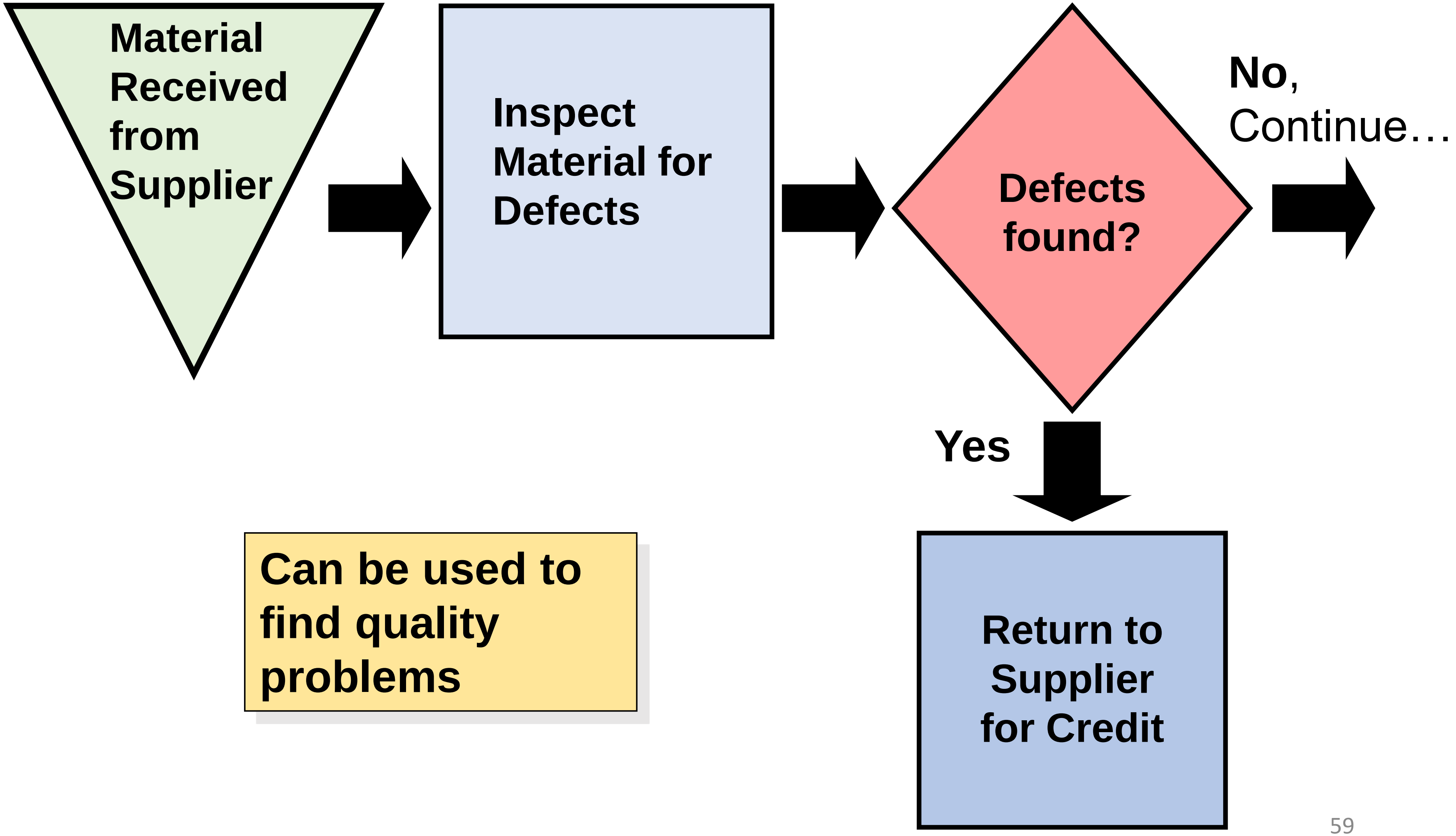
Step 4 – Improve

- Confirm the key variable and quantify their effect on CTQ.

Step 5 – Control

- Statistical Process Control (SPC)
  - Use data from the actual process
  - Estimate distributions
  - Look at capability - is good quality possible
  - Statistically monitor the process over time

Analytical Tools for Six Sigma and Continuous Improvement: Flow Chart



Material Received from Supplier

Inspect Material for Defects

Defects found?

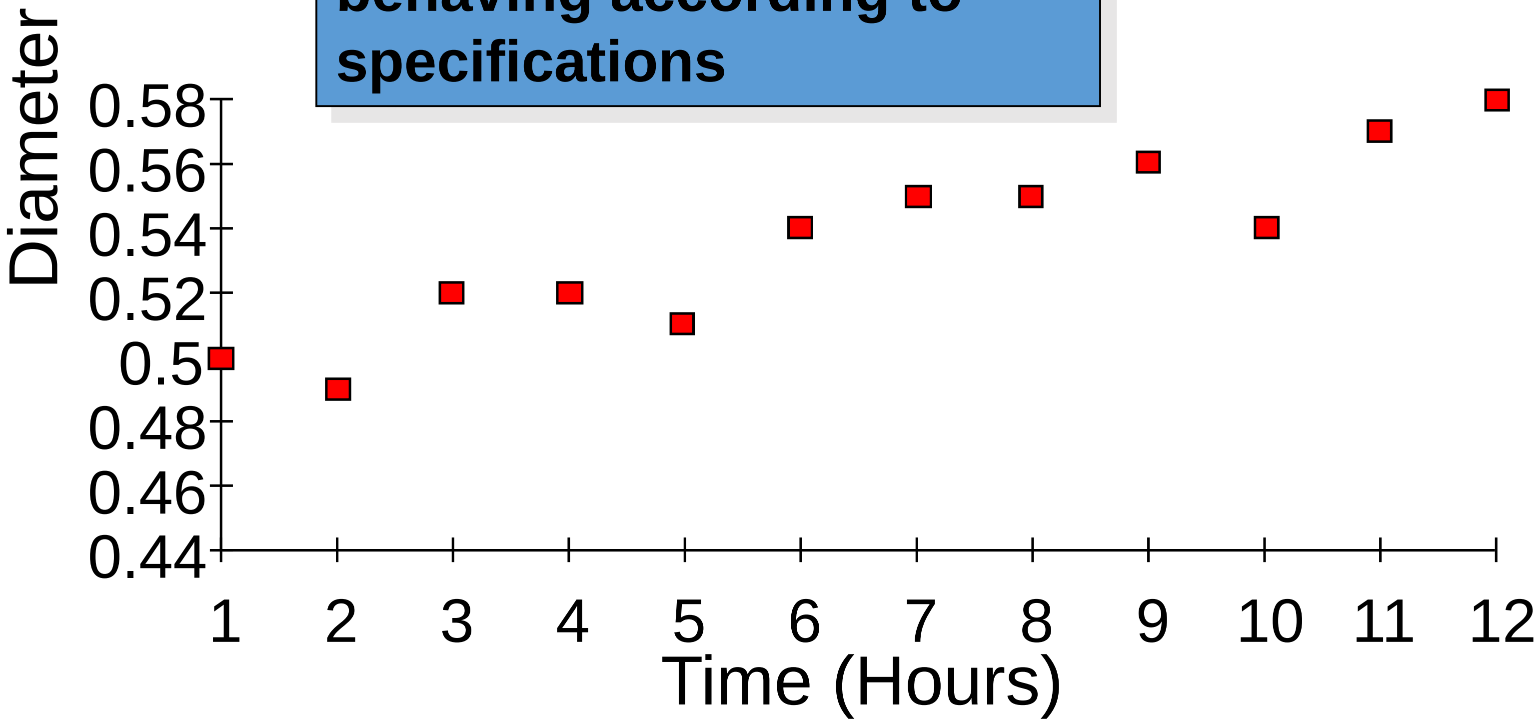
No, Continue…

Yes

Return to Supplier for Credit

Can be used to find quality problems

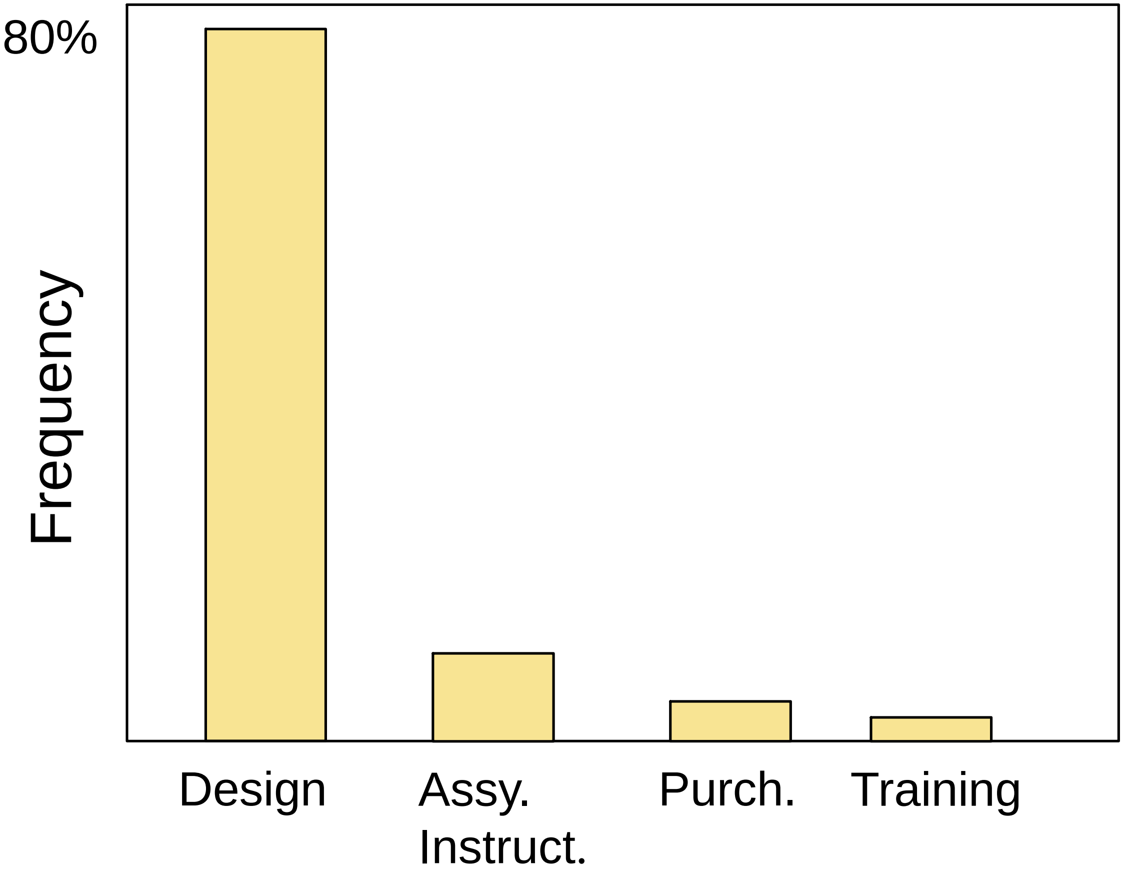
Analytical Tools for Six Sigma and Continuous Improvement: Run Chart



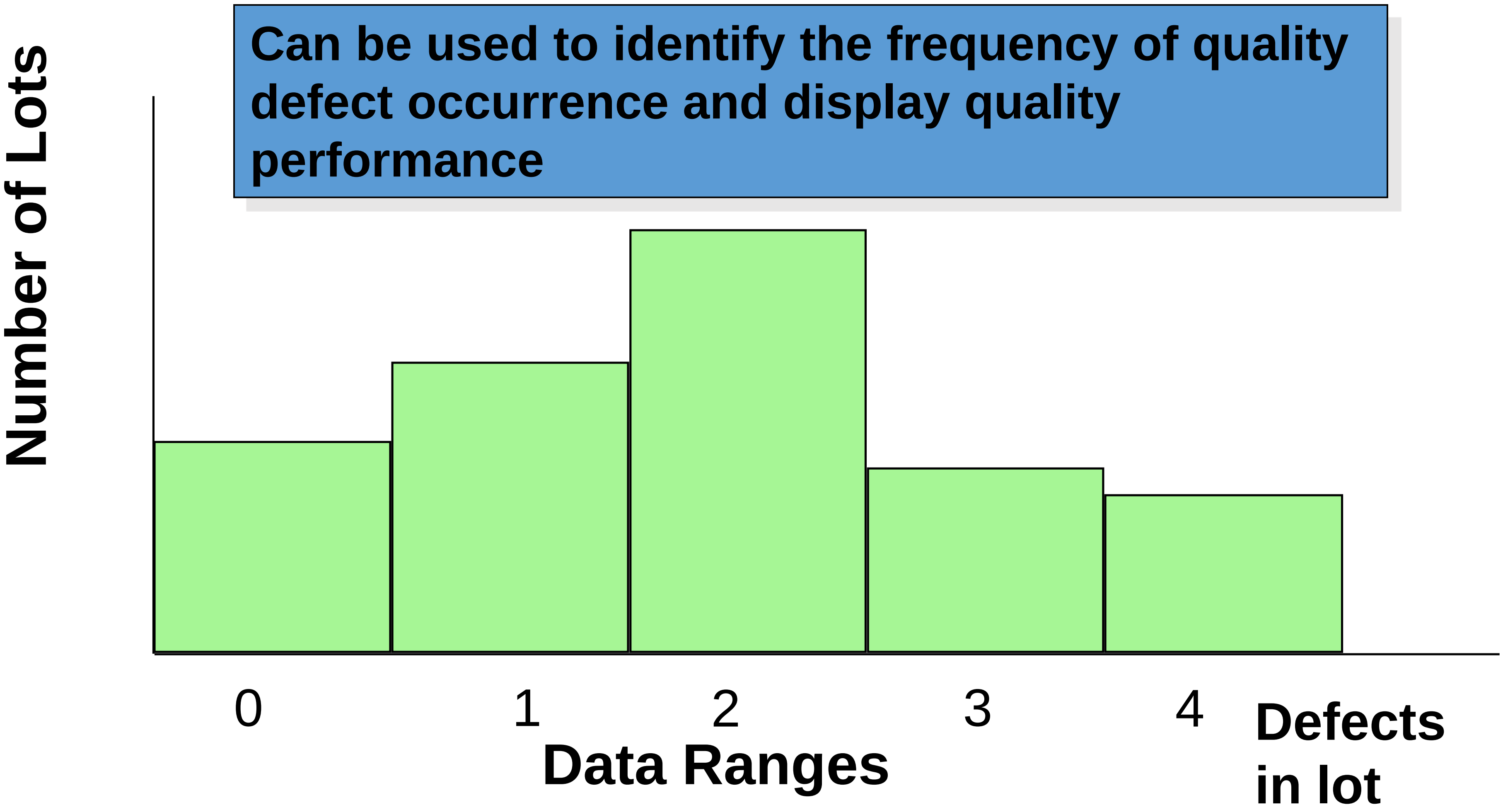
Can be used to identify when equipment or processes are not behaving according to specifications

Analytical Tools for Six Sigma and Continuous Improvement: Pareto Analysis

Can be used to find when 80% of the problems may be attributed to 20% of the causes

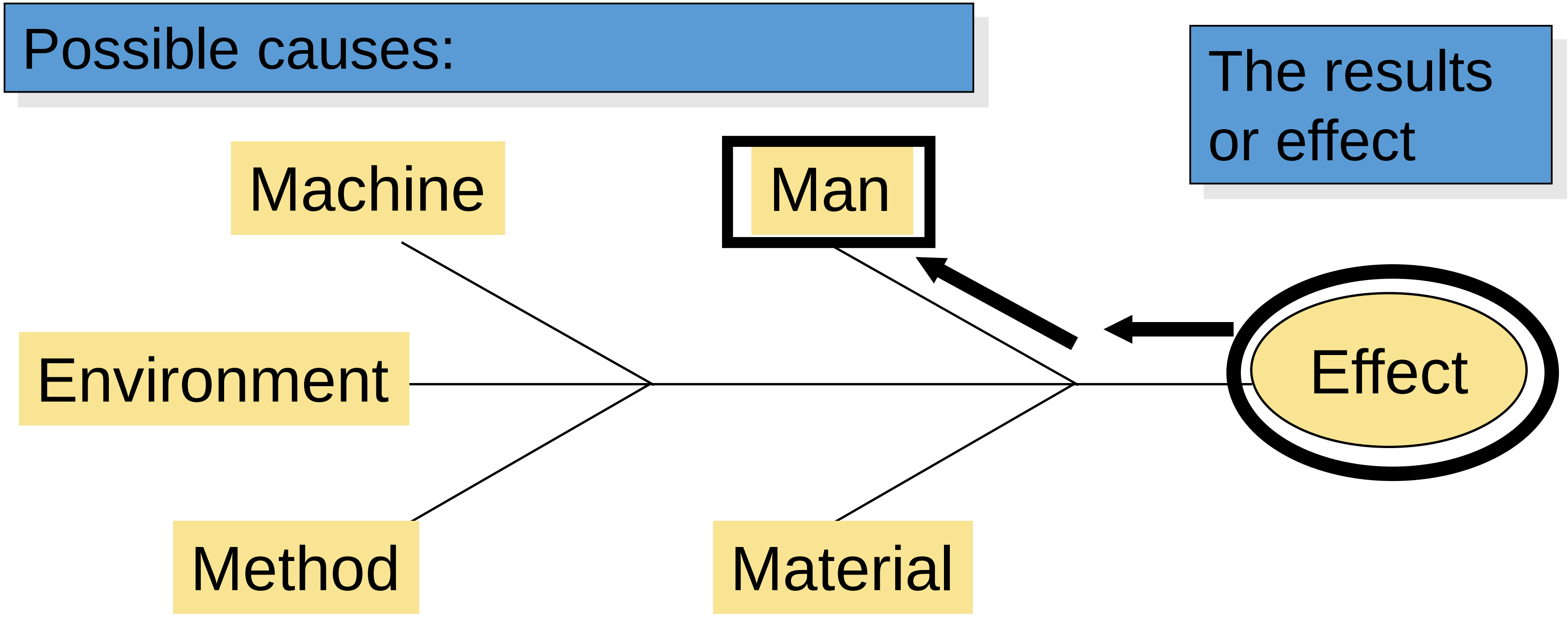


Analytical Tools for Six Sigma and Continuous Improvement: Histogram



Can be used to identify the frequency of quality defect occurrence and display quality performance

Analytical Tools for Six Sigma and Continuous Improvement: Cause & Effect Diagram



Possible causes:

The results or effect

Machine

Man

Environment

Effect

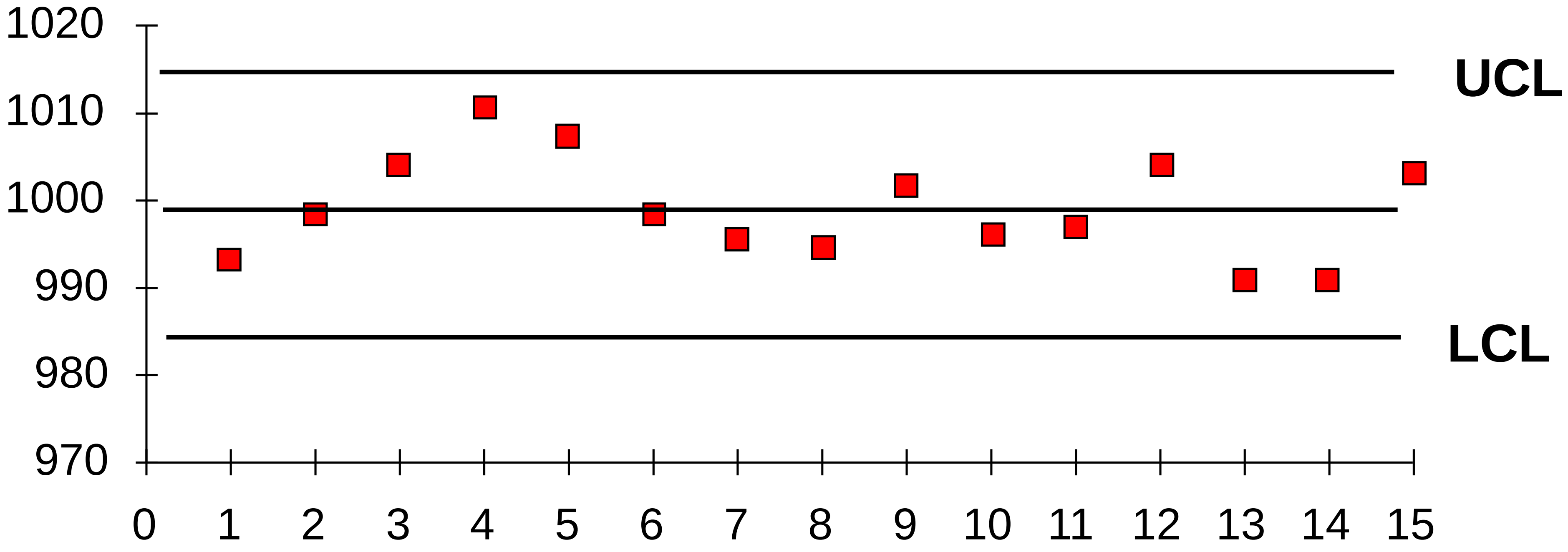
Method

Material

Can be used to systematically track backwards to find a possible cause of a quality problem (or effect)

Analytical Tools for Six Sigma and Continuous Improvement: Control Chart

Can be used to monitor ongoing production process quality and quality conformance to stated standards of quality



Six Sigma Roles and Responsibilities

1. Executive leaders must champion the process of improvement
2. Corporation-wide training in Six Sigma concepts and tools
3. Setting stretch objectives for improvement
4. Continuous reinforcement and rewards

Case Study

A1 Bakers Company (ABC) is a leading bakery chain providing various bakery products to its customers throughout India and headquartered at Indore. The organization has currently employees 580 full time employees. Currently the firm generates excessive waste from one of their production lines named “Cookies”. The average daily waste is around 8%. This waste is equivalent to the loss of Rs 7 Crore annually. The management of the firm is willing to redesign the waste tracking system by identifying the various root causes. It is estimated that there will be a saving of more than Rs 4 Crore even by reducing the daily wastage by 25%.

In order to achieve the waste reduction, the senior management constituted a team comprising of the operations manager, senior members of the research and development and some members from the finance department. The entire process was analyzed by the team members through various steps such as the supplier selection, input material, machine operators as well as the process of machining. The ultimate purpose of the team was to gather the waste at various points in the production line. The goal of the team was to determine various data points and the impact of various factors on daily waste. The team consulted a professional six sigma consultant in order to develop a thorough measurement plan considering the major reasons behind the waste.

Discussion Questions

- Considering yourself as the head of the team, do you think that DMAIC process can be developed for the production line. Why or why not?
- Develop all phases of DMAIC process in order to implement Six Sigma at ABC.

Statistical Process Control

What we learn?

- **Explain** the purpose of a control chart
- **Explain** the role of the central limit theorem in SPC
- **Build** $\bar{x}$-charts and *R*-charts
- **List** the five steps involved in building control charts
- **Build** *p*-charts and *c*-charts
- **Explain** process capability and compute C_p and C_{pk}

Statistical Process Control (SPC)

The objective of a process control system is to provide a statistical signal when assignable causes of variation are present

- Variability is inherent in every process
  - Natural or common causes
  - Special or assignable causes
- **Provides a statistical signal when assignable causes are present**
- Quickens appropriate actions to eliminate assignable causes

Natural Variations

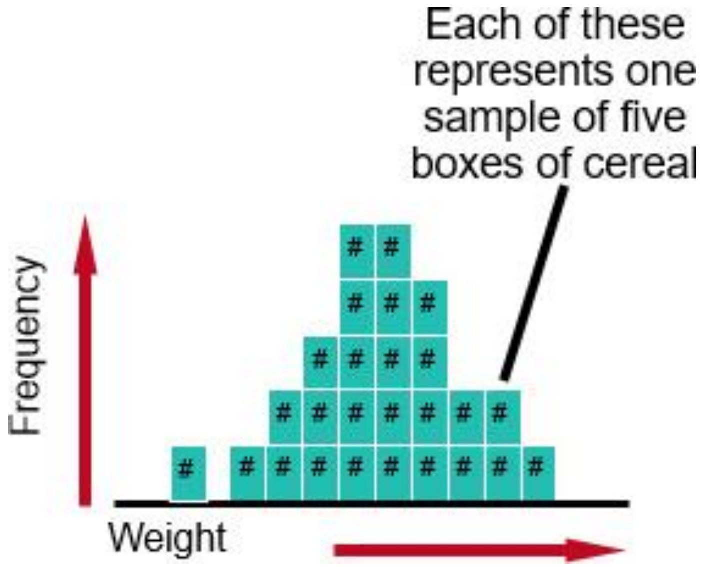
- Also called common causes
- Affect virtually all production processes
- Expected amount of variation
- Output measures follow a probability distribution
- For any distribution there is a measure of central tendency and dispersion
- If the distribution of outputs falls within acceptable limits, the process is said to be “in control”

Assignable Variations

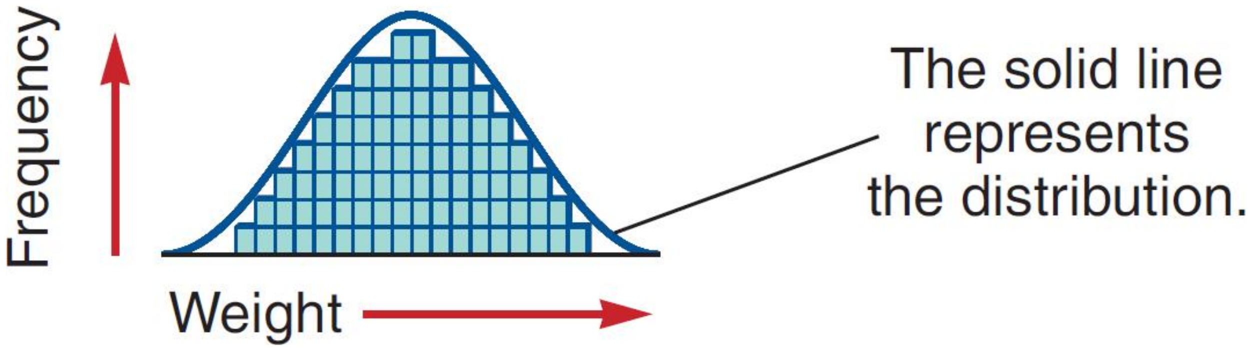
- Also called special causes of variation
  - Generally, this is some change in the process
- Variations that can be traced to a specific reason
- The objective is to discover when assignable causes are present
  - Eliminate the bad causes
  - Incorporate the good causes

Samples

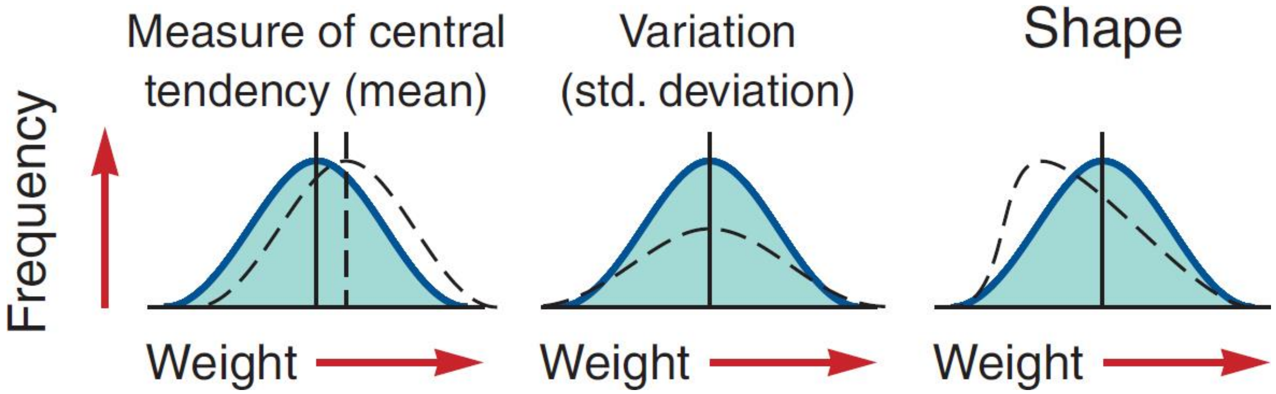
To measure the process, we take samples and analyze the sample statistics following these steps


Each of these represents one sample of five boxes of cereal

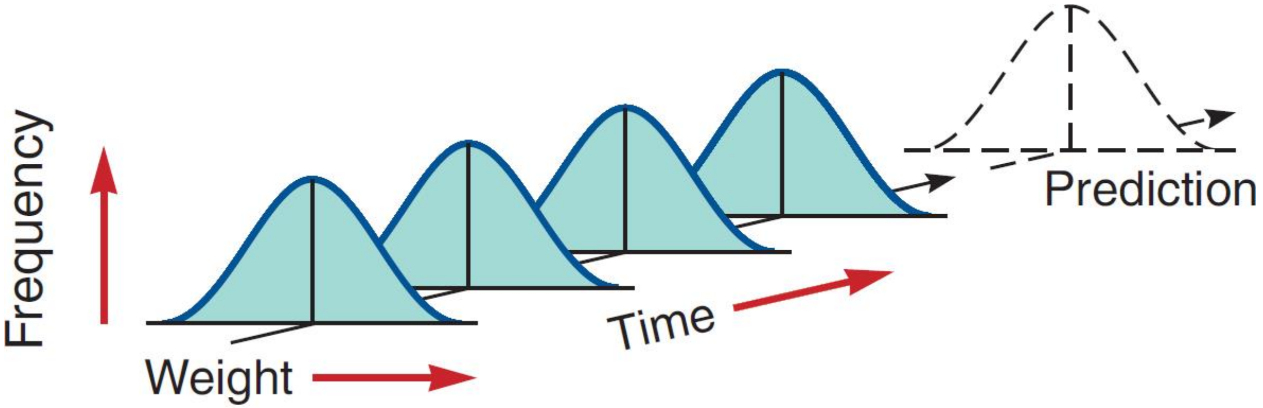
Natural and Assignable Variation (a) Samples of the product, say five boxes of cereal taken off the filling machine line, vary from each other in weight



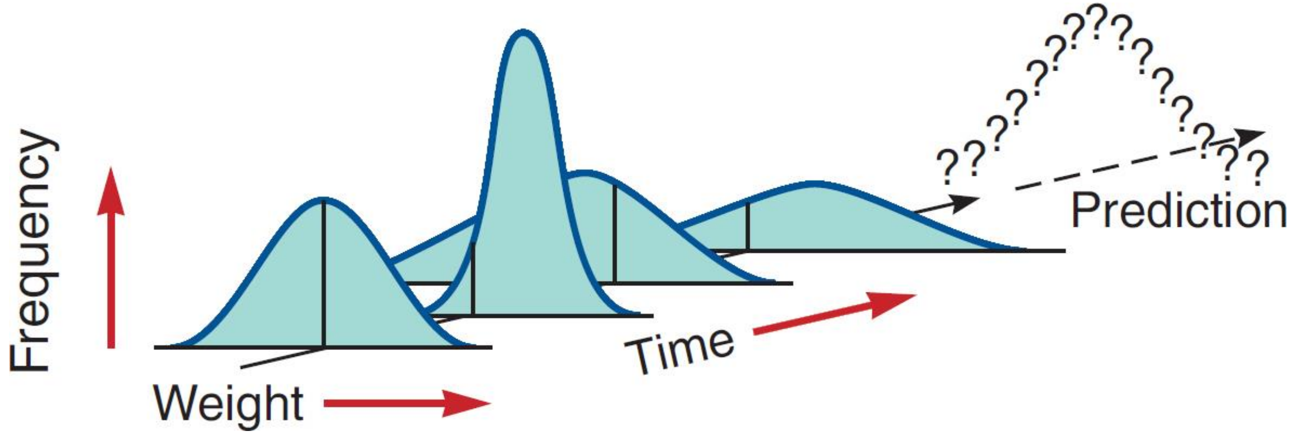
Natural and Assignable Variation (b) After enough samples are taken from a stable process, they form a pattern called a **distribution**



Natural and Assignable Variation (c) There are many types of distributions, including the normal (bell-shaped) distribution, but distributions do differ in terms of central tendency (mean), standard deviation or variance, and shape



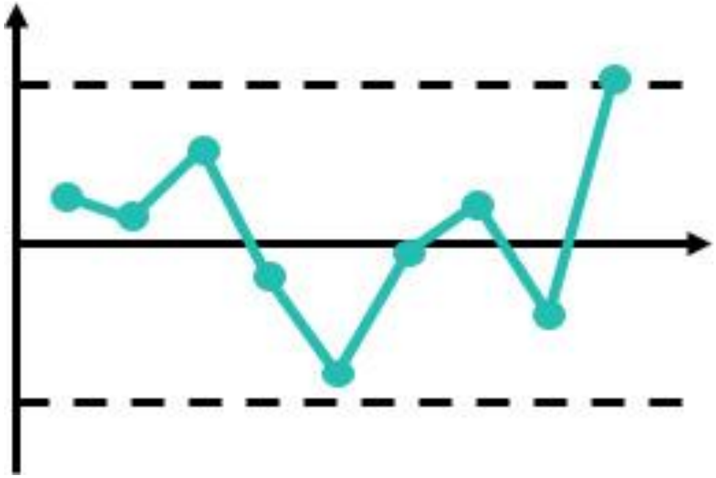
Natural and Assignable Variation (d) If only natural causes of variation are present, the output of a process forms a distribution that is stable over time and is predictable



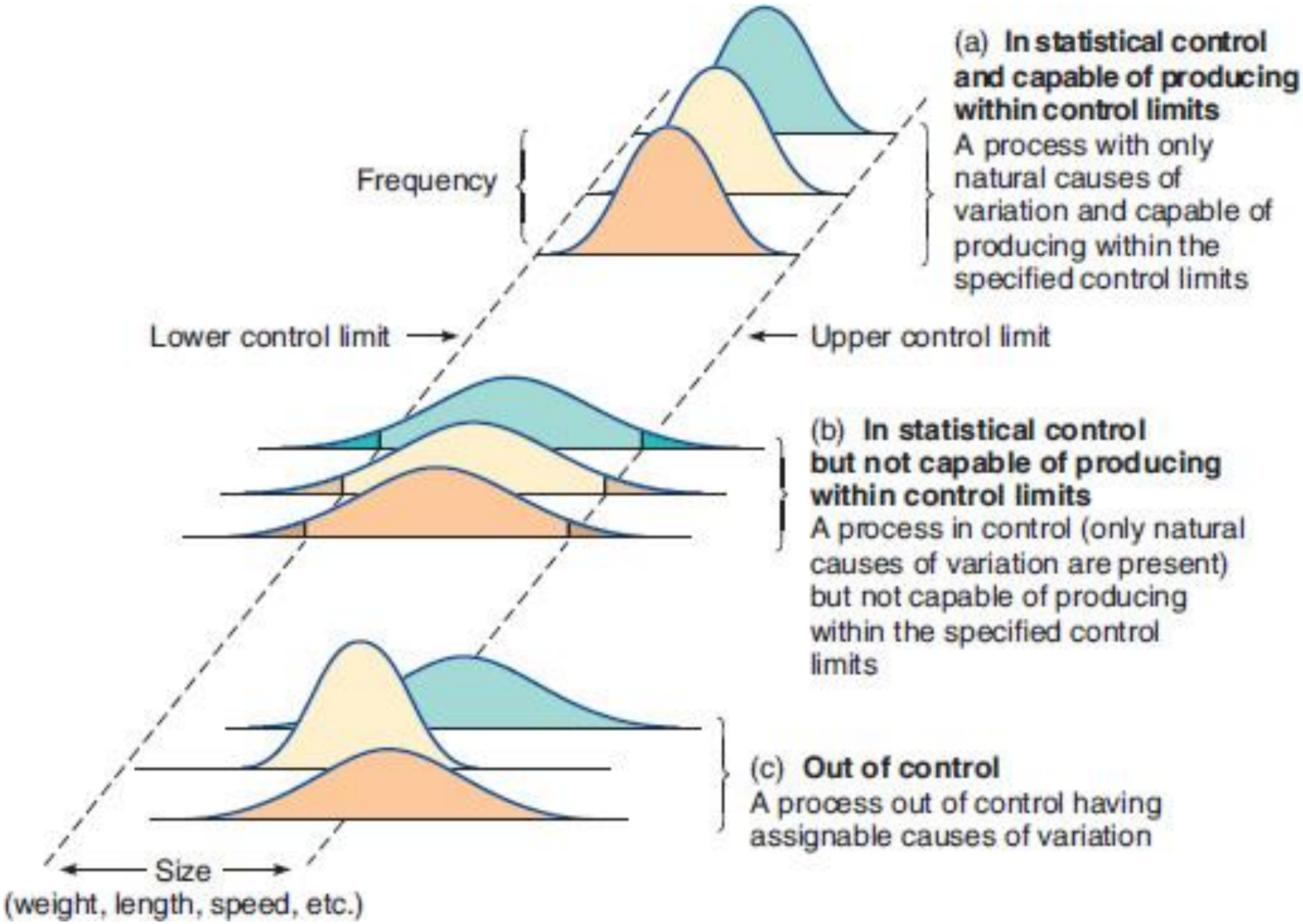
Natural and Assignable Variation (e) If assignable causes are present, the process output is not stable over time and is not predicable

Control Charts

Constructed from historical data, the purpose of control charts is to help distinguish between natural variations and variations due to assignable causes



Process Control



(a) **In statistical control and capable of producing within control limits**
A process with only natural causes of variation and capable of producing within the specified control limits

(b) **In statistical control but not capable of producing within control limits**
A process in control (only natural causes of variation are present) but not capable of producing within the specified control limits

(c) **Out of control**
A process out of control having assignable causes of variation

Control Charts

- **Control chart for variables**
  - X-bar chart
  - R Chart
- **Control chart for Attributes**
  - p-chart
  - c-chart

Control Charts for Variables

- Characteristics that can take any real value
- May be in whole or in fractional numbers
- Continuous random variables

$\overline{X}$ **-chart** tracks changes in the central tendency

***R*-chart** indicates a gain or loss of dispersion

These two charts must be used together

Central Limit Theorem

Regardless of the distribution of the population, the distribution of sample means drawn from the population will tend to follow a normal curve

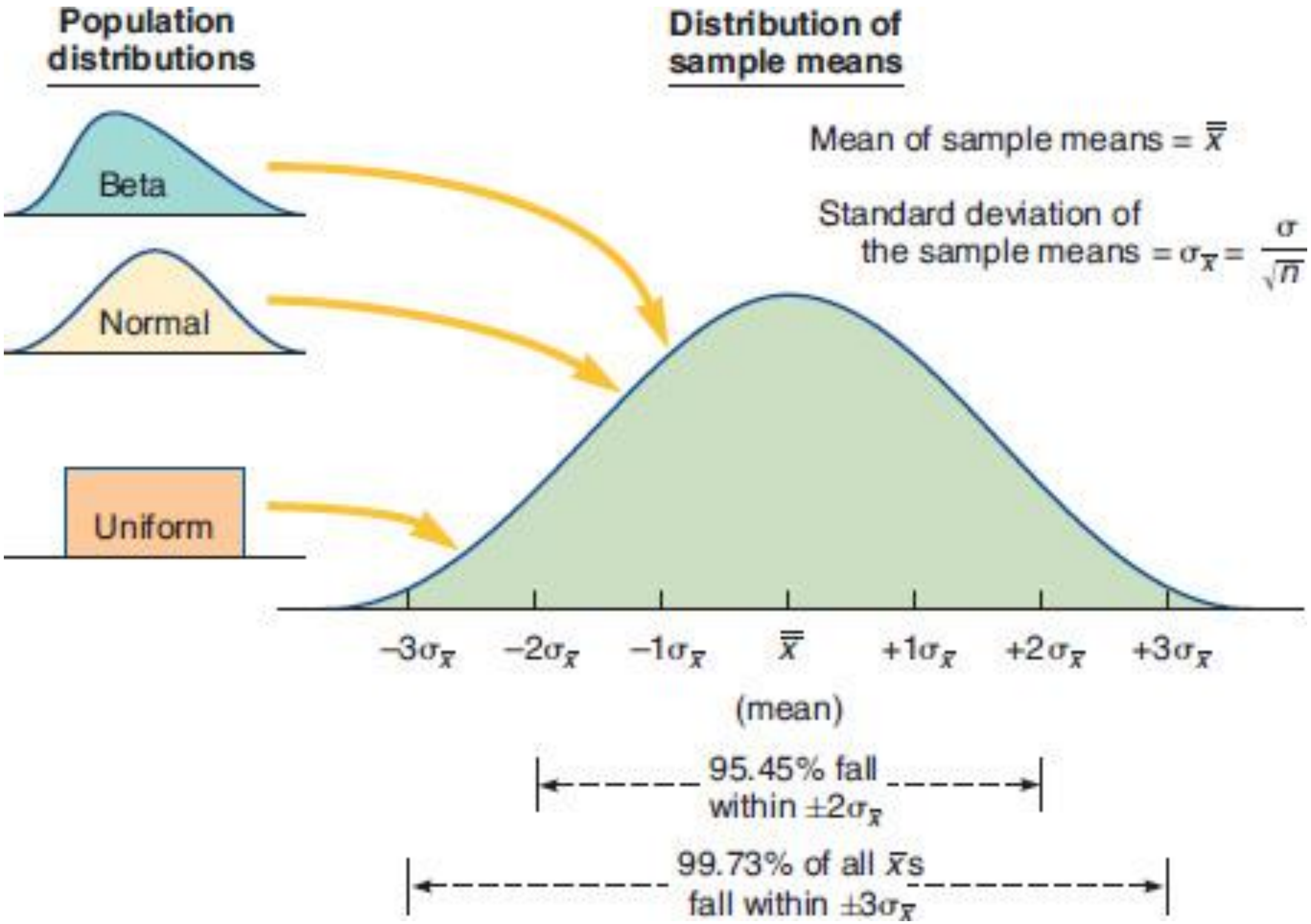
1) The mean of the sampling distribution will be the same as the population mean μ

$$\bar{\bar{x}} = \mu$$

2) The standard deviation of the sampling distribution $(\sigma_{\bar{x}})$ will equal the population standard deviation (σ) divided by the square root of the sample size, *n*

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

Population and Sampling Distributions



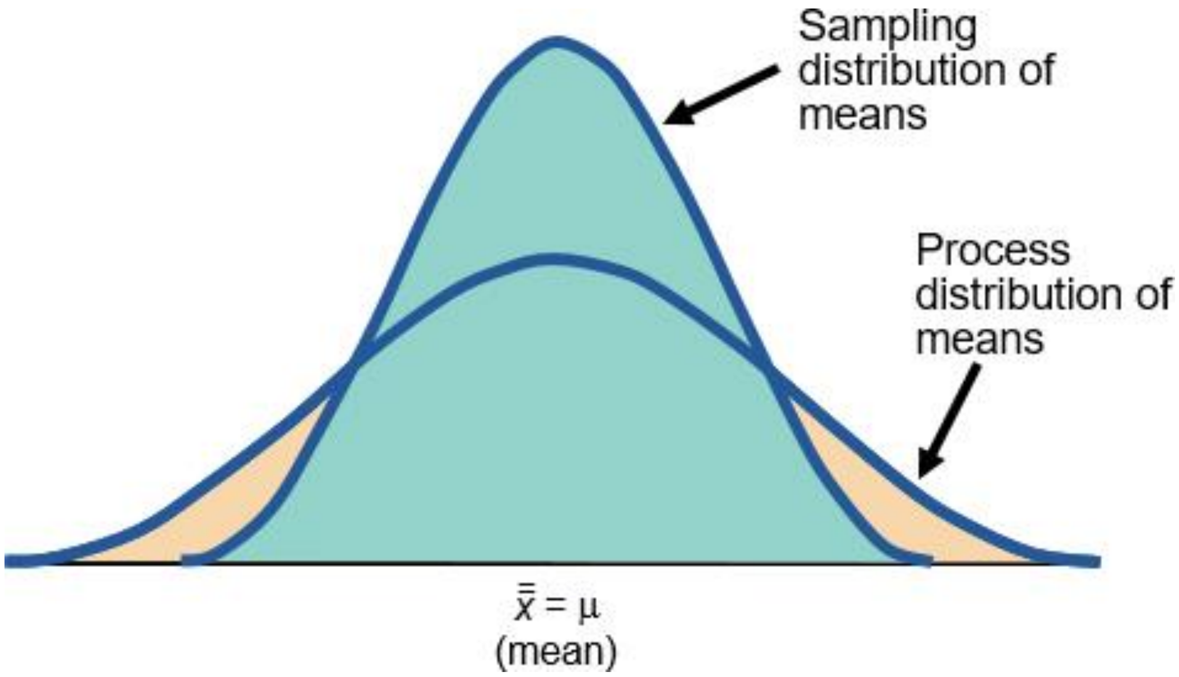
Mean of sample means = $\bar{\bar{x}}$

Standard deviation of the sample means = $\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$

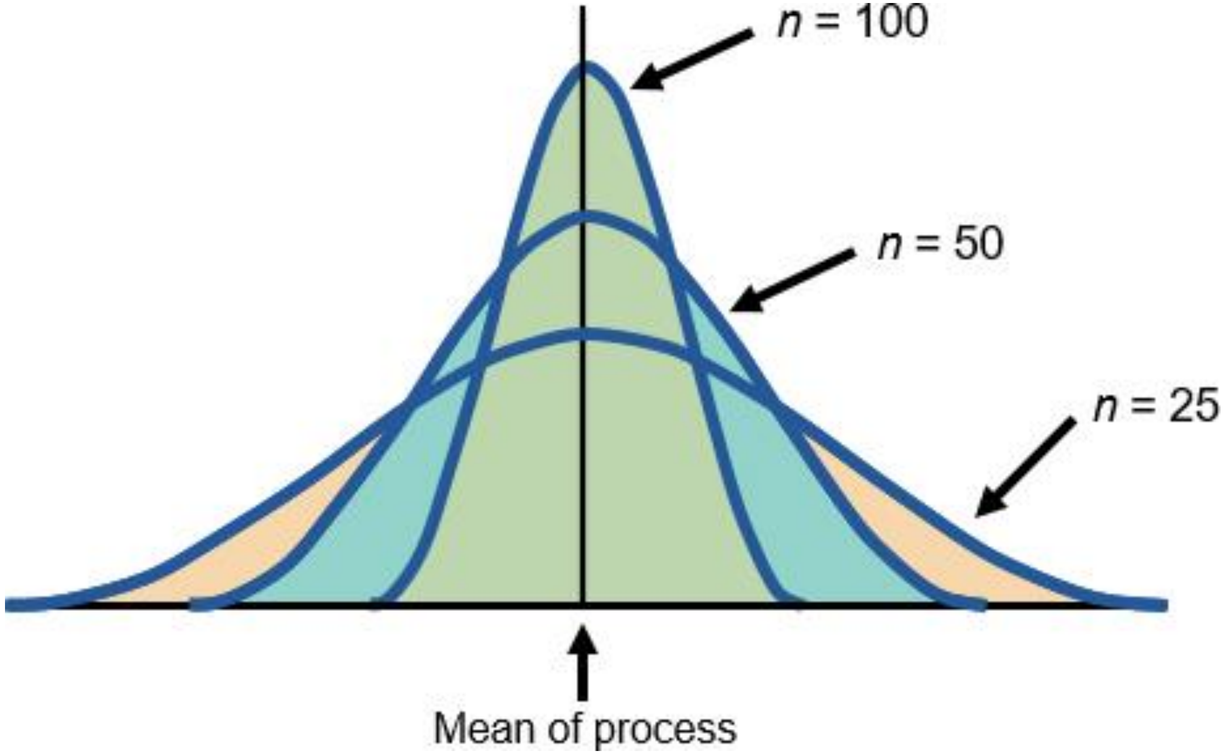
95.45% fall within $\pm 2\sigma_{\bar{x}}$

99.73% of all $\bar{x}$s fall within $\pm 3\sigma_{\bar{x}}$

Sampling Distribution



The Sampling Distribution of Means is Normal (a) The sampling distribution has less variability than the process distribution



The Sampling Distribution of Means is Normal (b) As the sample size increases, the sampling distribution narrows

Setting Chart Limits

For $\bar{x}$ -Charts when we know σ

$$\text{Upper control limit (UCL)} = \bar{\bar{x}} + z\sigma_{\bar{x}}$$

$$\text{Lower control limit (LCL)} = \bar{\bar{x}} - z\sigma_{\bar{x}}$$

Where

$\bar{\bar{x}}$ = mean of the sample means or a target value set for the process

z = number of normal standard deviations

σ_x = standard deviation of the sample means $= \dfrac{\sigma}{\sqrt{n}}$

σ = population (process) standard deviation

n = sample size

Example

Setting Control Limits for X-bar Chart

- Randomly select and weigh nine $(n = 9)$ boxes each hour

Average weight in the first sample $= \dfrac{17+13+16+18+17+16+15+17+16}{9} = 16.1 \text{ounces}$

Weight of Sample		Weight of Sample		Weight of Sample	
Hour	(Average of 9 Boxes)	Hour	(Average of 9 Boxes)	Hour	(Average of 9 Boxes)
1	16.1	5	16.5	9	16.3
2	16.8	6	16.4	10	14.8
3	15.5	7	15.2	11	14.2
4	16.5	8	16.4	12	17.3

Average mean
of 12 samples

$$= \left[\bar{\bar{x}} = \frac{\sum_{i=1}^{12} (\text{Avg of 9 boxes})}{12} \right]$$

$\bar{\bar{x}} = 16$ ounces

$n = 9$

$z = 3$

$\sigma = 1$ ounce

Number
of samples $= 12$

Average mean of 12 samples

$$= \left[\bar{\bar{x}} = \frac{\sum_{i=1}^{12} (\text{Avg of 9 boxes})}{12} \right]$$

$\bar{\bar{x}} = 16$ ounces

$n = 9$

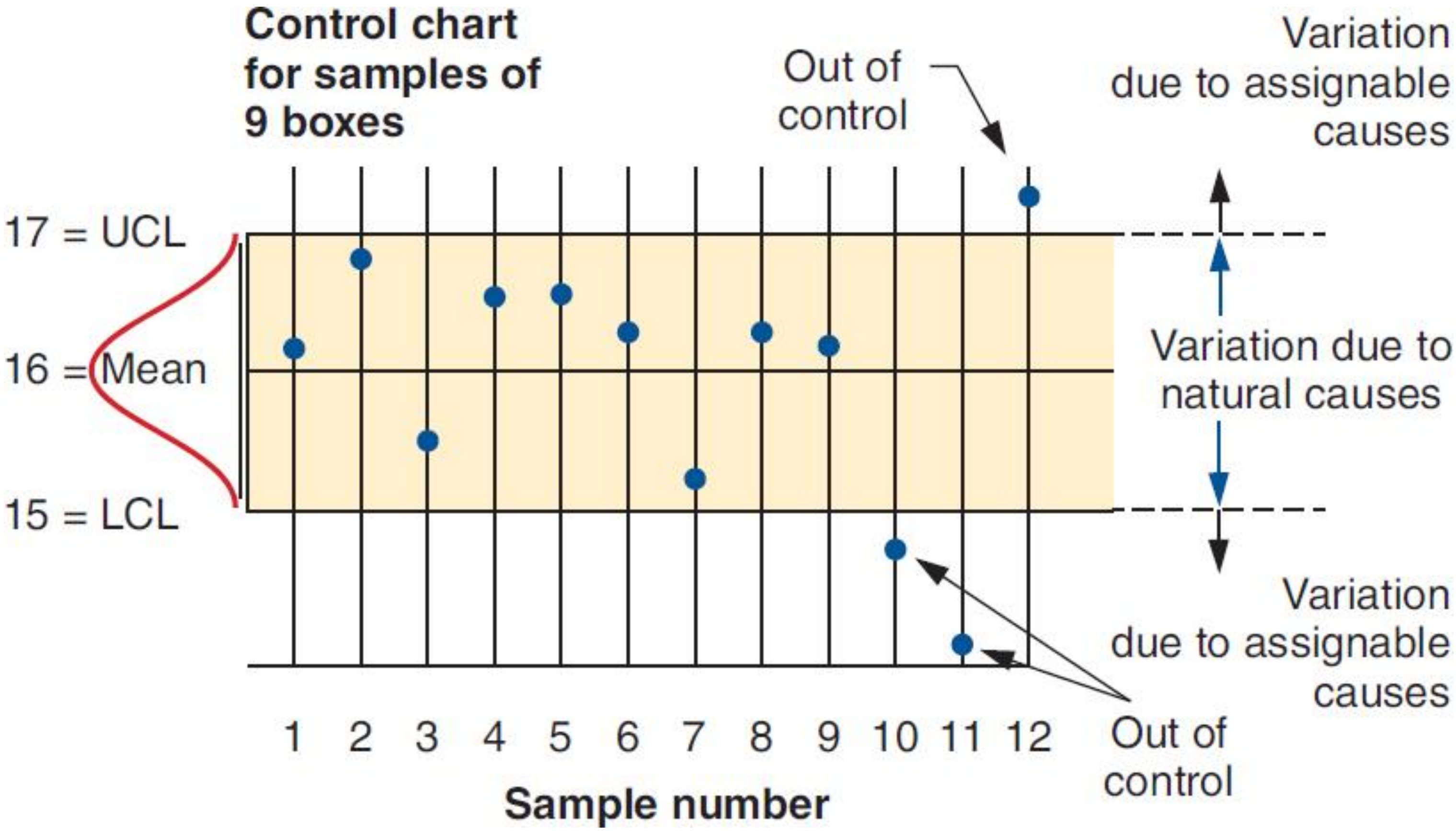
$z = 3$

$\sigma = 1$ ounce

Number of samples $= 12$

$$\text{UCL}_{\bar{x}} = \bar{\bar{x}} + z\sigma_{\bar{x}} = 16 + 3\left(\frac{1}{\sqrt{9}}\right) = 16 + 3\left(\frac{1}{3}\right) = 17 \text{ ounces}$$

$$\text{LCL}_{\bar{x}} = \bar{\bar{x}} - z\sigma_{\bar{x}} = 16 - 3\left(\frac{1}{\sqrt{9}}\right) = 16 - 3\left(\frac{1}{3}\right) = 15 \text{ ounces}$$


Control chart
for samples of
9 boxes
Out of
control
Variation
due to assignable
causes
17 = UCL
16 = Mean
15 = LCL
Variation due to
natural causes
Variation
due to assignable
causes
1 2 3 4 5 6 7 8 9 10 11 12
Out of
control
Sample number

For $\bar{X}$ - Charts when we don't know σ

$$\mathrm{UCL}_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R}$$

$$\mathrm{LCL}_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R}$$

where $\bar{R} = \dfrac{\sum_{i=1}^{k} R_i}{k} =$ average range of the samples

$A_2 =$ control chart factor found in Table of control chart factors

$\bar{\bar{x}} =$ mean of the sample means

$R_i =$ range for sample *i*

$k =$ total number of samples

Table: Control Chart Factors

Factors for Computing Control Chart Limits (3 sigma)

Sample Size, *n*	**Mean Factor,** A_2	**Upper Range,** D_4	**Lower Range,** D_3
2	1.880	3.268	0
3	1.023	2.574	0
4	.729	2.282	0
5	.577	2.115	0
6	.483	2.004	0
7	.419	1.924	0.076
8	.373	1.864	0.136
9	.337	1.816	0.184
10	.308	1.777	0.223
12	.266	1.716	0.284

Example

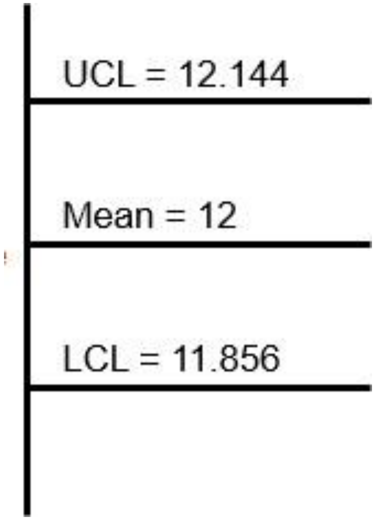
Super Cola example labeled as “net weight 12 ounces”

Process average = 12 ounces Average range = .25 ounces Sample size = 5

$$
\begin{aligned}
\text{UCL}_{\bar{x}} &= \bar{\bar{x}} + A_2\bar{R} \\
&= 12 + (.577)(.25) \\
&= 12 + .144 \\
&= 12.144 \text{ ounces}
\end{aligned}
$$

From Table

$$
\begin{aligned}
\text{LCL}_{\bar{x}} &= \bar{\bar{x}} - A_2\bar{R} \\
&= 12 - .144 \\
&= 11.856 \text{ ounces}
\end{aligned}
$$



R – Chart

- Type of variables control chart
- Shows sample ranges over time
  - Difference between smallest and largest values in sample
- Monitors process variability
- Independent from process mean

Setting Chart Limits

For *R*-Charts

$$\text{Upper control limit } (\text{UCL}_R) = D_4\bar{R}$$

$$\text{Lower control limit } (\text{LCL}_R) = D_3\bar{R}$$

where

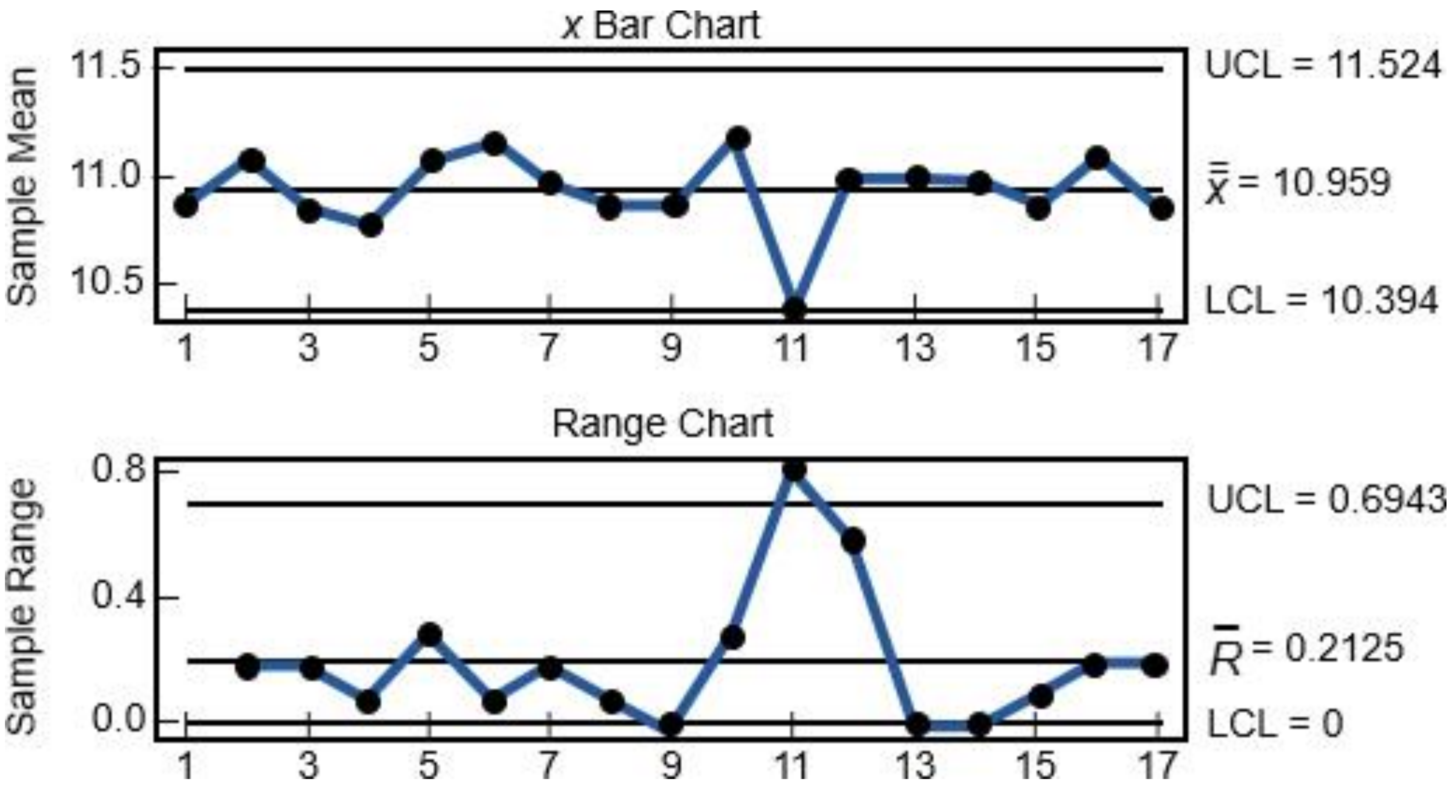
UCL_R = upper control limit for the range

LCL_R = lower control limit for the range

D_4 and D_3 = values from Table of control chart factors

Example: Restaurant Control Limits

For salmon fillets at Darden Restaurants



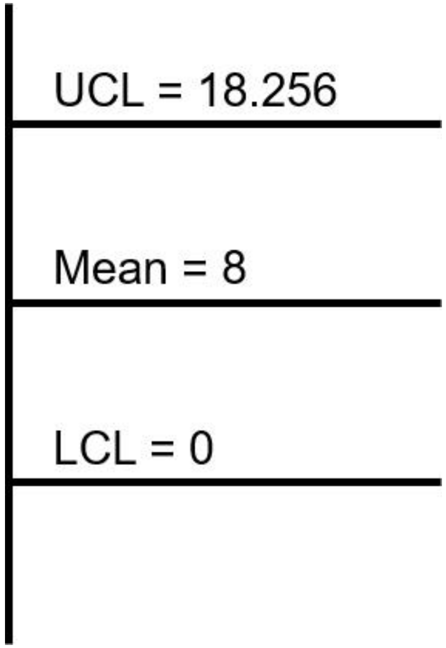
Average range = 8 minutes

Sample size = 4

From Table S6.1 $D_4 = 2.282$, $D_3 = 0$

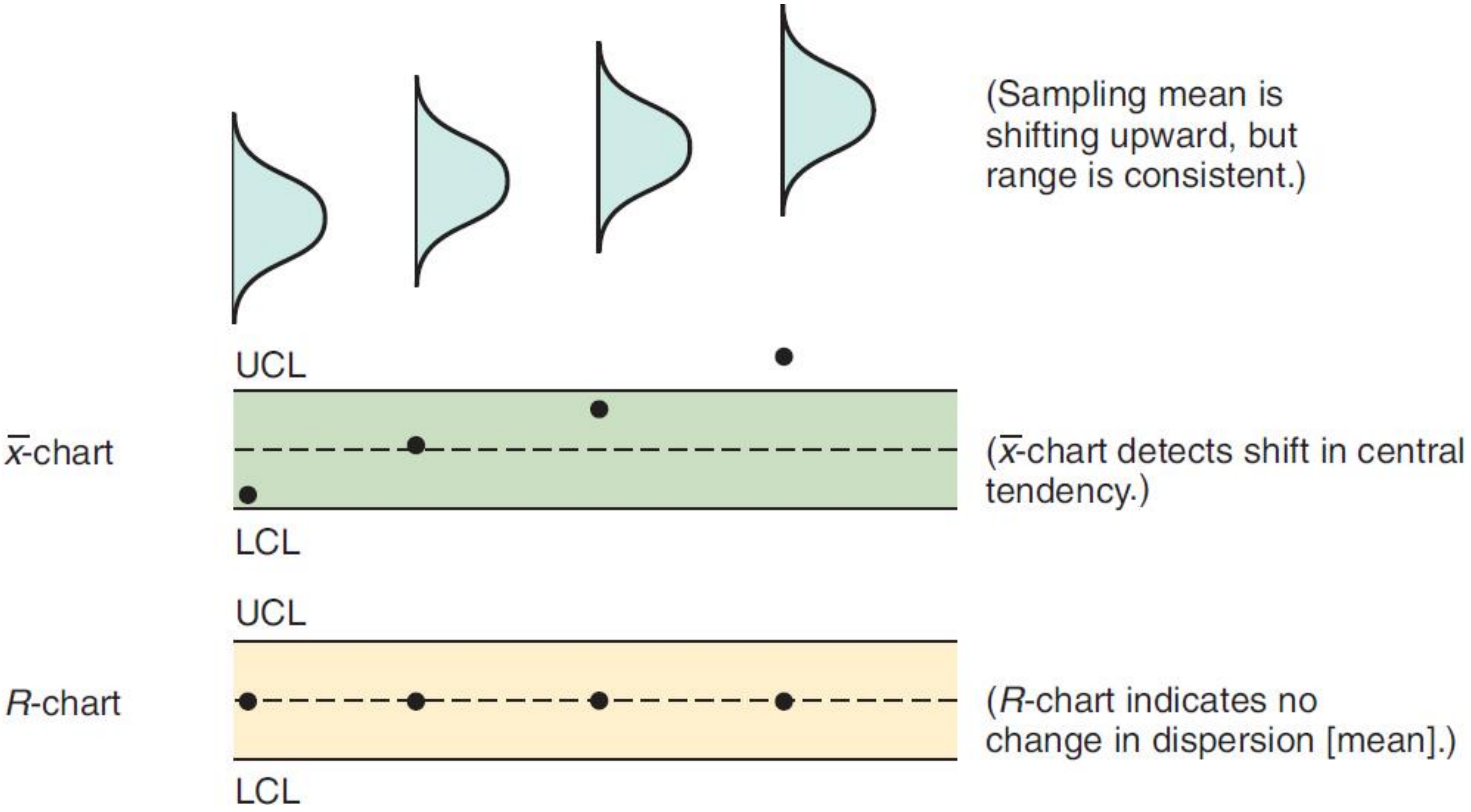
$$
\begin{aligned}
\text{UCL}_R &= D_4\bar{R} \\
&= (2.282)(8) \\
&= 18.256 \text{ minutes}
\end{aligned}
$$

$$
\begin{aligned}
\text{LCL}_R &= D_3\bar{R} \\
&= (0)(8) \\
&= 0 \text{ minutes}
\end{aligned}
$$

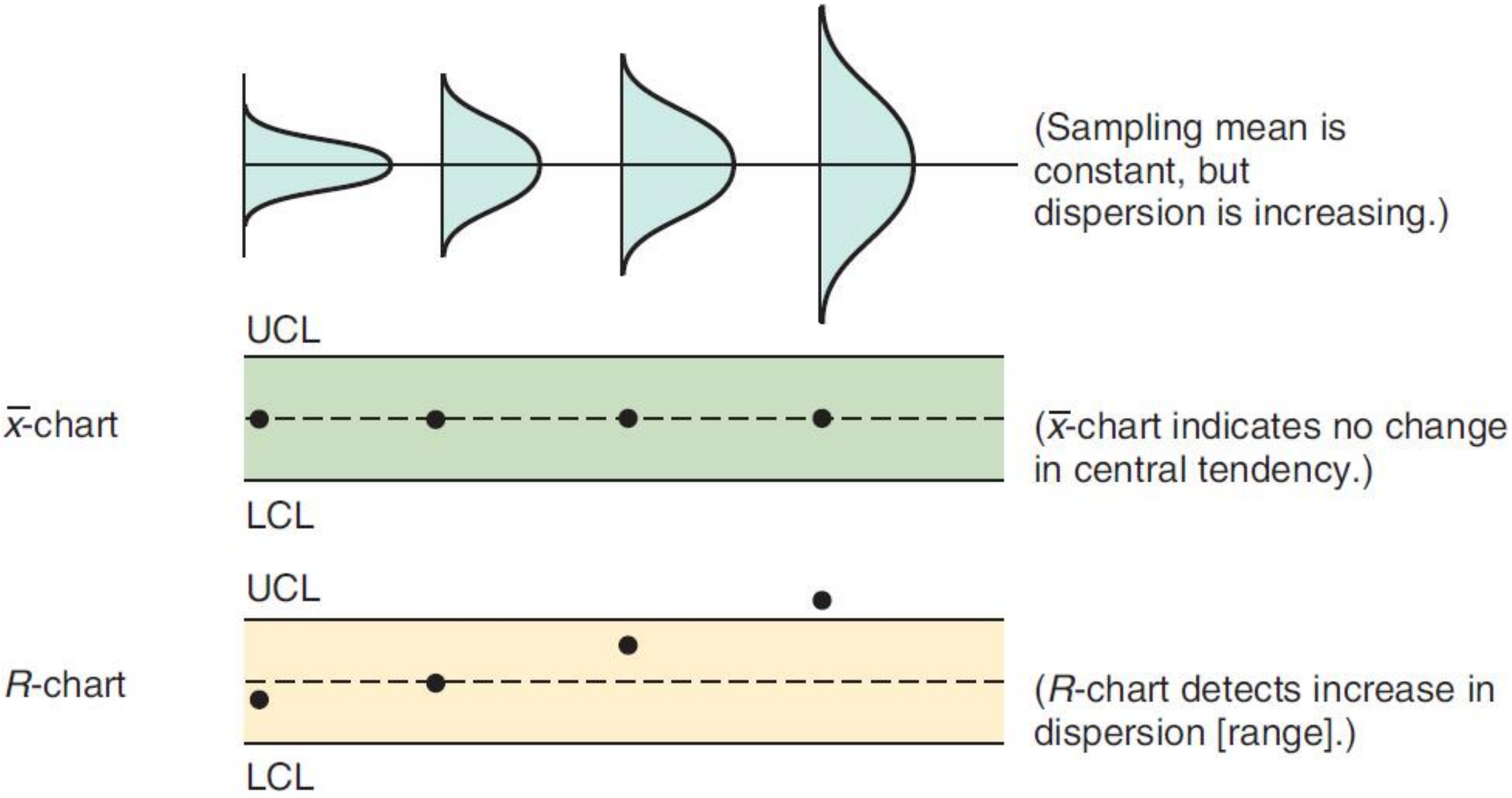


Mean and Range Charts

(a) These sampling distributions result in the charts below



(b) These sampling distributions result in the charts below



Steps in Building Control Charts

1. Collect 20 to 25 samples, often of n = 4 or n = 5 observations each, from a stable process, and compute the mean and range of each

2. Compute the overall means $\bar{\bar{x}}$ and $\bar{R}$, set appropriate control limits, usually at the 99.73% level, and calculate the preliminary upper and lower control limits

- **If the process is not currently stable and in control**, use the desired mean, μ, instead of $\bar{\bar{x}}$ to calculate limits.

3. Graph the sample means and ranges on their respective control charts and determine whether they fall outside the acceptable limits

4. Investigate points or patterns that indicate the process is out of control – try to assign causes for the variation, address the causes, and then resume the process

5. Collect additional samples and, if necessary, revalidate the control limits using the new data

Setting Other Control Limits

Common *z* Values

Desired Control Limit (%)	Z-Value (Standard Deviation Required for Desired Level of Confidence)
90.0	1.65
95.0	1.96
95.45	2.00
99.0	2.58
99.73	3.00

Control Charts for Attributes

- For variables that are categorical
  - **Defective/ nondefective**, good/ bad, yes/no, acceptable/unacceptable
- Measurement is typically counting defectives
- Charts may measure

1. **Percent** defective (*p*-chart)
2. **Number** of defects (*c*-chart)

Control Limits for p-Charts

Population will be a binomial distribution, but applying the central limit theorem allows us to assume a normal distribution for the sample statistics

$$\text{UCL}_p = \bar{p} + z\sigma_p$$
$$\text{LCL}_p = \bar{p} - z\sigma_p$$

σ_p is estimated by

$$\hat{\sigma}_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

where

$\bar{p} =$ mean fraction (percent) defective in the samples

$z =$ number of standard deviations

$\sigma_p =$ standard deviation of the sampling distribution

$n =$ number of observation in **each** sample

Example: p-Chart for Data Entry

Sample Number	**Number Of Errors**	**Fraction Defective**	**Sample Number**	**Number Of Errors**	**Fraction Defective**
1	6	.06	11	6	.06
2	5	.05	12	1	.01
3	0	.00	13	8	.08
4	1	.01	14	7	.07
5	4	.04	15	5	.05
6	2	.02	16	4	.04
7	5	.05	17	11	.11
8	3	.03	18	3	.03
9	3	.03	19	0	.00
10	2	.02	20	4	.04
				80	

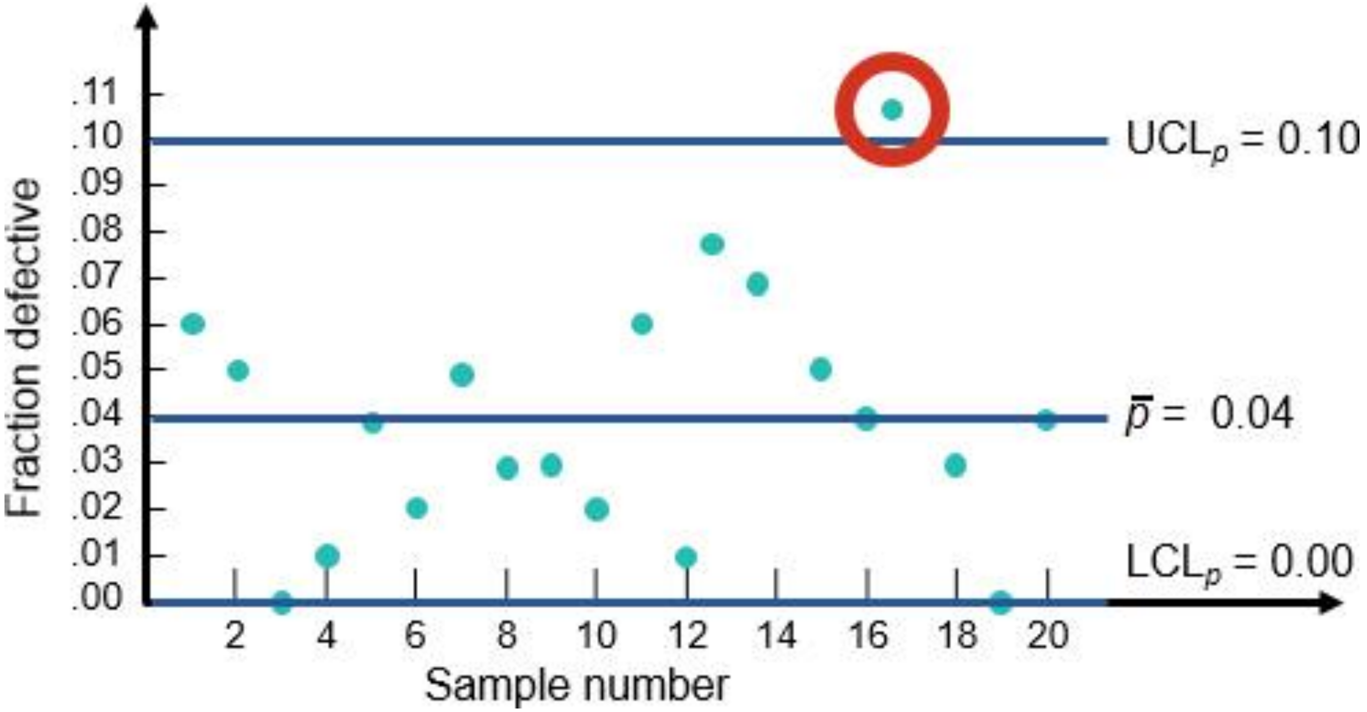
$$\bar{p} = \frac{\text{Total number of errors}}{\text{Total number of records examined}} = \frac{80}{(100)(20)} = .04$$

$$\hat{\sigma}_p = \sqrt{\frac{(.04)(1-.04)}{100}} = .02 \text{ (rounded up from .0196)}$$

$$\text{UCL}_p = \bar{p} + z\hat{\sigma}_p = .04 + 3(.02) = .10$$

$$\text{LCL}_p = \bar{p} - z\hat{\sigma}_p = .04 - 3(.02) = 0$$

(because we cannot have a negative percent defective)



Possible assignable causes present

Control Limits for c-Charts

Population will be a Poisson distribution, but applying the central limit theorem allows us to assume a normal distribution for the sample statistics

$\bar{c}$ = mean number of defects per unit

$\sqrt{\bar{c}}$ = standard deviation of defects per unit

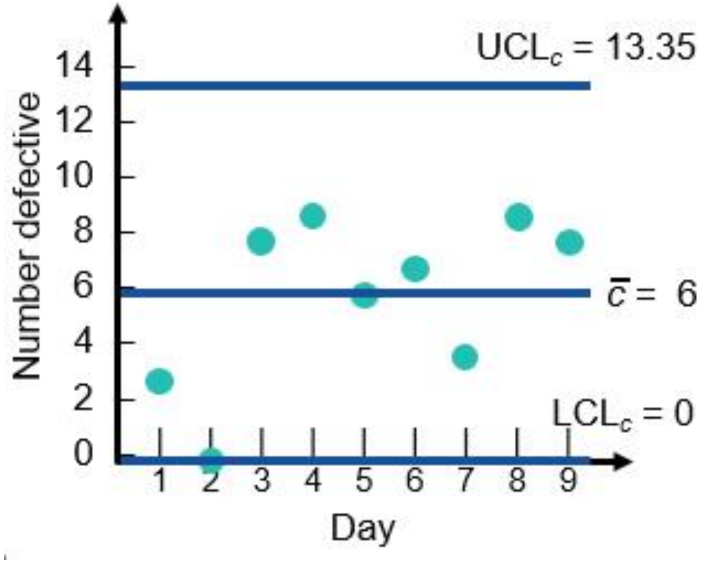
$$\text{Control limits (99.73\%)} = \bar{c} \pm 3\sqrt{\bar{c}}$$

Example: c-Chart for Cab Company

$$\bar{c} = \text{54 complaints / 9 days} = \text{6 complaints / day}$$

$$\begin{aligned}\text{UCL}_c &= \bar{c} + 3\sqrt{\bar{c}} \\ &= 6 + 3\sqrt{6} \\ &= 13.35\end{aligned}$$

$$\begin{aligned}\text{LCL}_c &= \bar{c} - 3\sqrt{\bar{c}} \\ &= 6 - 3\sqrt{6} \\ &= 0\end{aligned}$$



Cannot be a negative number

Managerial Issues and Control Charts

Three major management decisions:

- Select points in the processes that need SPC
- Determine the appropriate charting technique
- Set clear and specific SPC policies and procedures

Which Control Chart to Use

Helping You Decide Which Control Chart to Use

Variable Data Using an $\bar{x}$ -Chart and *R*-chart

1. Observations are **variables**
2. Collect 20 – 25 samples of *n* = 4, or *n* = 5, or more, each from a stable process and compute the mean for the -chart and $\bar{x}$ range for the *R*-chart
3. Track samples of *n* observations

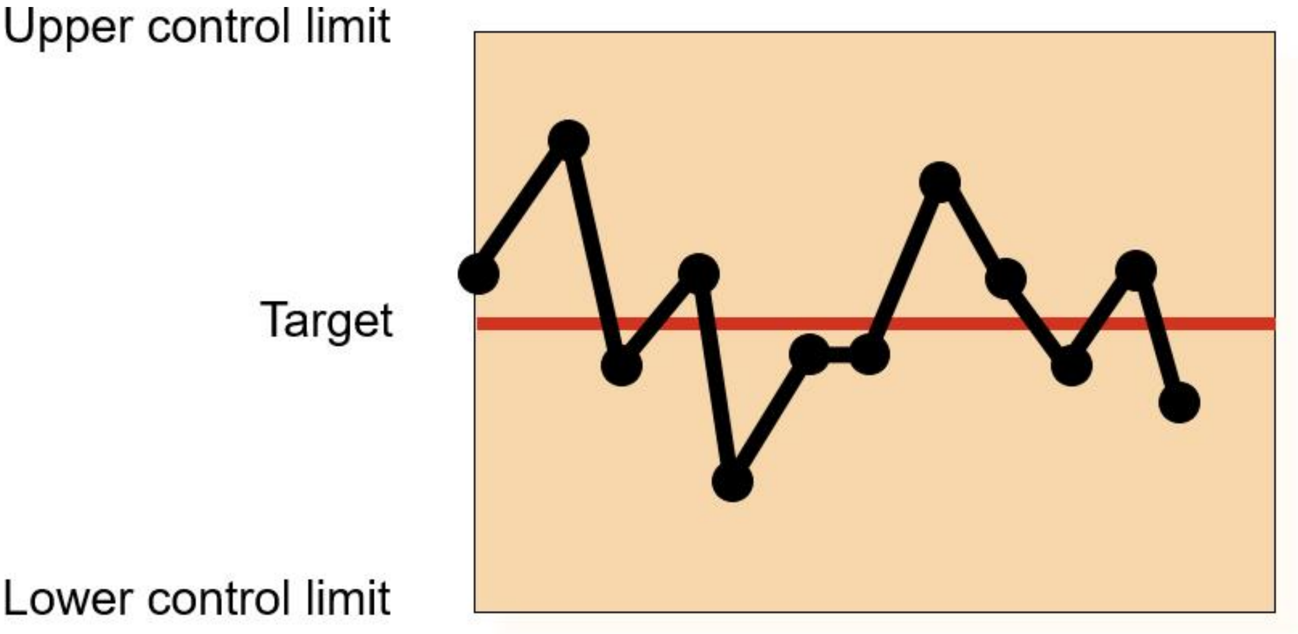
Attribute Data Using a P-Chart

1. Observations are **attributes** that can be categorized as good or bad (or pass–fail, or functional–broken), that is, in two states
2. We deal with fraction, proportion, or percent defectives
3. There are several samples, with many observations in each

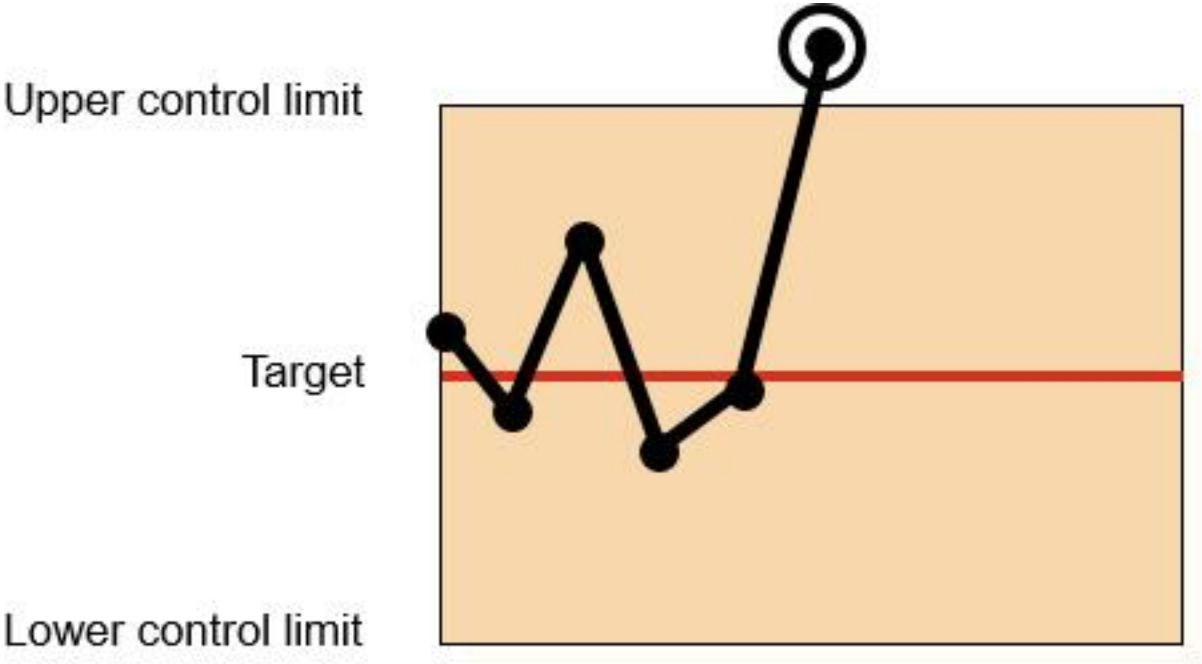
Attribute Data Using a C-Chart

1. Observations are **attributes** whose defects per unit of output can be counted
2. We deal with the number counted, which is a small part of the possible occurrences
3. Defects may be: number of blemishes on a desk; flaws in a bolt of cloth; crimes in a year; broken seats in a stadium; typos in a chapter of this text; or complaints in a day

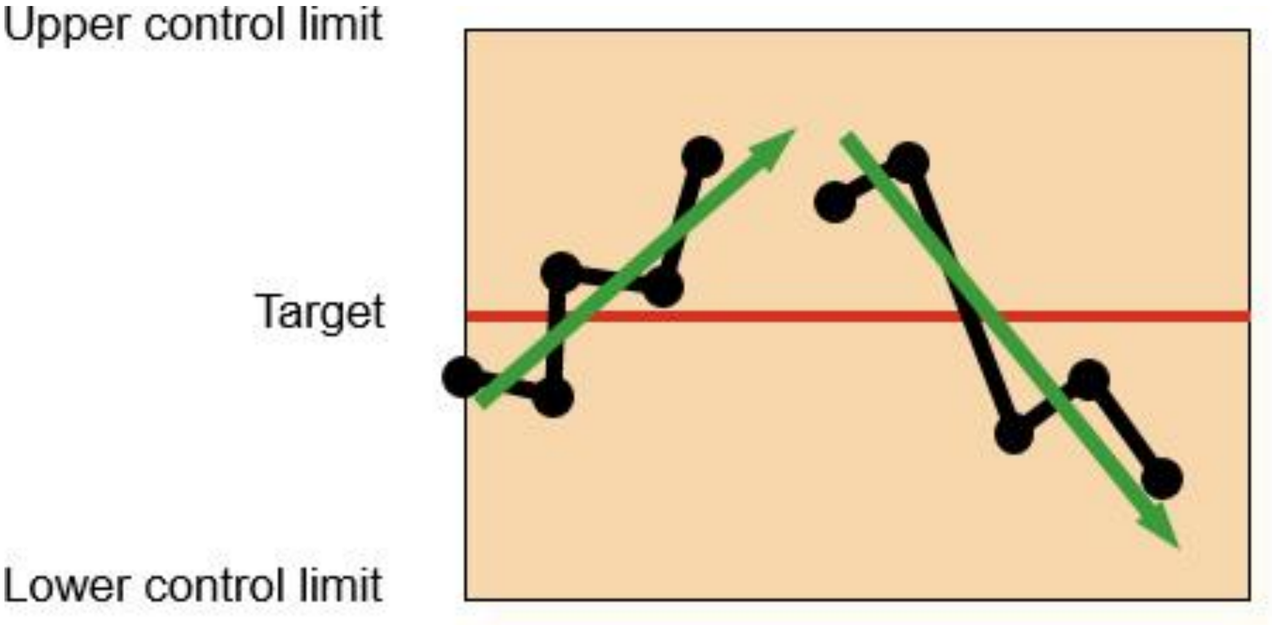
Patterns in Control Charts



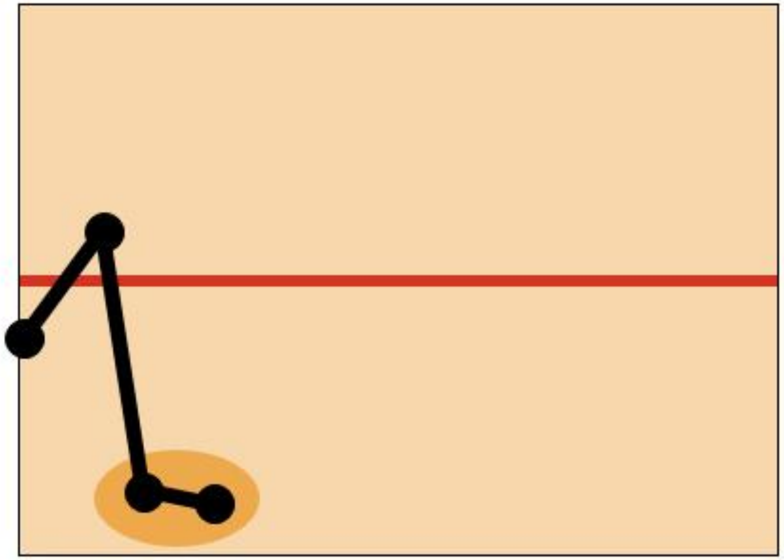
Normal behavior. Process is "in control."



One plot out above (or below). Investigate for cause. Process is "out of control."



Trends in either direction, 5 plots. Investigate for cause of progressive change.

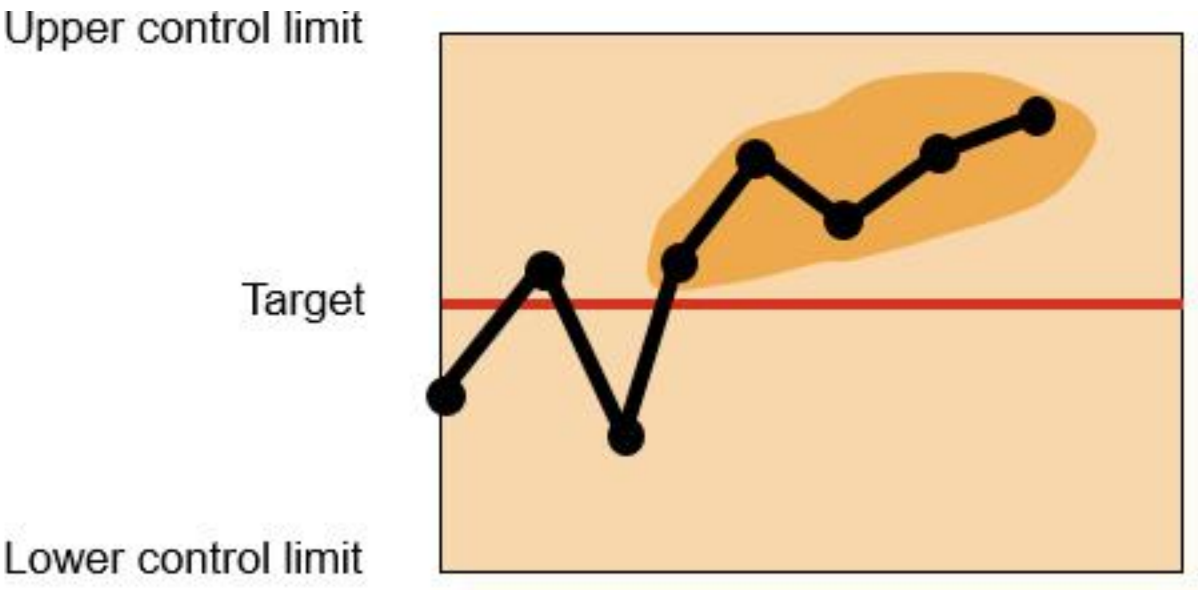


Upper control limit

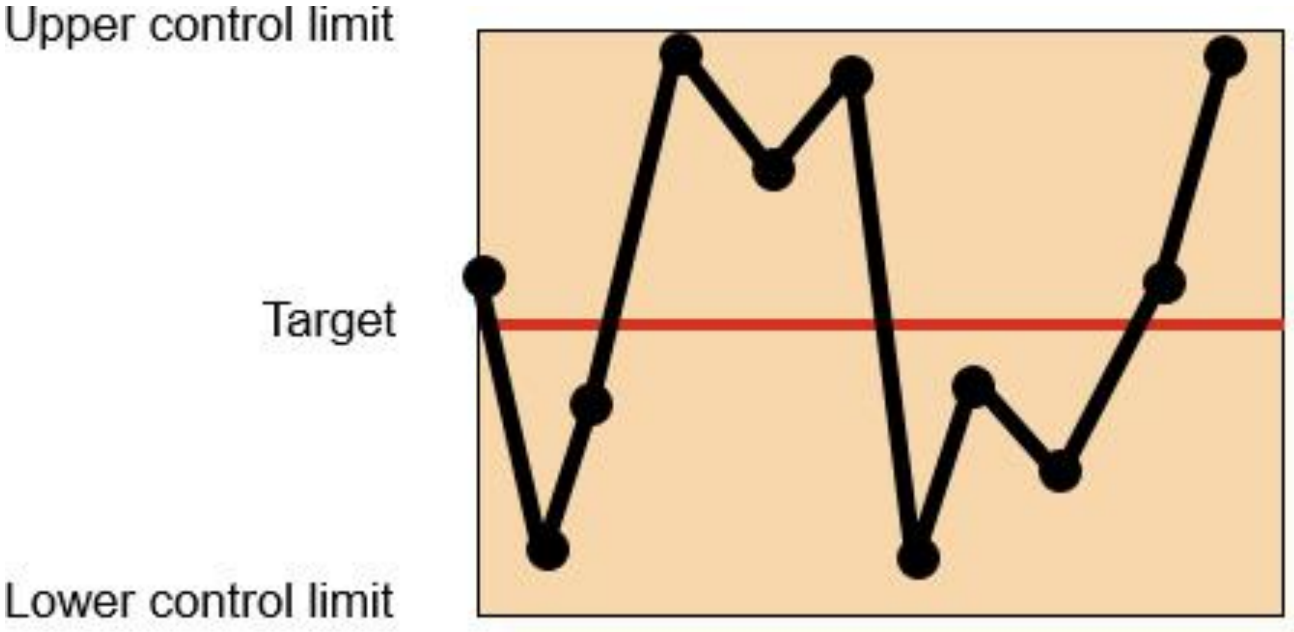
Target

Lower control limit

Two plots very near lower (or upper) control. Investigate for cause.



Run of 5 above (or below) central line. Investigate for cause.



Erratic behavior. Investigate.

Patterns in Control Charts

- **Run test**
  - Identify abnormalities in a process
  - Runs of 5 or 6 points above or below the target or centerline suggest assignable causes may be present
  - Process may not be in statistical control
  - There are a variety of run tests

Process Capability

- The natural variation of a process should be small enough to produce products that meet the standards required
- A process in statistical control does not necessarily meet the design specifications
- **Process capability** is a measure of the relationship between the natural variation of the process and the design specifications

Process Capability Ratio

$$C_P = \frac{\text{Upper Specification} - \text{Lower Specification}}{6\sigma}$$

- A capable process must have a C_p of at least 1.0
- Does not look at how well the process is centered in the specification range
- Often a target value of $C_p = 1.33$ is used to allow for off-center processes
- Six Sigma quality requires a $C_p = 2.0$

Insurance claims process

Process mean $\bar{x} = 210.0$ minutes

Process standard deviation $\sigma = .516$ minutes

Design specification $= 210 \pm 3$ minutes

$$\mathrm{C_p} = \frac{\text{Upper Specification} - \text{Lower Specification}}{6\sigma}$$

Insurance claims process

Process mean $\bar{x} = 210.0$ minutes

Process standard deviation $\sigma = .516$ minutes

Design specification $= 210 \pm 3$ minutes

$$C_p = \frac{\text{Upper Specification} - \text{Lower Specification}}{6\sigma}$$

$$= \frac{213 - 207}{6(.516)} = 1.938$$

Process is capable

$$\mathrm{C_{pk}} = \text{minimum of}\left[\left(\frac{\text{Upper Specification Limit} - \bar{\mathrm{x}}}{3\sigma}\right), \left(\frac{\bar{\mathrm{x}} - \text{Upper Specification Limit}}{3\sigma}\right)\right]$$

- A capable process must have a $\mathrm{C_{pk}}$ of at least 1.0
- A capable process is not necessarily in the center of the specification, but it falls within the specification limit at both extremes

New Cutting Machine

New process mean $\bar{x} = .250$ inches

Process standard deviation $\sigma = .0005$ inches

Upper Specification Limit = .251 inches

Lower Specification Limit = .249 inches

$$C_{pk} = \text{minimum of} \left(\frac{(.251) - .250}{(3).0005} \right),$$

New Cutting Machine

New process mean $\bar{x} = .250$ inches

Process standard deviation $\sigma = .0005$ inches

Upper Specification Limit = .251 inches

Lower Specification Limit = .249 inches

$$C_{pk} = \text{minimum of} \left(\frac{(.251) - .250}{(3).0005} \right), \left(\frac{.250 - (.249)}{(3).0005} \right)$$

Process Capability Index

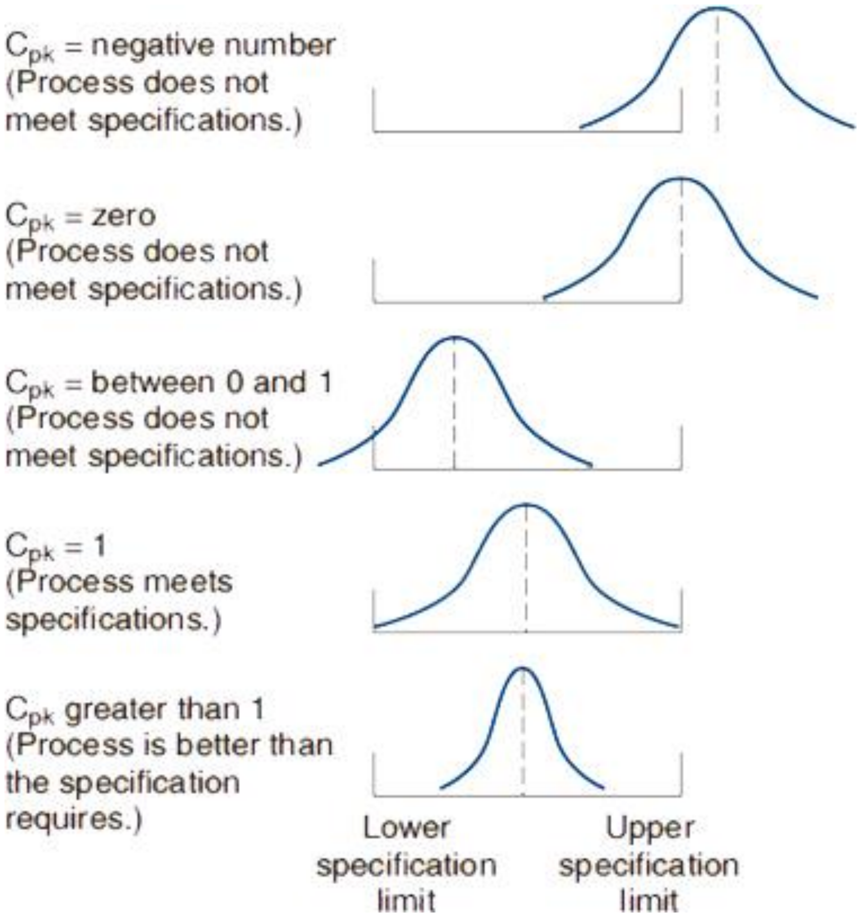
Both calculations result in

$$C_{pk} = \frac{.001}{.0015} = \boxed{0.67}$$

New machine is NOT capable

Interpreting Cpk

Meanings of C_{pk} Measures



Automated Inspection

- Modern technologies allow virtually 100% inspection at minimal costs
- Not suitable for all situations

Practice Problems

P.1)

The overall average on a process you are attempting to monitor is 100 units. The process population standard deviation is 3.44. Determine the upper and lower control limits for a mean chart, if you choose to use a sample size of 5.

a) Set $z = 3$.

b) Now set $z = 2$. How do the control limits change?

P.2)

A traffic police person is checking wether cars have recently mandated smart numbers plates or not at a busy road crossing. He is checking 200 cars as targeting reporting how many cars do not have smart number plates. The sample size is fixed at n=200 each day. Sample data for the last 10 days are shown in the following table:

Day	Cars without Smart Number Plates
1	16
2	15
3	12
4	17
5	20
6	13
7	18
8	16
9	10
10	19

(a) Estimate overall proportion of cars without smart number plates and the standard deviation of proportions,

(b) Calculate the LCL and UCL for ±3σ limits

P.3)

Poster Banner Shop wishes to monitor the blemishes count in the painted posters of big size. Develop a 3-sigma *c*-chart for the painting process, suggest that the process is under control. Blemish count data for sample posters are as follow:

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

Case Study

Teleplast company (hypothetical name) is one of the leading manufacturing companies of “plastic injection moulding parts” for the telecommunication market. With the increase in competition in telecommunication product supplier market, the company is planning to reduce cost and simultaneously provide better quality products in order to achieve higher profits. As a result, the company is planning to design and implement a quality improvement program.

Quality improvement for the company also aims at improving the productivity and reducing the rejection rate. The quality improvement should be focused on both the internal and external customers. In order to appropriately design the quality improvement program, the company’s Sr. Manager Ravi decided to personally have look on the number of defective parts. In the previous 30 weeks, Ravi took a random sample of 200 plastic injection moulded parts in each week for determining the rejection rates. The table given below indicates the number of defective parts obtained each week through the sample:

Sample Week	Defective Lenses	Sample Week	Defective Lenses	Sample Week	Defective Lenses
1	5	11	10	21	2
2	10	12	4	22	5
3	1	13	3	23	3
4	0	14	5	24	6
5	7	15	2	25	11
6	6	16	7	26	7
7	12	17	1	27	9
8	11	18	1	28	3
9	3	19	12	29	0
10	2	20	13	30	1

Questions

1. Using 95% confidence level, plot the overall percentage of defective parts (p) and upper and lower control limits on a control chart.
2. Plot the percentage of defective lenses in each sample. Do all the samples fall within the control limits of Teleplast. What should be done when one falls outside the control limits.
3. What should be reported by Ravi about the quality of production?


Thank You!