Construction Quality and Safety management..........(7hrs)

- <u>Quality assurance & control</u>:
  - key aspects , Quality Assurance Policy, **use of manuals and checklists for quality control(Typical checklist for concreting, formwork and reinforcement activity), role of inspection,**
  - Introduction to TQM, quality audit, cost of quality, ISO standards

Statistical Quality Control

- Fundamentals of statistical terms
- Acceptance Sampling
- Control Charts

Few fundamentals of Descriptive Statistics

- **Mean** - It is arithmetic average of all observations.
- **Mid-range** - It is mid-point between the highest & lowest observations.
- **Mode** -It is most commonly occurring observations.
- **Median** - It is the middle observation when all observations are arranged in order of magnitude

Means , medians & Mode are useful when

- We talk about bowling average.
- Average income of India is up.
- Average age of our team is 28.

But they don,t tell the whole story.

They give some reference of centering but we need to determine how the numbers are spread.

- Are same runs scored in every over?
- Are all incomes higher?
- Is age of every player same?

- Statistics help us describe understand variability.

Spread

Spread is how far apart the ends of the group are.

- Bowling average

4, 2 , 6 , 0 , 3 , 5 , 2 , 1 , 3 , 4

Average / mean = 3 Spread = 6

- Income Rs.

400, 200 , 660 , 90 , 300 , 250 , 100 , 300 , 480 ,180

Average / Mean = 296 Spread=570

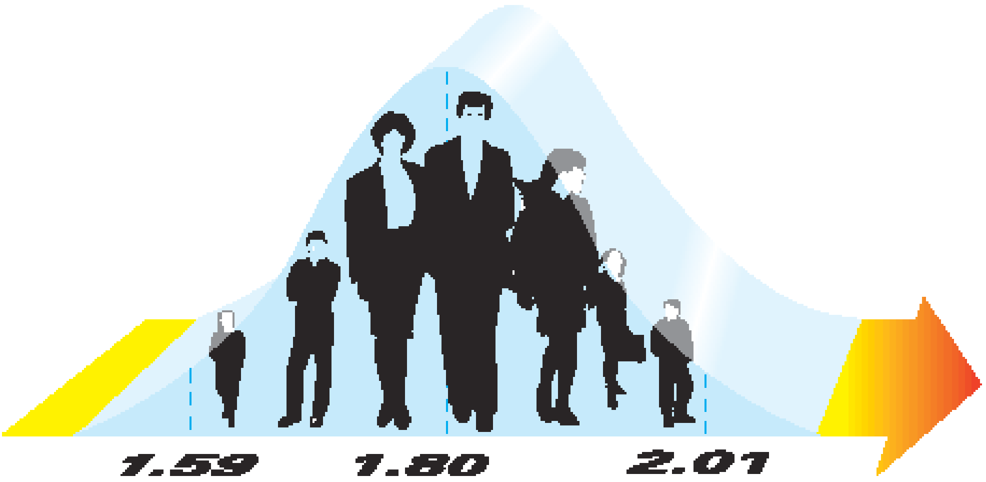
Another term that relates spread is S.D.

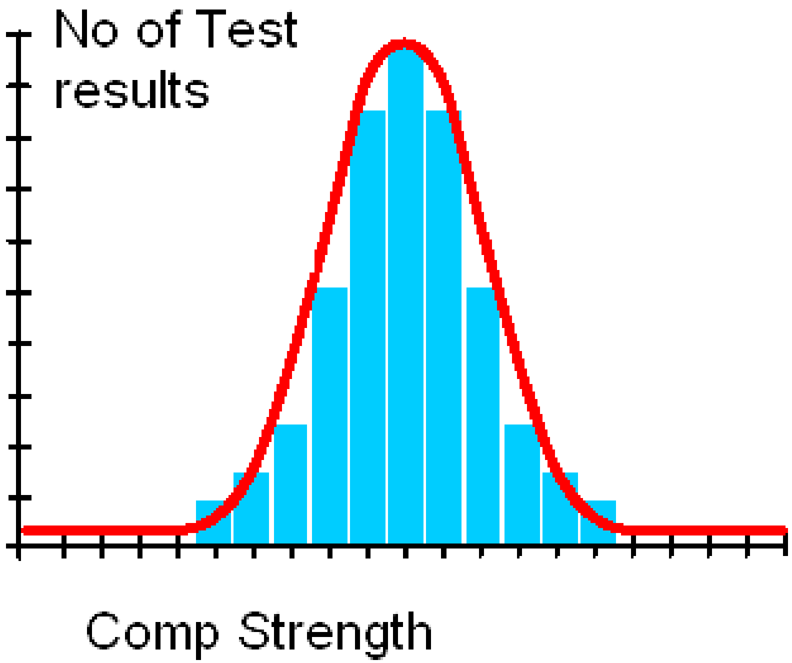
Standard deviation (ó) :

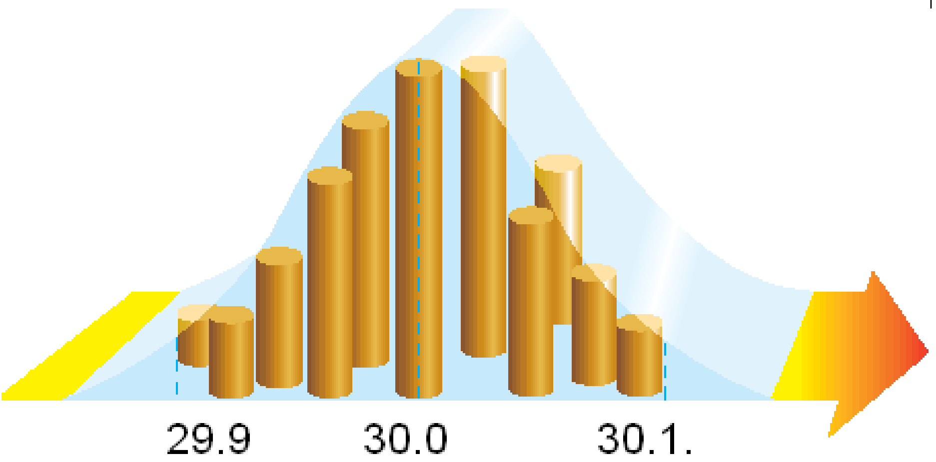
- The amount by which each reading is most likely to deviate from the average . “Or” how far a known percentage of the distribution lies from the mean.
- What is the practical use of standard deviation?
  1. Mean tells us the average value of the distribution and standard deviation indicates the scatter.
  2. We can use it to estimate how many of our values will come within a certain range.

Normal Distribution

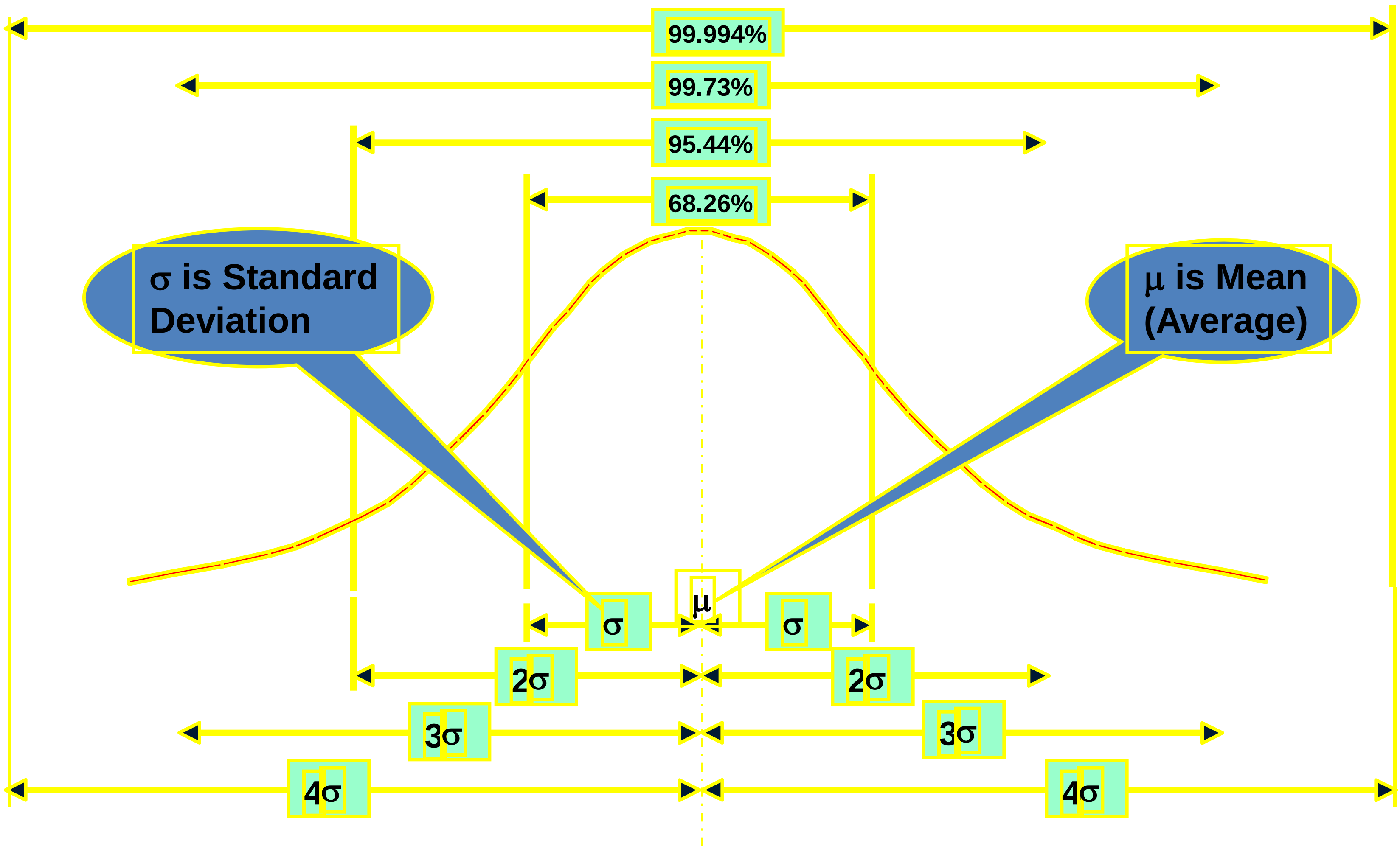
❖The height of people is one example.
❖ Another example can be if you try to cut off sticks to the same length.

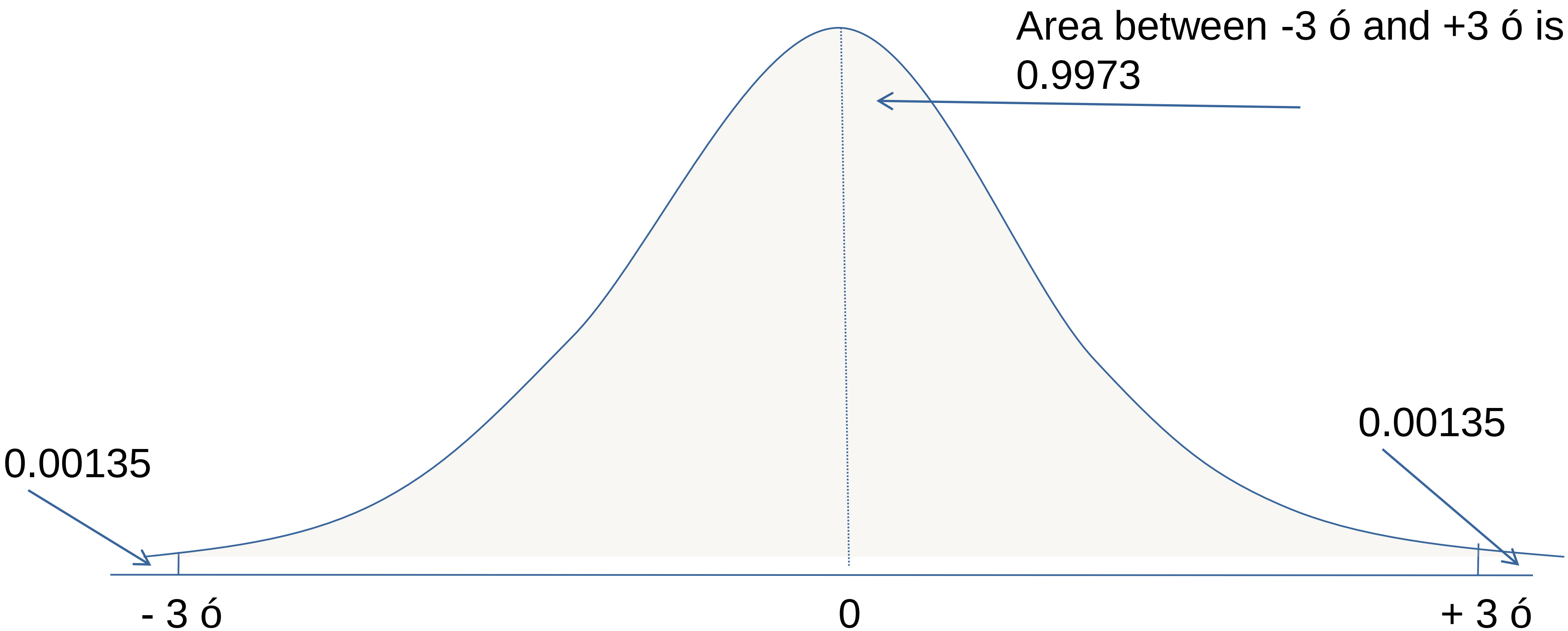






Normal Distribution



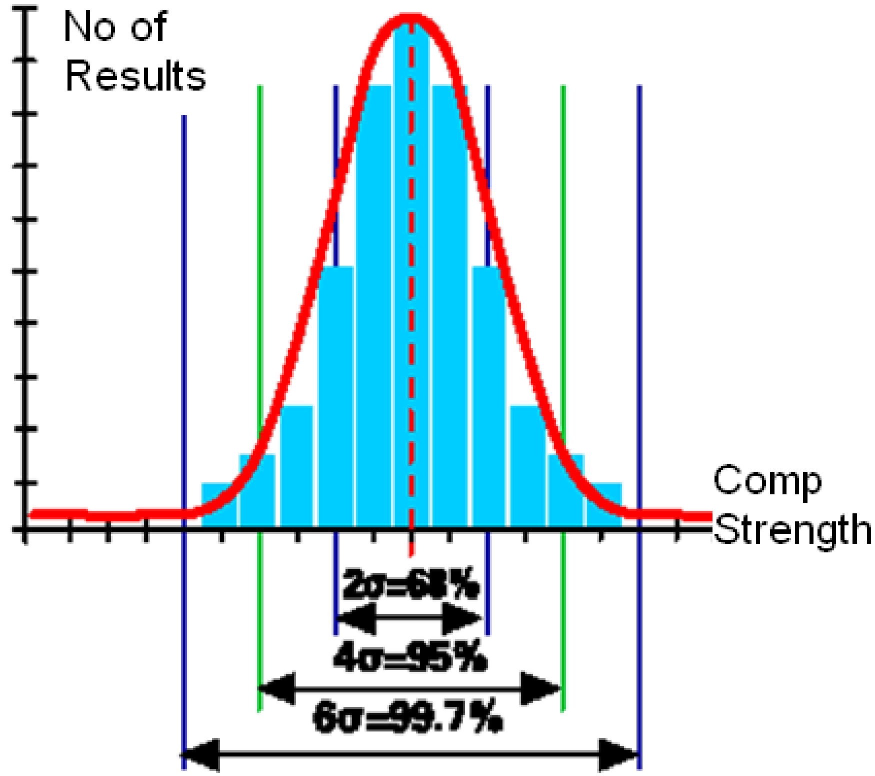


Computing the Probability or Area Under the Normal Curve

❖ For a manufacturing process, the ó value indicates how well that process is performing.

❖ A low ó value indicates that most of the values are close to the target.

❖ A high ó value indicates that the spread is big and that the values deviate more from the target value.



❑ It is mathematically proven that there is a 68 certainty that all data lies between +/- ó, 95% certainty that all data lies between +/- 2 ó, and 99.7% certainty that all data lies between +/- 3

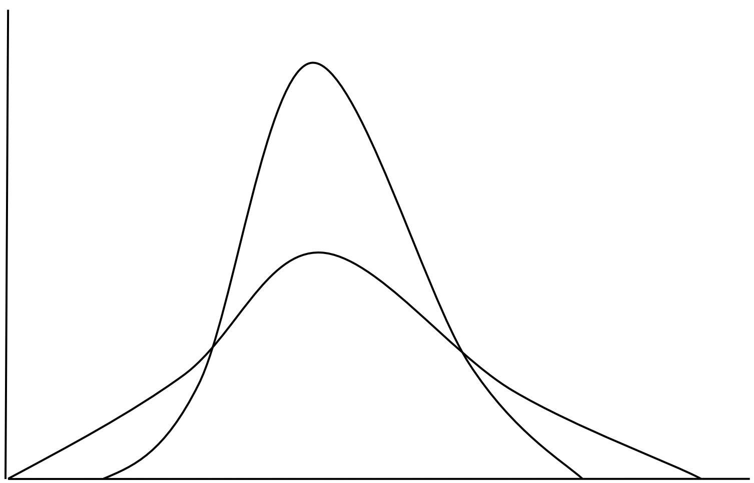
❑ we can predict how the process will behave in the future.

❖ As long as we have the comp strength within the 3ó limits, the process is only affected by Random Variations and is under control.

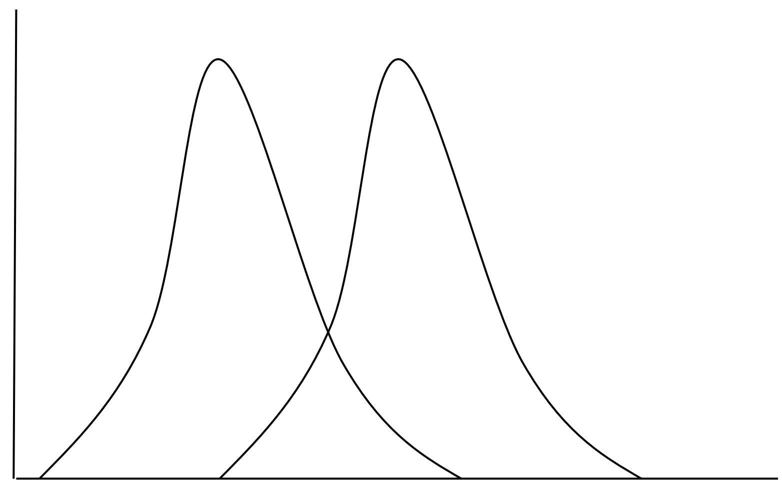
❖ When Comp strength is outside the 3ó limits, the process is affected by Systematic Variation and is not under control.

❖ Something new and strange has started to affect the comp strength.

❖ We need to find the reason for this and eliminate it.



Two curves with the same average, but different deviation.



Two curves with same deviation but different averages

First seven tools

- In the quality improvement movement in Japan in the latter half of the 20th century, the Japanese Union of Scientists and Engineers (JUSE) were influential in defining a set of basic tools that could be used for improving processes.

1. Cause-Effect Diagram
2. Pareto Chart
3. Check Sheet
4. Scatter Chart
5. Bar Chart and other graphs
6. Histogram
7. Control Chart

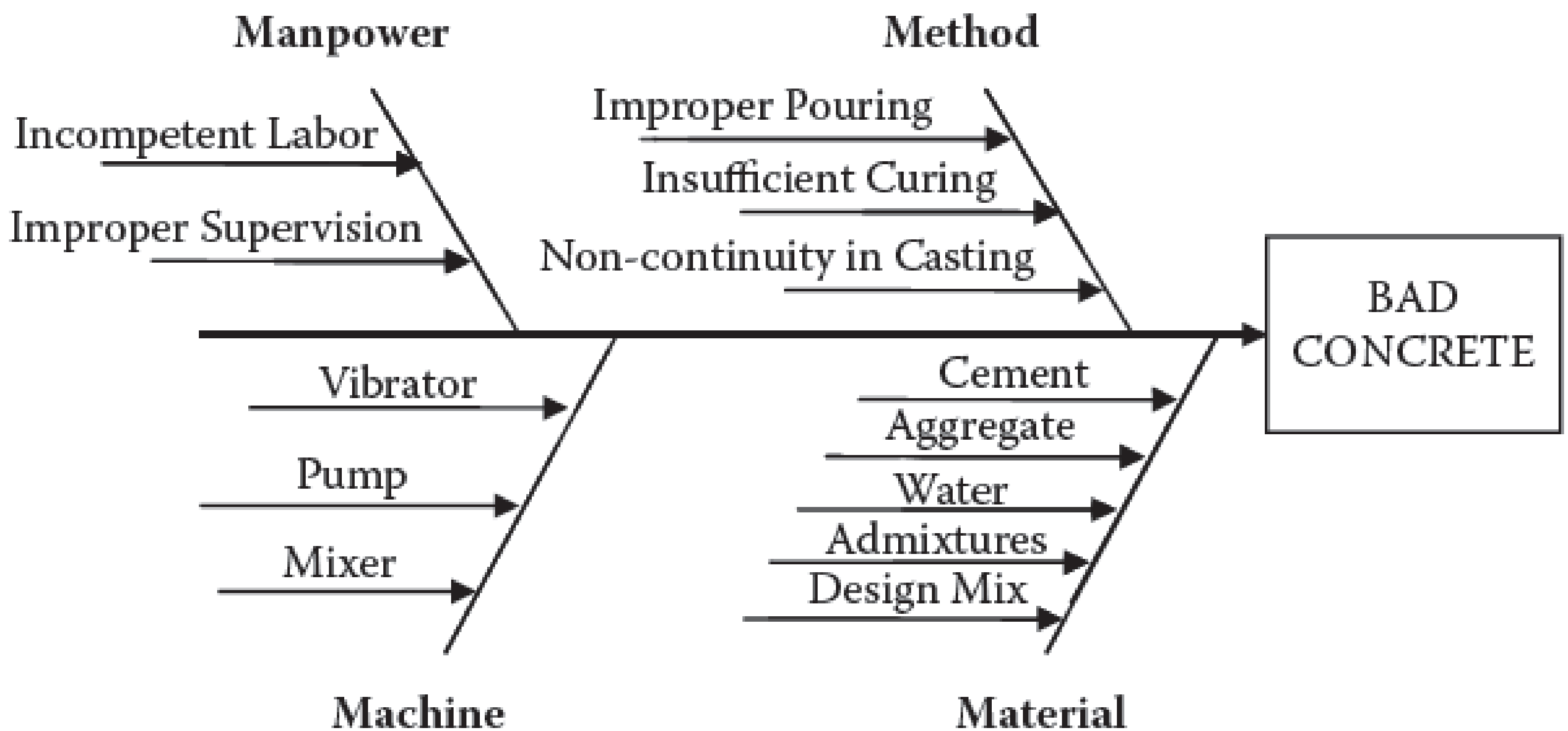
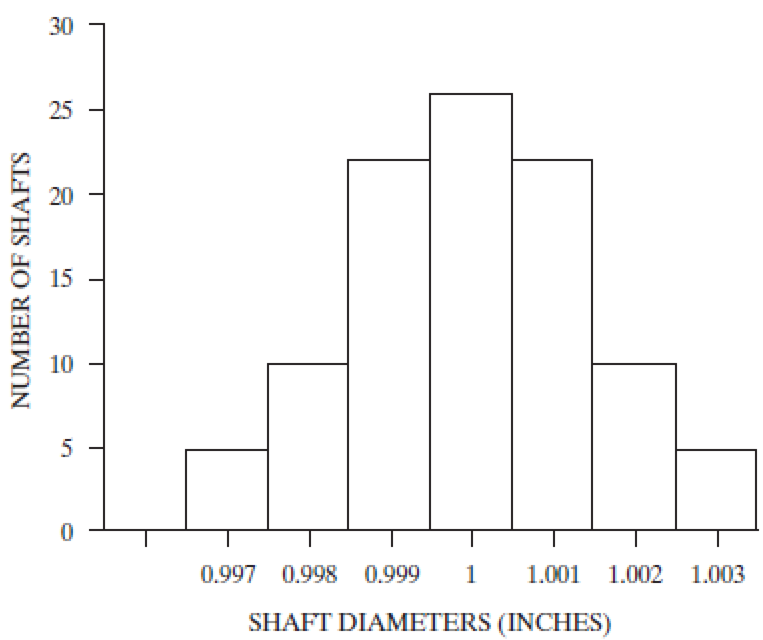


FIGURE 1.4
Cause-and-effect diagram for bad concrete.

VARIATION AS A WAY OF LIFE

- Variability exists in everything—people, machines, or nature.
  - People do not perform the same task in exactly the same way each time, nor can machines be relied upon to perform exactly the same way each time.
  - It is really a question of how much variability there is.(varaince, S.D. etc.)

Figure 16.3 Frequency distribution (Histogram) of shaft diameters.



Variation

Chance (natural) Variation

- is inherent in the process.
- comes from everything influencing the process

Assignable variation.

- specific reason causes assignable variation
- **Mistakes:** tool may shift, a gauge may move, a machine may wear,

There is no way to alter chance variation except to change the process. If the process produces too many defects, then it must be changed.

"As long as only chance variation exists, the system is said to be in statistical control"

1. Chance variation

Inherent in the process. This variation comes from following six categories.

1. *People.* Poorly trained operators tend to be more inconsistent compared with well-trained operators.

2. *Machine*. Well-maintained machines tend to give more consistent output than a poorly maintained, sloppy machine.

3. *Material*. Consistent raw materials give better results than poor quality, inconsistent, ungraded materials.

***4. Method*.** Changes in the method of doing a job will alter the quality.

5. *Environment*. Changes in temperature, humidity, dust, and so on can affect some processes.

6. *Measurement.* Measuring tools that may be in error can cause incorrect adjustments and poor process performance.

Assignable variation

- A tool may shift, a gauge may move, a machine may wear, or an operator may make a mistake.
- There is a specific reason for these causes of variation, which is called **assignable variation.**

Statistical control

“As long as only chance variation exists, the system is said to be in statistical control”

- assignable cause for variation,:::::::: the process is not in control and is unlikely to produce a good product.
- **objective of statistical process control**
  - to detect the presence of assignable causes of variation. exists.

Objectives of SPC

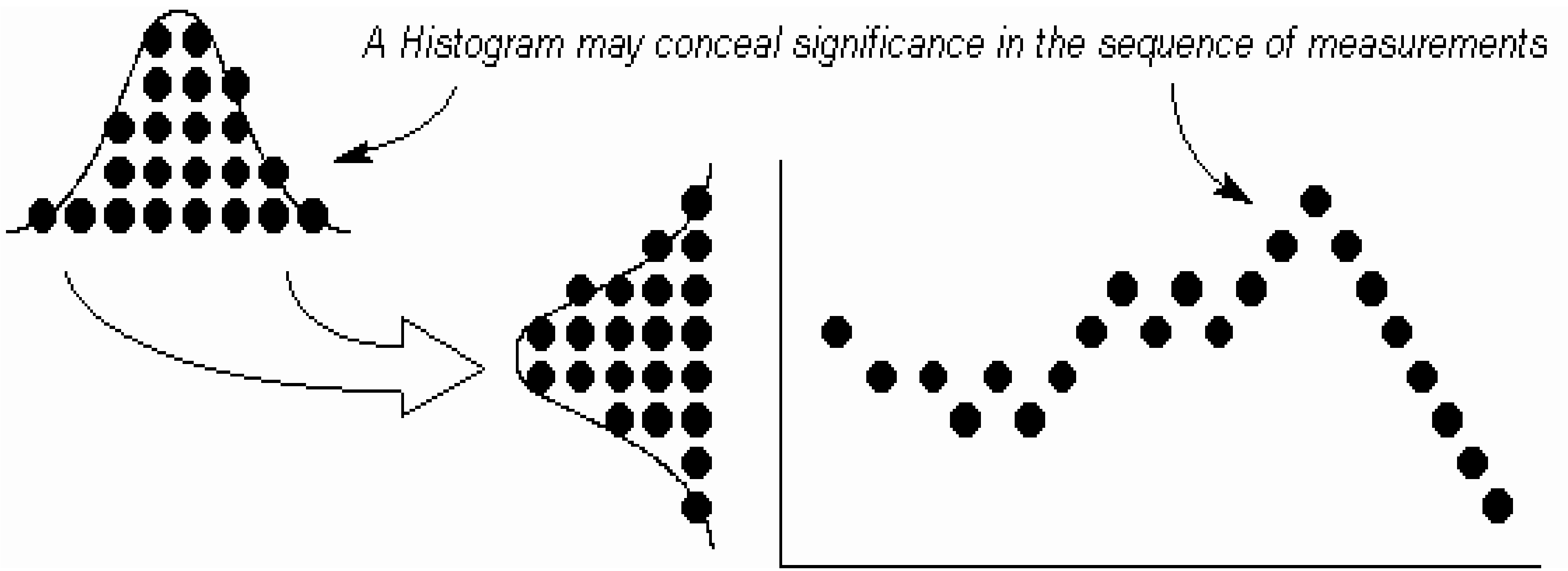
- •To help select/design processes capable of producing the required quality with minimum defects.
- •To monitor a process to be sure it continues to produce the required quality and no assignable cause for variation

Control Chart: When to use it

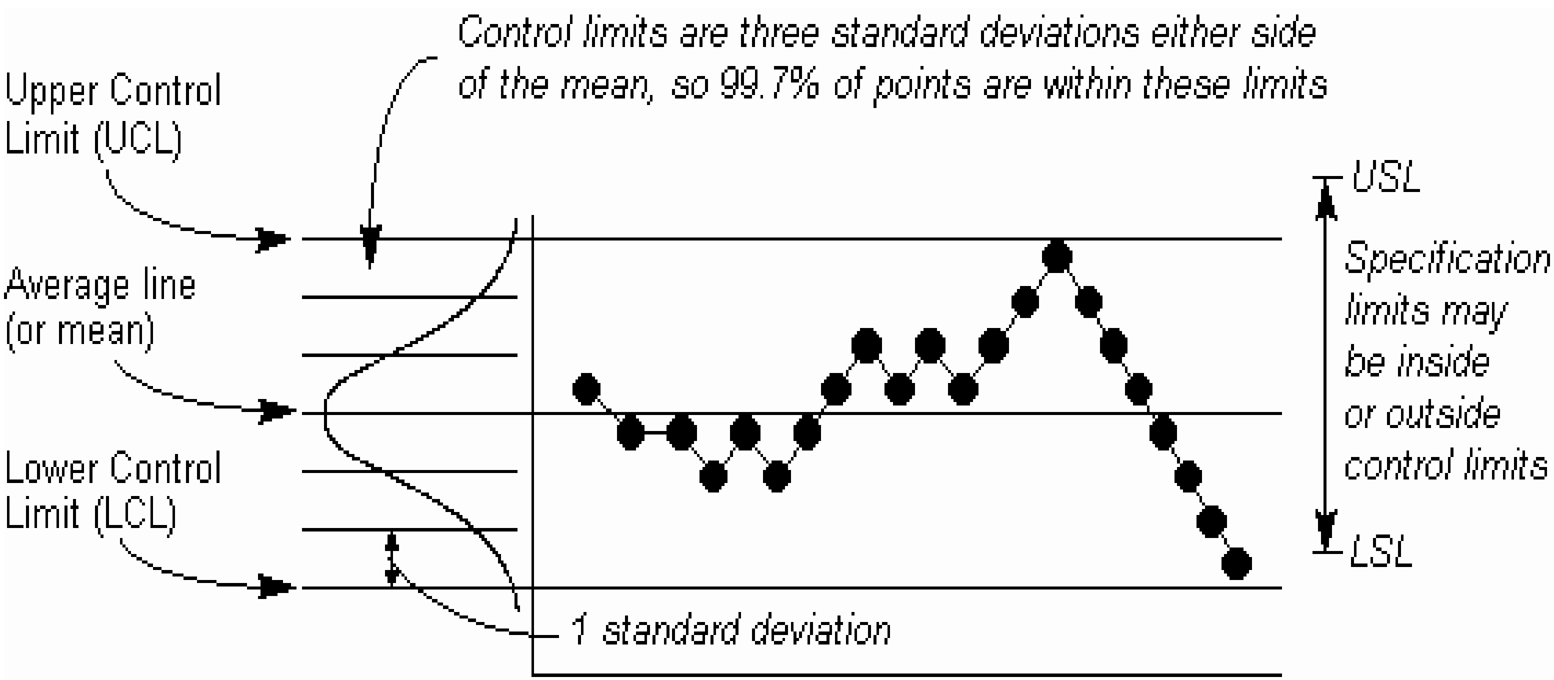
- Use when investigating a process, to determine whether it is in a state of statistical control and thus whether actions are required to bring the process under control.
- Use it to differentiate between special and common causes of variation,
- Use it to detect statistically significant trends in measurements;
- Use it as an ongoing 'health' measure of a process, to help spot problems before they become significant.
- It is only practical to use it when regular measurements of a process can be made. Typically this is in processes that repeat within a reasonably short space of time.

How to understand it ?

- When a process is run repeatedly, even under apparently stable conditions, measurements made of it will seldom be identical.



- A Control Chart usually has three horizontal lines in addition to the main plot line
- The central line is the average (or *mean*).
- The outer two lines are at three standard deviations either side of the mean.
- Thus 99.7% of all measurements will fall between these two lines.



Quality control measurements

- Attributes – A performance characteristics *that is either present or absent* in the product or service under consideration.
- Examples: Order is either complete or incomplete; an invoice can have one, two, or more errors.
- Attributes data are *discrete and tell whether the characteristics conforms to specifications*.
- Attributes measurements typically represented as proportions or rates. e.g. rate of errors per opportunity.
- Typically measured by “Go-No Go” gauges.

Quality control measurements

Variable – Continuous data that is concerned with degree of conformance to specifications.

- Generally expressed with statistical measures such as *averages and standard deviations*.

- In statistical sense, attributes inspection less efficient than variable inspection.
- Attribute data requires larger sample than variable inspection to obtain same amount of statistical information.
- Most quality characteristics in service industry are attributes.

Principle : *Central Limit Theorem of statistics.*

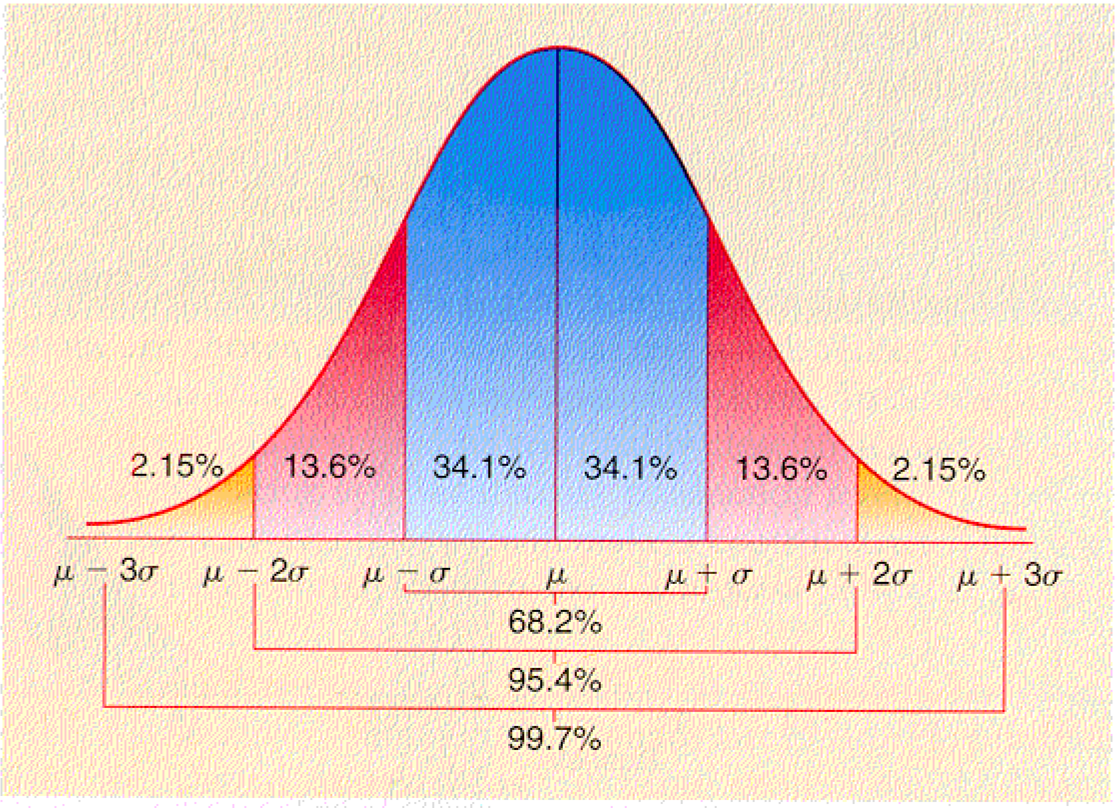
"the distribution of a sum of independent and identically distributed (IID) random variables approaches the ***normal distribution*** *as the number of terms in the sum increases."*

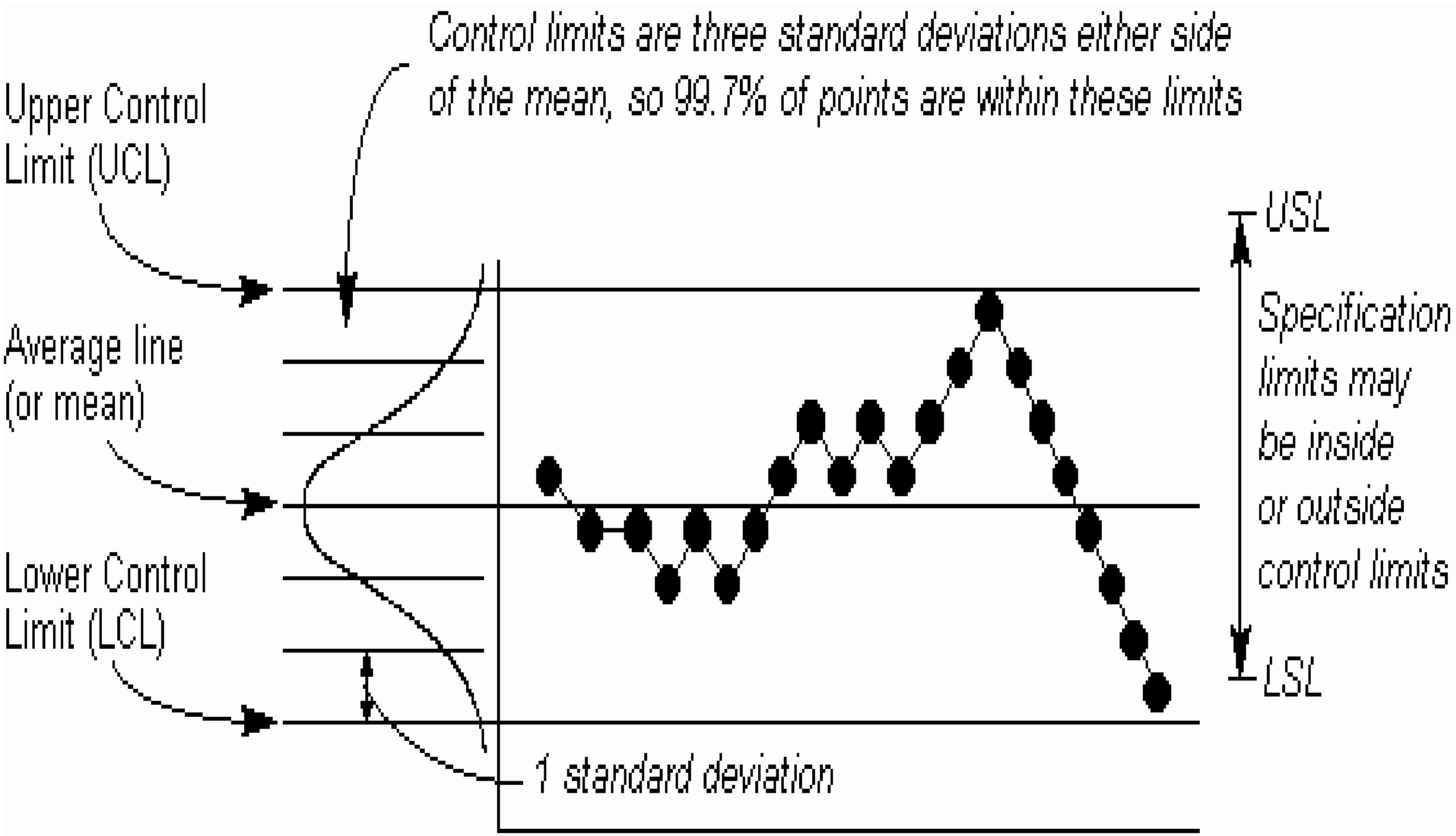
If *(X1, X2, . . . , Xn) is a random sample, the sample mean is defined as,*

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \ .$$

regardless of the distribution of *Xi, the sample* mean will have a normal distribution, provided the variables are IID.

Normal Distribution




Control limits are three standard deviations either side of the mean, so 99.7% of points are within these limits
Upper Control Limit (UCL)
Average line (or mean)
Lower Control Limit (LCL)
USL
Specification limits may be inside or outside control limits
LSL
1 standard deviation

PROCESS CAPABILITY

- Tolerances are the limits of deviation from perfection and are established by the product design engineers to meet a particular design function.
- For example….
- LSL and USL

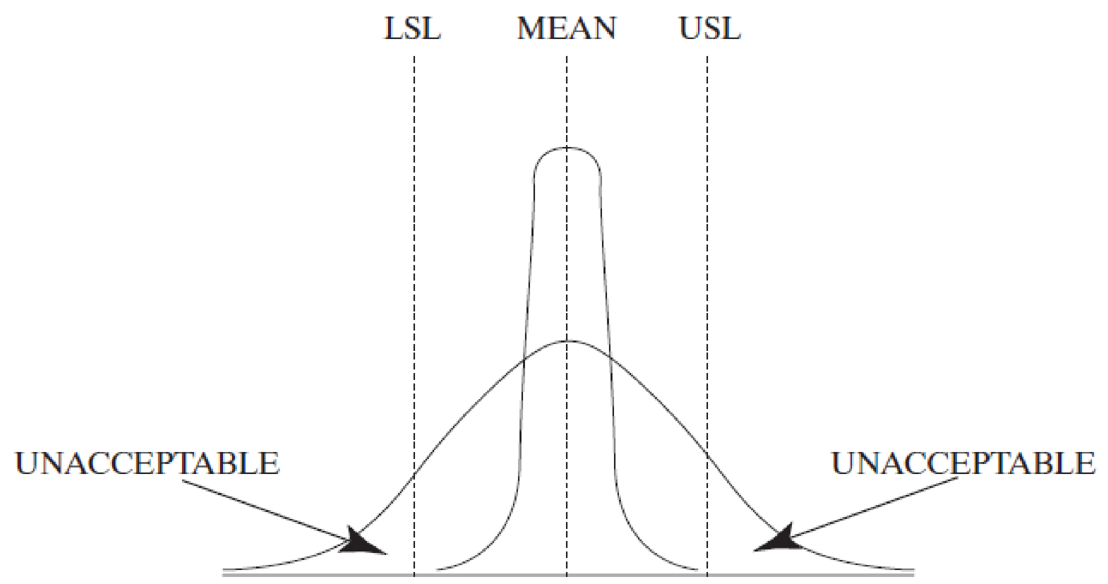


Figure 16.5 Effect of process spreads.

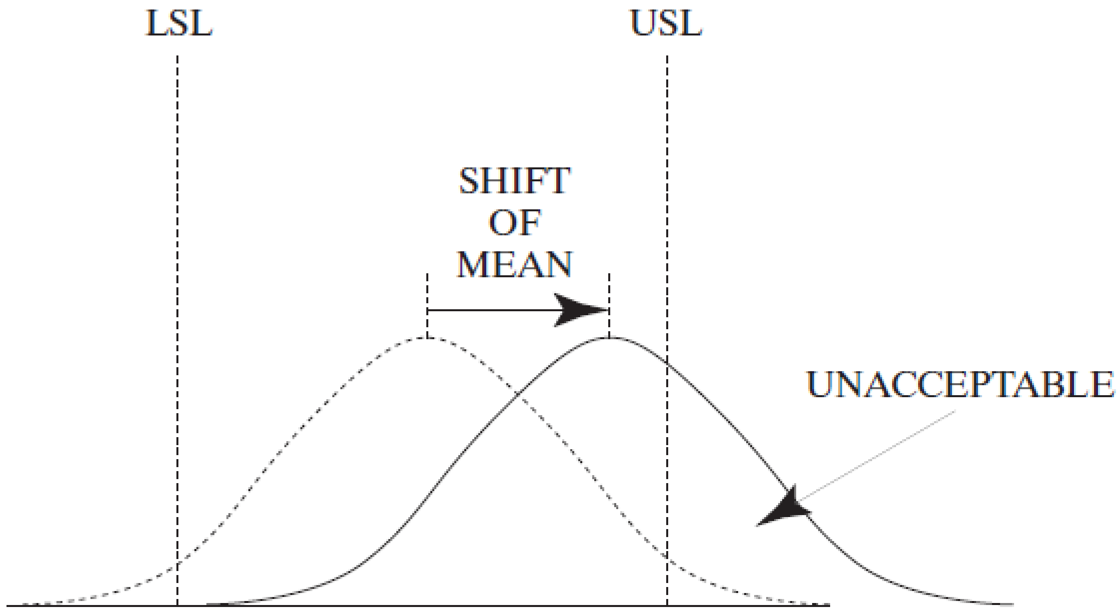
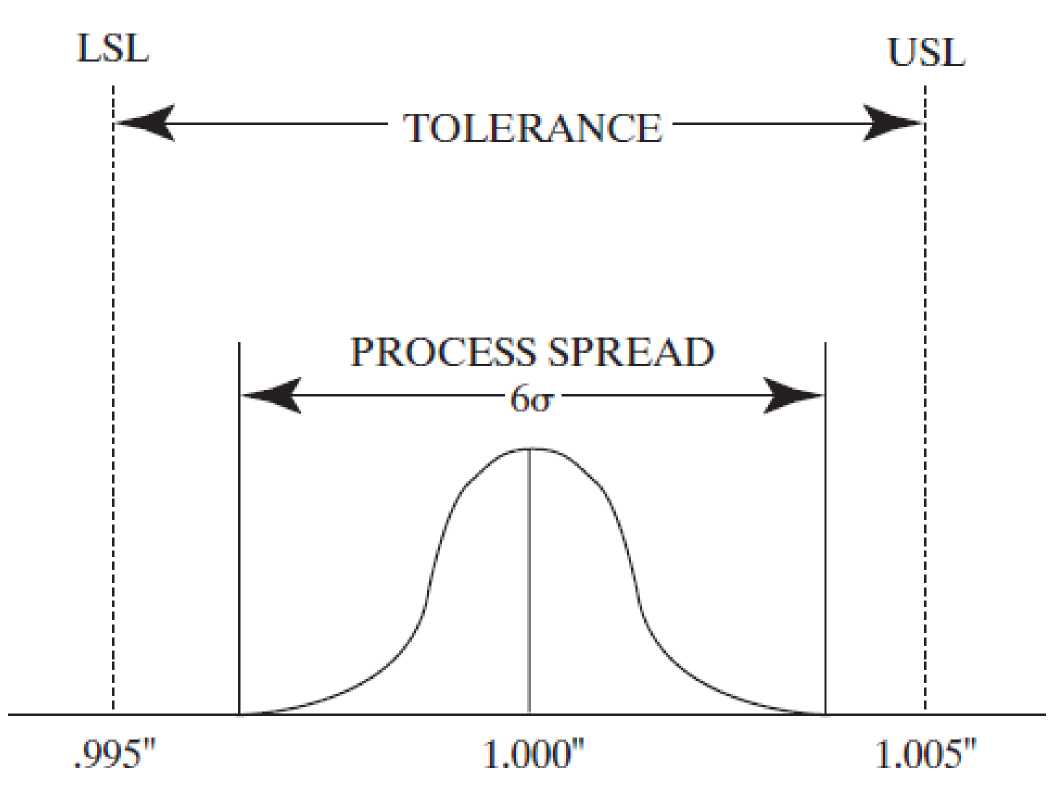


Figure 16.6 Effect of shift in the mean.

Process Capability Index (Cp)

$$C_p = \frac{USL - LSL}{6\sigma}$$



- If the capability index is greater than 1.00, the process is capable of producing 99.7% of parts within tolerance and is said to be capable.
- If CP is less than 1.00, the process is said to be not capable.
- Cp of 1.33 has become a standard of process capability.
- Some organizations use a higher value such as 2.
- ***The larger the capability index, the fewer the rejects and the greater the quality***.

C_{pk} Index

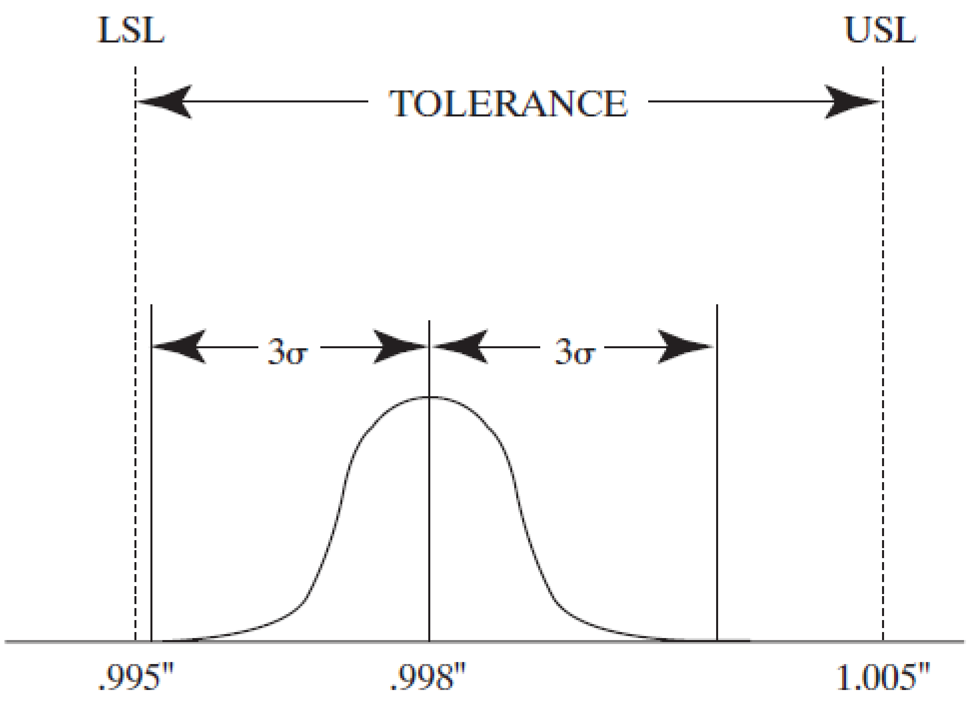
The C_{pk} index is the lesser of:

$$\frac{(USL - Mean)}{3\sigma} \quad \text{or} \quad \frac{(Mean - LSL)}{3\sigma}$$

- Why:
  - The process capability index indicates whether process variation is satisfactory,
  - but it does not measure whether the process is centered properly.
  - Thus it does not protect against out-of-specification product resulting from poor centering.
  - In some cases this is important to know.
- This index measures the effect of both center and variation at the same time.

- The philosophy of the **Cpk index** is that if the process distribution is well within specification on the worst-case side, then it is sure to be acceptable for the other specification limit.

C_{pk} index.



C_{pk} Value	Evaluation
Less than + 1	Unacceptable process. Part of process distribution is out of specification.
+ 1 to + 1.33	Marginal process. Process distribution barely within specification.
Greater than 1.33	Acceptable process. Process distribution is well within specification.

Control charts

- $\overline{X}$ chart and R chart

  " Process Control for variables"

- P chart

  " Analysis of fraction defectives(Attributes)"

- C chart

  " Control of no. of defects per unit"

$\overline{x}$ chart

- A typical quality control plan requires sampling one or more items from a production process periodically, and making the appropriate quality measurements.
- Whether Process capability is compatible with specifications?
- The $\overline{x}$ chart helps the quality control person decide whether the center (or average, or the location of central tendency) of the measurement has shifted.

Construction of $\overline{X}$ & R charts

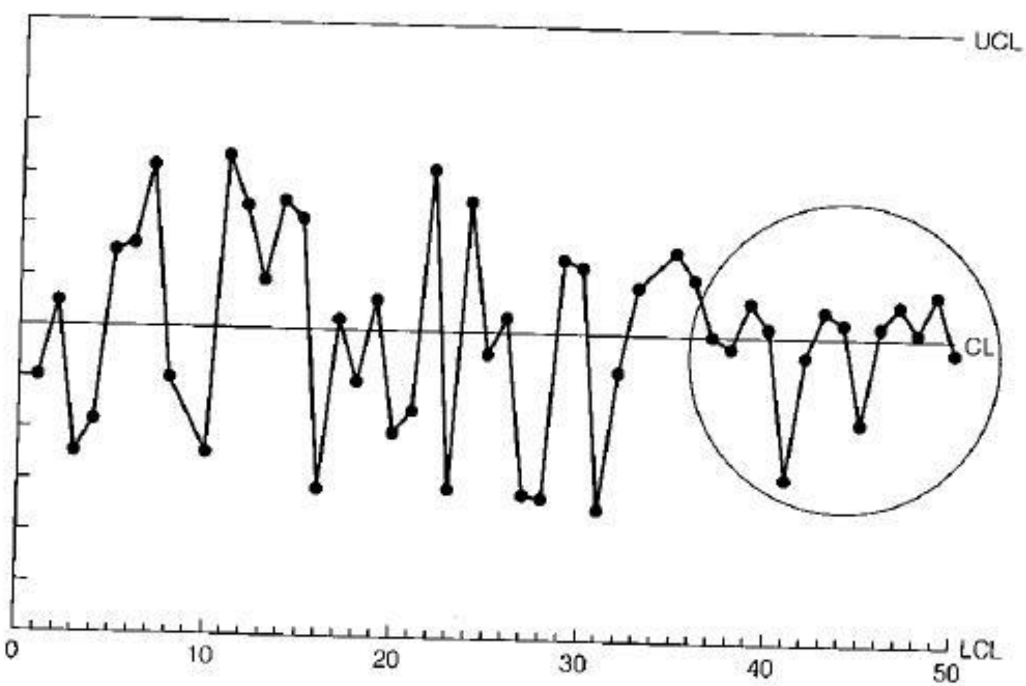
- Take ‘k’ no. of samples of size ‘n’ over period of time.
- Calculate ranges ‘R’ and averages $\overline{x}$ for each sample
- Calculate Central values $\overline{\overline{X}}$ and $\overline{R}$
- D4, D3 and A2 constants depending upon sample size n

$$\overline{R} = \frac{\sum_{i=1}^{k} R_i}{k}; \qquad \overline{\overline{x}} = \frac{\sum_{i=1}^{k} \overline{x_i}}{k}$$

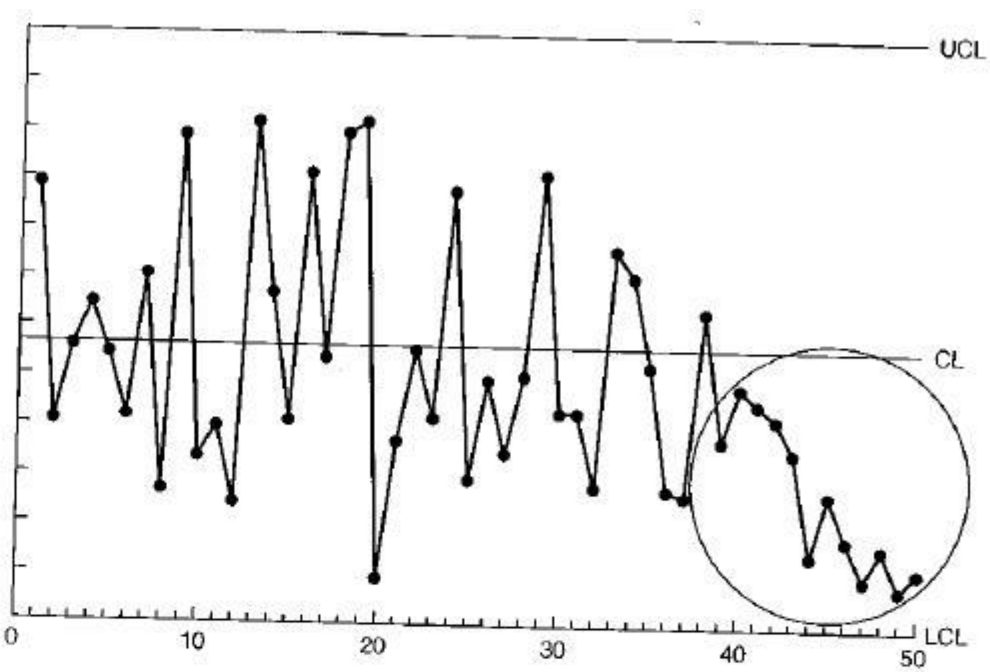
$$UCL_{\overline{R}} = D_4 \overline{R}; \qquad UCL_{\overline{\overline{x}}} = \overline{\overline{x}} + A_2 \overline{R}$$

$$LCL_{\overline{R}} = D_3 \overline{R}; \qquad LCL_{\overline{\overline{x}}} = \overline{\overline{x}} - A_2 \overline{R}$$

- $\overline{X}$ chart



- R charts



Calculations for Average and Range Control Charts

1. Calculate basic averages from measured values

Subgroup number	Subgroup measurements X_1	X_2	X_3	X_4	Average $\bar{X}$	Range R
1	2	3	1	6	3.0	5
2	5	4	9	4	5.5	5
3	3	4	3	4	3.5	1
24	1	9	3	7	5.0	8
25	3	3	3	3	3.0	0
				Totals	145.0	105
				Averages (= Totals / k)	5.8	4.2

k

$\bar{X}$ is the average of the subgroup measurements

$$3 = \frac{2+3+1+6}{4}$$

R is the difference between maximum and minimum subgroup measurements

$$8 = 9 - 1$$

Grand average, $\bar{\bar{X}}$

Average range, $\bar{R}$

Grand average, $\bar{\bar{X}}$

Average range, $\bar{R}$

These give the center-lines in the control charts, below

2. Calculate upper and lower control limits (UCL and LCL)

Use the number of measurements in each subgroup to select the values from this table for UCL and LCL calculation.

Larger subgroups result in control charts that are more sensitive to changes in the process

Subgroup size	A_2	D_3	D_4
2	1.880	0	3.268
3	1.023	0	2.574
4	0.729	0	2.282
5	0.577	0	2.114
6	0.483	0	2.004
7	0.419	0.076	1.924
8	0.373	0.136	1.864
9	0.337	0.184	1.816
10	0.308	0.223	1.777

In this example, there are four measurements in each subgroup, so:

$A_2 = 0.729$

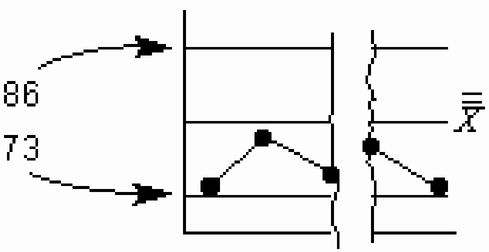
$D_3 = 0$

$D_4 = 2.282$

Average chart:

$$UCL = \bar{\bar{X}} + A_2\bar{R} = 5.8 + 0.729 \times 4.2 = 8.86$$

$$LCL = \bar{\bar{X}} - A_2\bar{R} = 5.8 - 0.729 \times 4.2 = 2.73$$

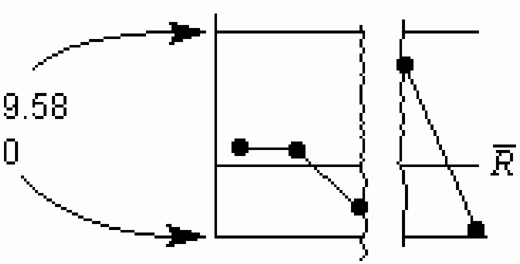


Average (X-bar or $\bar{X}$) control chart

Range chart:

$$UCL = D_4\bar{R} = 2.282 \times 4.2 = 9.58$$

$$LCL = D_3\bar{R} = 0 \times 4.2 = 0$$



Range (R) control chart

,Process out of Control: two types of changes

- ***A shift in the mean or average*.**
  - worn tool or
  - a guide that has moved.

- • ***A change in the spread*** *of the distribution.*

  *(*If the range increases but the sample averages remain the same)
  - gauge or tool becoming loose or
  - by some part of the machine becoming worn.

Interpreting patterns in control charts

- General rules to determine whether a process is in control:

1. No points outside the control limits.
2. The number of points above and below the center line are about the same.
3. Points seem to fall randomly above and below the center line.
4. Most points are near center line, and only a few are close to control limits.

- Basic assumption: *Central Limit Theorem*.

- Hugging the center line:

sample taken over various machines canceling out the variation within the sample.

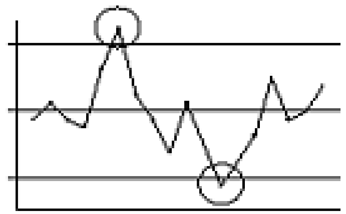
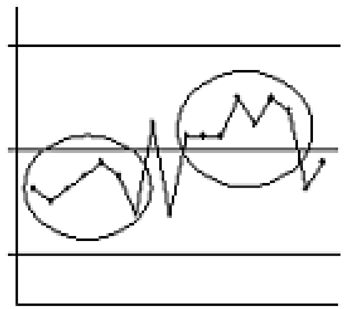
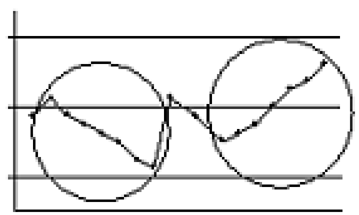
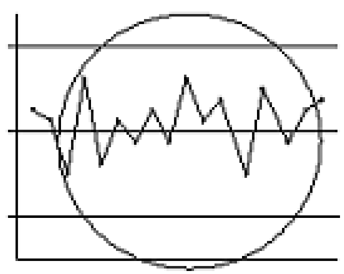
- Hugging the control limits:

sample taken over various machines *not* canceling out the variation within the sample.

- Instability:

difficult to identify causes. Typically, over-adjustment of machine.

(Always, R-chart analysis before the x-bar-chart analysis.)

Control Chart	Name	Description	Possible interpretation
	Special cause of variation	Point outside control limits.	Something unusual has happened. e.g. Person was interrupted.
	Shift	Seven or more consecutive points, all on one side of the central average line.	The overall average has changed. e.g. Showing result of process improvement.
	Trend	Seven or more consecutive points, all increasing or decreasing in value.	Gradual change in the process. e.g. A tool is wearing out.
	Cycle	Seven or more repeating patterns (possibly over several points).	Time-related effect. e.g. People changing with shifts.

Process is OUT of control if:

- One or multiple points outside the control limits
- Eight points in a row above the average value
- Multiple points in a row near the control limits

Process is IN control if:

- The sample points fall between the control limits
- There are no major trends forming, i.e.. The points vary, both above and below the average value.

When should we change the control limits?

- **When removing out-of-control data points.**
  - When a special cause has been identified and removed while you are working to achieve process stability,
  - Delete the data points affected by special causes and use the remaining data to compute new control limits.
- **When replacing trial limits.**
  - When a process has just started up, or has changed,
  - Calculate Trial control limits using only the limited data available.
  - Calculate new limits every time you add new data.
  - Once you have 20 or 30 groups of 4 or 5 measurements; you can use the limits to monitor future performance.

- **When there are changes in the process.**
  - When there are indications that your process has changed, it is necessary to recompute the control limits based on data collected since the change occurred.
  - **Some examples**
    - application of new or modified procedures,
    - the use of different machines,
    - the overhaul of existing machines,
    - and the introduction of new suppliers of critical input materials.